MENTERI ENERGI DAN SUMBER DAYA MINERAL
REPUBLIK INDONESIA

PERATURAN MENTERI ENERGI DAN SUMBER DAYA MINERAL
REPUBLIK INDONESIA
NOMOR 2 TAHUN 2024
TENTANG
PEMBANGKIT LISTRIK TENAGA SURYA ATAP
YANG TERHUBUNG PADA JARINGAN TENAGA LISTRIK
PEMEGANG IZIN USAHA PENYEDIAAN TENAGA LISTRIK
UNTUK KEPENTINGAN UMUM

DENGAN RAHMAT TUHAN YANG MAHA ESA

MENTERI ENERGI DAN SUMBER DAYA MINERAL REPUBLIK INDONESIA,

Menimbang : a. bahwa untuk meningkatkan tata kelola pemanfaatan energi surya yang ramah lingkungan untuk pembangkitan tenaga listrik menggunakan sistem pembangkit listrik tenaga surya atap yang digunakan untuk kepentingan sendiri, perlu dilakukan penyesuaian kebijakan dalam penggunaan pembangkit listrik tenaga surya atap, melalui penghapusan ketentuan mengenai batasan kapasitas, ekspor-impor energi listrik, dan biaya kapasitas (*capacity charge*), serta penambahan ketentuan kuota pengembangan pembangkit listrik tenaga surya atap;

b. bahwa Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 26 Tahun 2021 tentang Pembangkit Listrik Tenaga Surya Atap yang Terhubung pada Jaringan Tenaga Listrik Pemegang Izin Usaha Penyediaan Tenaga Listrik untuk Kepentingan Umum sudah tidak sesuai dengan kebutuhan, sehingga perlu diganti;

c. bahwa berdasarkan pertimbangan sebagaimana dimaksud dalam huruf a dan huruf b, perlu menetapkan Peraturan Menteri Energi dan Sumber Daya Mineral tentang Pembangkit Listrik Tenaga Surya Atap yang Terhubung pada Jaringan Tenaga Listrik Pemegang Izin Usaha Penyediaan Tenaga Listrik untuk Kepentingan Umum;

Mengingat : 1. Pasal 17 ayat (3) Undang-Undang Dasar Negara Republik Indonesia Tahun 1945;

2. Undang-Undang Nomor 30 Tahun 2007 tentang Energi (Lembaran Negara Republik Indonesia Tahun 2007 Nomor 96, Tambahan Lembaran Negara Republik Indonesia Nomor 4746);

3. Undang-Undang Nomor 39 Tahun 2008 tentang Kementerian Negara (Lembaran Negara Republik Indonesia Tahun 2008 Nomor 166, Tambahan Lembaran Negara Republik Indonesia Nomor 4916);

4. Undang-Undang Nomor 30 Tahun 2009 tentang Ketenagalistrikan (Lembaran Negara Republik Indonesia Tahun 2009 Nomor 133, Tambahan Lembaran Negara Republik Indonesia Nomor 5052);
5. Peraturan Pemerintah Nomor 14 Tahun 2012 tentang Kegiatan Usaha Penyediaan Tenaga Listrik (Lembaran Negara Republik Indonesia Tahun 2012 Nomor 28, Tambahan Lembaran Negara Republik Indonesia Nomor 5281) sebagaimana telah diubah dengan Peraturan Pemerintah Nomor 23 Tahun 2014 tentang Perubahan atas Peraturan Pemerintah Nomor 14 Tahun 2012 tentang Kegiatan Usaha Penyediaan Tenaga Listrik (Lembaran Negara Republik Indonesia Tahun 2014 Nomor 75, Tambahan Lembaran Negara Republik Indonesia Nomor 5530);
6. Peraturan Pemerintah Nomor 62 Tahun 2012 tentang Usaha Jasa Penunjang Tenaga Listrik (Lembaran Negara Republik Indonesia Tahun 2012 Nomor 141, Tambahan Lembaran Negara Republik Indonesia Nomor 5326);
7. Peraturan Presiden Nomor 97 Tahun 2021 tentang Kementerian Energi dan Sumber Daya Mineral (Lembaran Negara Republik Indonesia Tahun 2021 Nomor 244);
8. Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 20 Tahun 2020 tentang Aturan Jaringan Sistem Tenaga Listrik (*Grid Code*) (Berita Negara Republik Indonesia Tahun 2020 Nomor 1794);
9. Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 11 Tahun 2021 tentang Pelaksanaan Usaha Ketenagalistrikan (Berita Negara Republik Indonesia Tahun 2021 Nomor 671);
10. Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 15 Tahun 2021 tentang Organisasi dan Tata Kerja Kementerian Energi dan Sumber Daya Mineral (Berita Negara Republik Indonesia Tahun 2021 Nomor 733);

MEMUTUSKAN:

Menetapkan : PERATURAN MENTERI ENERGI DAN SUMBER DAYA MINERAL TENTANG PEMBANGKIT LISTRIK TENAGA SURYA ATAP YANG TERHUBUNG PADA JARINGAN TENAGA LISTRIK PEMEGANG IZIN USAHA PENYEDIAAN TENAGA LISTRIK UNTUK KEPENTINGAN UMUM.

BAB I
KETENTUAN UMUM

Pasal 1

Dalam Peraturan Menteri ini yang dimaksud dengan:

1. Sistem Pembangkit Listrik Tenaga Surya Atap yang selanjutnya disebut Sistem PLTS Atap adalah pembangkit tenaga listrik dengan menggunakan modul fotovoltaik yang dipasang dan diletakkan pada atap, dinding, atau bagian lain dari bangunan milik pelanggan PLTS Atap serta menyalurkan energi listrik melalui sistem sambungan listrik pelanggan PLTS Atap.

2. Pelanggan PLTS Atap adalah setiap orang atau badan yang memasang Sistem PLTS Atap yang terhubung pada sistem tenaga listrik pemegang izin usaha penyediaan tenaga listrik untuk kepentingan umum.
3. Pemegang Izin Usaha Penyediaan Tenaga Listrik untuk Kepentingan Umum yang selanjutnya disebut Pemegang IUPTLU adalah badan yang memiliki izin untuk melakukan usaha penyediaan tenaga listrik untuk kepentingan umum yang memiliki wilayah usaha sesuai dengan ketentuan peraturan perundang-undangan di bidang ketenagalistrikan.
4. *Advanced Meter* adalah meter *kilowatt hour* (kWh) yang disediakan dan dipasang oleh Pemegang IUPTLU pada instalasi milik Pelanggan PLTS Atap yang dapat melakukan komunikasi dan pengukuran dua arah.
5. Pemegang Izin Usaha Jasa Penunjang Tenaga Listrik yang selanjutnya disebut Badan Usaha adalah badan usaha yang memiliki sertifikat badan usaha di bidang ketenagalistrikan untuk melakukan usaha jasa penunjang tenaga listrik sesuai dengan ketentuan peraturan perundang-undangan di bidang ketenagalistrikan.
6. Sertifikat Laik Operasi yang selanjutnya disingkat SLO adalah bukti pengakuan formal suatu instalasi tenaga listrik telah berfungsi sebagaimana kesesuaian persyaratan yang ditentukan dan dinyatakan laik dioperasikan.
7. Sistem Tenaga Listrik adalah suatu rangkaian dalam tenaga listrik yang berfungsi untuk menyalurkan tenaga listrik dari pembangkit tenaga listrik ke konsumen tenaga listrik.
8. Perseroan Terbatas Perusahaan Listrik Negara (Perusahaan Perseroan) yang selanjutnya disebut PT PLN (Persero) adalah badan usaha milik negara yang didirikan berdasarkan Peraturan Pemerintah Nomor 23 Tahun 1994 tentang Pengalihan Bentuk Perusahaan Umum (Perum) Listrik Negara Menjadi Perusahaan Perseroan (Persero).
9. Menteri adalah menteri yang menyelenggarakan urusan pemerintahan di bidang energi dan sumber daya mineral.
10. Direktur Jenderal Energi Baru, Terbarukan, dan Konservasi Energi yang selanjutnya disebut Direktur Jenderal EBTKE adalah pejabat tinggi madya yang memiliki tugas menyelenggarakan perumusan dan pelaksanaan kebijakan pembinaan, pengendalian, dan pengawasan bidang energi baru, energi terbarukan, dan konservasi energi.
11. Direktur Jenderal Ketenagalistrikan adalah pejabat tinggi madya yang memiliki tugas menyelenggarakan perumusan dan pelaksanaan kebijakan pembinaan, pengendalian, dan pengawasan di bidang ketenagalistrikan.

Pasal 2

Ruang lingkup pengaturan Peraturan Menteri ini mencakup Sistem PLTS Atap yang terhubung pada Sistem Tenaga Listrik Pemegang IUPTLU baik menyalurkan maupun tidak menyalurkan energi listrik ke Sistem Tenaga Listrik Pemegang IUPTLU.

Pasal 3

Penggunaan Sistem PLTS Atap bertujuan untuk:

a. menghemat tagihan listrik Pelanggan PLTS Atap;
b. mendapatkan listrik dari sumber energi terbarukan; dan/atau
c. berkontribusi menurunkan emisi gas rumah kaca.

BAB II
SISTEM PLTS ATAP

Bagian Kesatu
Umum

Pasal 4

(1) Sistem PLTS Atap meliputi modul surya, *inverter*, sambungan listrik, dan sistem pengaman.
(2) Sistem PLTS Atap sebagaimana dimaksud pada ayat (1) harus dilengkapi dengan *Advanced Meter.*
(3) Sistem PLTS Atap sebagaimana dimaksud pada ayat (1) dapat dilengkapi dengan baterai atau media penyimpanan energi listrik lainnya dengan tetap memenuhi ketentuan keselamatan ketenagalistrikan.
(4) Sistem PLTS Atap sebagaimana dimaksud pada ayat (1) dan ayat (3) sesuai dengan diagram instalasi dan standar spesifikasi teknis Sistem PLTS Atap yang tercantum dalam Lampiran I yang merupakan bagian tidak terpisahkan dari Peraturan Menteri ini.

Pasal 5

(1) Penggunaan Sistem PLTS Atap sebagaimana dimaksud dalam Pasal 4, wajib memperhatikan keamanan dan keandalan operasi jaringan tenaga listrik Pemegang IUPTLU sesuai dengan ketentuan peraturan perundang-undangan di bidang ketenagalistrikan.
(2) Penggunaan peralatan Sistem PLTS Atap sebagaimana dimaksud pada ayat (1) dilaksanakan sesuai dengan ketentuan peraturan perundang-undangan di bidang penggunaan barang/jasa dalam negeri.

Pasal 6

Untuk menjamin keamanan dan keandalan operasi jaringan tenaga listrik Pemegang IUPTLU, instalasi Sistem PLTS Atap wajib mengikuti standar nasional Indonesia dan/atau standar internasional sesuai dengan ketentuan peraturan perundang-undangan.

Bagian Kedua
Kuota Pengembangan Sistem PLTS Atap

Pasal 7

(1) Pemegang IUPTLU wajib menyusun kuota pengembangan Sistem PLTS Atap untuk setiap Sistem Tenaga Listrik.
(2) Penyusunan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud pada ayat (1) paling sedikit mempertimbangkan:
    a. arah kebijakan energi nasional;
    b. rencana dan realisasi rencana usaha penyediaan tenaga listrik; dan
    c. keandalan Sistem Tenaga Listrik sesuai dengan ketentuan dalam aturan jaringan Sistem Tenaga Listrik (*grid code*) Pemegang IUPTLU.
(3) Kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud pada ayat (1) disusun untuk jangka waktu 5 (lima) tahun yang dirinci untuk setiap tahun dari bulan Januari sampai dengan bulan Desember.

Pasal 8

(1) Kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud dalam Pasal 7 ayat (1) diusulkan kepada Direktur Jenderal Ketenagalistrikan dengan tembusan kepada Direktur Jenderal EBTKE.
(2) Usulan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud pada ayat (1) dilengkapi dengan dokumen kajian teknis.
(3) Usulan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud pada ayat (1) untuk tahun 2024 sampai dengan tahun 2028, disampaikan paling lambat 3 (tiga) bulan sejak Peraturan Menteri ini diundangkan.
(4) Usulan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud pada ayat (1) untuk tahun selanjutnya disampaikan paling lambat pada bulan Oktober sebelum tahun berjalan.
(5) Direktur Jenderal Ketenagalistrikan melakukan evaluasi terhadap usulan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud pada ayat (3) dan ayat (4).
(6) Dalam pelaksanaan evaluasi sebagaimana dimaksud pada ayat (5) Direktur Jenderal Ketenagalistrikan melibatkan Direktur Jenderal EBTKE dan dapat melibatkan kementerian/lembaga terkait dan/atau pemerintah daerah.

Pasal 9

(1) Berdasarkan hasil evaluasi sebagaimana dimaksud dalam Pasal 8 ayat (6), Direktur Jenderal Ketenagalistrikan menetapkan kuota pengembangan Sistem PLTS Atap paling lambat:
    a. 1 (satu) bulan sejak usulan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud dalam Pasal 8 ayat (3) disampaikan secara lengkap dan benar; dan

b. pada bulan Desember sebelum tahun berjalan, setelah usulan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud dalam Pasal 8 ayat (4) disampaikan.

(2) Penetapan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud pada ayat (1) disampaikan kepada Pemegang IUPTLU.

(3) Berdasarkan penetapan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud pada ayat (2), Pemegang IUPTLU menyusun kuota pengembangan Sistem PLTS Atap berdasarkan *clustering.*

(4) *Clustering* sebagaimana dimaksud pada ayat (3) merupakan Sistem Tenaga Listrik pada unit pelayanan pelanggan Pemegang IUPTLU.

(5) Kuota pengembangan Sistem PLTS Atap berdasarkan *clustering* sebagaimana dimaksud pada ayat (3) harus:
a. dilaporkan kepada Direktur Jenderal Ketenagalistrikan dan Direktur Jenderal EBTKE; dan
b. dipublikasikan melalui laman, aplikasi, dan/atau media sosial resmi Pemegang IUPTLU,
dalam jangka waktu paling lambat 10 (sepuluh) hari kerja sejak kuota pengembangan Sistem PLTS Atap ditetapkan.

Pasal 10

(1) Pemegang IUPTLU dapat mengusulkan perubahan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud dalam Pasal 9 ayat (2).

(2) Mekanisme dan tata cara usulan perubahan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud pada ayat (1) dilaksanakan sesuai dengan mekanisme dan tata cara usulan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud dalam Pasal 7 sampai dengan Pasal 9.

(3) Dalam hal Pemegang IUPTLU tidak mengajukan perubahan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud pada ayat (1), besaran kuota pengembangan Sistem PLTS Atap mengikuti rincian kuota pengembangan Sistem PLTS Atap yang telah ditetapkan sebagaimana dimaksud dalam Pasal 9 ayat (2).

Pasal 11

Dalam hal kuota pengembangan Sistem PLTS Atap pada akhir tahun berjalan masih tersedia, kuota pengembangan Sistem PLTS Atap yang masih tersedia menjadi tambahan kuota pengembangan Sistem PLTS Atap pada tahun berikutnya.

Bagian Ketiga
Penggunaan Sistem PLTS Atap

Pasal 12

(1) Kapasitas Sistem PLTS Atap yang akan dipasang oleh calon Pelanggan PLTS Atap di wilayah usaha Pemegang IUPTLU disesuaikan dengan kapasitas kebutuhan calon Pelanggan PLTS Atap berdasarkan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud dalam Pasal 9.

(2) Dalam hal kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud pada ayat (1) belum ditetapkan, kapasitas Sistem PLTS Atap calon Pelanggan PLTS Atap disesuaikan berdasarkan kondisi Sistem Tenaga Listrik Pemegang IUPTLU.

Pasal 13

Kelebihan energi listrik dari Sistem PLTS Atap yang masuk ke jaringan Pemegang IUPTLU tidak diperhitungkan dalam penentuan jumlah tagihan listrik Pelanggan PLTS Atap.

Paragraf 1
Permohonan

Pasal 14

(1) Calon Pelanggan PLTS Atap harus mengajukan permohonan pembangunan dan pemasangan Sistem PLTS Atap kepada Pemegang IUPTLU dengan tembusan kepada Direktur Jenderal EBTKE dan Direktur Jenderal Ketenagalistrikan.
(2) Permohonan sebagaimana dimaksud pada ayat (1) disampaikan pada bulan Januari atau pada bulan Juli setiap tahunnya.
(3) Pengajuan permohonan sebagaimana dimaksud pada ayat (1) untuk pertama kali setelah Peraturan Menteri ini diundangkan, disampaikan dalam jangka waktu paling lama 1 (satu) bulan sejak publikasi kuota pengembangan Sistem PLTS Atap berdasarkan *clustering* sebagaimana dimaksud dalam Pasal 9 ayat (5) huruf b.
(4) Permohonan sebagaimana dimaksud pada ayat (1) sesuai dengan format yang tercantum dalam Lampiran II yang merupakan bagian tidak terpisahkan dari Peraturan Menteri ini.

Pasal 15

(1) Pemegang IUPTLU harus memberikan persetujuan atau penolakan terhadap permohonan sebagaimana dimaksud dalam Pasal 14 ayat (1) dalam jangka waktu paling lambat 30 (tiga puluh) hari kalender sejak batas permohonan sebagaimana dimaksud dalam Pasal 14 ayat (2) dan ayat (3) berakhir.
(2) Dalam hal Pemegang IUPTLU tidak memberikan persetujuan atau penolakan terhadap permohonan dalam jangka waktu sebagaimana dimaksud pada ayat (1), permohonan dianggap disetujui.
(3) Dalam hal permohonan disetujui sebagaimana dimaksud pada ayat (1), Pemegang IUPTLU menyampaikan pemberitahuan kepada calon Pelanggan PLTS Atap.
(4) Dalam hal permohonan disetujui sebagaimana dimaksud pada ayat (2), melalui Peraturan Menteri ini berlaku sebagai persetujuan Pemegang IUPTLU kepada calon Pelanggan PLTS Atap.

(5) Menteri melalui Direktur Jenderal EBTKE menyampaikan pemberitahuan persetujuan sebagaimana dimaksud pada ayat (4) kepada Pemegang IUPTLU.
(6) Dalam hal permohonan ditolak sebagaimana dimaksud pada ayat (1), Pemegang IUPTLU menyampaikan secara tertulis kepada calon Pelanggan PLTS Atap disertai dengan alasan penolakan.
(7) Dalam hal permohonan ditolak sebagaimana dimaksud pada ayat (6), calon Pelanggan PLTS Atap dapat mengajukan permohonan kembali sesuai dengan ketentuan dalam Pasal 14.
(8) Dalam hal permohonan ditolak dengan alasan kuota pengembangan Sistem PLTS Atap sebagaimana dimaksud dalam Pasal 9 tidak tersedia, calon Pelanggan PLTS Atap dimasukkan dalam daftar tunggu untuk diproses pada periode berikutnya sepanjang kuota pengembangan Sistem PLTS Atap telah tersedia.

Pasal 16

(1) Dalam hal pembayaran tarif tenaga listrik calon Pelanggan PLTS Atap menggunakan mekanisme prabayar, permohonan sebagaimana dimaksud dalam Pasal 14 ayat (1) berlaku sebagai permohonan perubahan mekanisme pembayaran tarif tenaga listrik prabayar menjadi pascabayar.
(2) Pemegang IUPTLU wajib menyetujui permohonan perubahan mekanisme pembayaran tarif tenaga listrik sebagaimana dimaksud pada ayat (1).
(3) Berdasarkan persetujuan atas permohonan perubahan mekanisme pembayaran tarif tenaga listrik sebagaimana dimaksud pada ayat (2), Pemegang IUPTLU mengubah mekanisme pembayaran tarif tenaga listrik dari prabayar menjadi pascabayar bersamaan dengan pemasangan *Advanced Meter*.

Paragraf 2
Perizinan

Pasal 17

(1) Calon Pelanggan PLTS Atap yang melakukan pembangunan dan pemasangan Sistem PLTS Atap dengan total kapasitas lebih dari 500 kW (lima ratus kilowatt) yang terhubung dalam 1 (satu) sistem instalasi tenaga listrik, wajib memiliki izin usaha penyediaan tenaga listrik untuk kepentingan sendiri.
(2) Izin usaha penyediaan tenaga listrik untuk kepentingan sendiri sebagaimana dimaksud pada ayat (1), diberikan oleh Menteri atau gubernur sesuai dengan ketentuan peraturan perundang-undangan di bidang ketenagalistrikan.

Pasal 18

(1) Calon Pelanggan PLTS Atap yang melakukan pembangunan dan pemasangan Sistem PLTS Atap dengan total kapasitas sampai dengan 500 kW (lima ratus kilowatt) yang terhubung dalam 1 (satu) sistem instalasi tenaga listrik, wajib memenuhi kewajiban perizinan berusaha untuk kegiatan penyediaan tenaga listrik untuk kepentingan sendiri berupa laporan kepada Menteri atau gubernur.
(2) Laporan sebagaimana dimaksud pada ayat (1), dilakukan sebelum melaksanakan pembangunan dan pemasangan Sistem PLTS Atap, sebanyak 1 (satu) kali sesuai dengan ketentuan peraturan perundang-undangan di bidang ketenagalistrikan.
(3) Laporan sebagaimana dimaksud pada ayat (2) sesuai dengan format yang tercantum dalam Lampiran III yang merupakan bagian tidak terpisahkan dari Peraturan Menteri ini.

Pasal 19

Kapasitas Sistem PLTS Atap sebagaimana dimaksud dalam Pasal 17 ayat (1) dan Pasal 18 ayat (1) ditentukan berdasarkan kapasitas total *inverter*.

Pasal 20

Penerbitan izin usaha penyediaan tenaga listrik untuk kepentingan sendiri sebagaimana dimaksud dalam Pasal 17 ayat (2) dan penyampaian laporan sebagaimana dimaksud dalam Pasal 18 ayat (2), dilaksanakan sesuai dengan ketentuan peraturan perundang-undangan mengenai perizinan berusaha berbasis risiko.

Paragraf 3
Pembangunan dan Pemasangan

Pasal 21

(1) Pelaksanaan pembangunan dan pemasangan Sistem PLTS Atap wajib dilakukan oleh Badan Usaha sesuai dengan ketentuan peraturan perundang-undangan di bidang ketenagalistrikan.
(2) Pelaksanaan pembangunan dan pemasangan Sistem PLTS Atap oleh Badan Usaha sebagaimana dimaksud pada ayat (1), wajib memenuhi ketentuan peraturan perundang-undangan di bidang keselamatan ketenagalistrikan.

Pasal 22

(1) Sistem PLTS Atap hanya dapat dibangun dan dipasang setelah mendapatkan persetujuan Pemegang IUPTLU sebagaimana dimaksud dalam Pasal 15 ayat (3) atau mendapatkan persetujuan berdasarkan ketentuan sebagaimana dimaksud dalam Pasal 15 ayat (5).

(2) Dalam hal Sistem PLTS Atap telah dibangun dan dipasang sebelum adanya persetujuan dari Pemegang IUPTLU sebagaimana dimaksud dalam Pasal 15 ayat (3), Sistem PLTS Atap hanya dapat beroperasi terhubung dengan jaringan Pemegang IUPTLU setelah mendapatkan persetujuan Pemegang IUPTLU.

Pasal 23

(1) Dalam hal ditemukan Sistem PLTS Atap beroperasi terhubung dengan jaringan Pemegang IUPTLU sebelum mendapatkan persetujuan Pemegang IUPTLU, Pemegang IUPTLU menyampaikan surat pemberitahuan kepada pelanggan Pemegang IUPTLU untuk:
   a. memutus Sistem PLTS Atap dari jaringan Pemegang IUPTLU; dan
   b. membayar pinalti kepada Pemegang IUPTLU berdasarkan perhitungan kapasitas total *inverter* dikali 240 (dua ratus empat puluh) jam dikali tarif tenaga listrik.
(2) Dalam hal pelanggan Pemegang IUPTLU tidak memenuhi ketentuan sebagaimana dimaksud pada ayat (1) dalam jangka waktu 1 (satu) bulan sejak surat pemberitahuan disampaikan, Pemegang IUPTLU dapat melakukan pemutusan sementara layanan pelanggan.
(3) Pemutusan sementara layanan pelanggan sebagaimana dimaksud pada ayat (2) berakhir setelah pelanggan Pemegang IUPTLU memenuhi ketentuan sebagaimana dimaksud pada ayat (1).
(4) Dalam hal pelanggan Pemegang IUPTLU akan menyambungkan Sistem PLTS Atap dengan jaringan Pemegang IUPTLU, pelanggan Pemegang IUPTLU mengajukan permohonan Sistem PLTS Atap sebagaimana dimaksud dalam Pasal 14.

Paragraf 4
Pemeriksaan dan Pengujian

Pasal 24

(1) Sistem PLTS Atap dengan total kapasitas:
   a. lebih dari 500 kW (lima ratus kilowatt) yang terhubung dalam 1 (satu) sistem instalasi tenaga listrik; dan
   b. sampai dengan 500 kW (lima ratus kilowatt) dengan spesifikasi teknis kontrol panel menjadi 1 (satu) bagian terpisahkan,

   wajib memiliki SLO.
(2) SLO sebagaimana dimaksud pada ayat (1) diterbitkan oleh lembaga inspeksi teknik sesuai dengan ketentuan peraturan perundang-undangan di bidang ketenagalistrikan.

Pasal 25

(1) Sistem PLTS Atap dengan total kapasitas sampai dengan 500 kW (lima ratus kilowatt) dengan spesifikasi teknis kontrol panel yang menjadi 1 (satu) bagian tidak terpisahkan dan dapat dioperasikan secara *plug and play* yang memenuhi ketentuan:
    a. kondisi Sistem PLTS Atap menggunakan:
        1) satu *inverter*; atau
        2) lebih dari satu *inverter* dengan total kapasitas lebih kecil dari 10 kW (sepuluh kilowatt),
    b. rangkaian modul surya dalam satu bagian konstruksi bangunan yang sama;
    c. Sistem PLTS Atap dalam pembumian yang sama; dan
    d. Sistem PLTS Atap melayani satu instalasi pemanfaatan yang sama,

    dinyatakan telah memenuhi ketentuan wajib SLO.
(2) Sistem PLTS Atap sebagaimana dimaksud pada ayat (1), wajib dilengkapi dengan surat pernyataan bertanggung jawab terhadap aspek keselamatan ketenagalistrikan dari pemilik instalasi tenaga listrik atau Badan Usaha.
(3) Surat pernyataan sebagaimana dimaksud pada ayat (2) sesuai dengan format yang tercantum dalam Lampiran IV yang merupakan bagian tidak terpisahkan dari Peraturan Menteri ini.
(4) Surat pernyataan sebagaimana dimaksud pada ayat (3), dilengkapi dengan dokumen berupa:
    a. sertifikat produk;
    b. garansi pabrikan yang masih berlaku;
    c. hasil uji komisioning dari teknisi distributor atau Badan Usaha; atau
    d. dokumen pemeliharaan instalasi pembangkit tenaga listrik.
(5) Dokumen sebagaimana dimaksud pada ayat (4) dievaluasi oleh Menteri dan wajib mendapatkan nomor registrasi dari Menteri.
(6) Pelaksanaan uji komisioning sebagaimana dimaksud pada ayat (4) huruf c mengikuti persyaratan yang tercantum dalam Lampiran V yang merupakan bagian tidak terpisahkan dari Peraturan Menteri ini.

Pasal 26

Dalam hal calon Pelanggan PLTS Atap:
a. belum memiliki SLO sebagaimana dimaksud dalam Pasal 24 ayat (1) dalam jangka waktu paling lambat 6 (enam) bulan sejak mendapatkan persetujuan dari Pemegang IUPTLU; atau
b. belum memiliki nomor registrasi dari Menteri sebagaimana dimaksud dalam Pasal 25 ayat (5) dalam jangka waktu paling lambat 3 (tiga) bulan sejak mendapatkan persetujuan dari Pemegang IUPTLU,

Pemegang IUPTLU membatalkan persetujuan sebagaimana dimaksud dalam Pasal 15 ayat (3) dan ayat (5).

Pasal 27

Kapasitas Sistem PLTS Atap sebagaimana dimaksud dalam Pasal 24 ayat (1) dan Pasal 25 ayat (1) ditentukan berdasarkan kapasitas total *inverter*.

Paragraf 5
Penyediaan dan Pemasangan *Advanced Meter*

Pasal 28

(1) Pemegang IUPTLU wajib menyediakan dan memasang *Advanced Meter* bagi calon Pelanggan PLTS Atap yang telah memenuhi ketentuan wajib SLO sebagaimana dimaksud dalam Pasal 24 atau Pasal 25.
(2) *Advanced Meter* sebagaimana dimaksud pada ayat (1), disediakan dan dipasang oleh Pemegang IUPTLU paling lambat 15 (lima belas) hari kerja sejak:
    a. SLO yang diterbitkan oleh lembaga inspeksi teknik sebagaimana dimaksud dalam Pasal 24 ayat (2); atau
    b. bukti penerbitan nomor registrasi dari Menteri sebagaimana dimaksud dalam Pasal 25 ayat (5),

    diterima oleh Pemegang IUPTLU dari calon Pelanggan PLTS Atap.
(3) Biaya penyediaan dan pemasangan *Advanced Meter* sebagaimana dimaksud pada ayat (1) ditanggung oleh Pemegang IUPTLU.

Paragraf 6
Biaya Operasi Paralel Sistem PLTS Atap

Pasal 29

Sistem PLTS Atap yang dibangun dan dipasang oleh Pelanggan PLTS Atap tidak dikenai biaya operasi paralel.

Bagian Keempat
Aplikasi Sistem PLTS Atap Secara Elektronik

Pasal 30

(1) Menteri melalui Direktur Jenderal EBTKE membangun aplikasi sistem pelayanan dan pelaporan terintegrasi Sistem PLTS Atap secara elektronik untuk:
    a. permohonan Sistem PLTS Atap oleh calon Pelanggan PLTS Atap;
    b. pemberian persetujuan dan penolakan oleh Pemegang IUPTLU;
    c. informasi pemenuhan kewajiban perizinan berusaha untuk kegiatan penyediaan tenaga listrik untuk kepentingan sendiri;
    d. pelaporan penggunaan Sistem PLTS Atap oleh Pemegang IUPTLU; dan
    e. akses data produksi energi listrik Sistem PLTS Atap milik Pelanggan PLTS Atap.
(2) Aplikasi sebagaimana dimaksud pada ayat (1), paling sedikit menampilkan informasi mengenai:

a. alur proses pembangunan dan pemasangan Sistem PLTS Atap;
b. status permohonan calon Pelanggan PLTS Atap;
c. status pelaporan oleh Pelanggan PLTS Atap dan Pemegang IUPTLU; dan
d. daftar Badan Usaha.

(3) Dalam monitoring pelaksanaan Sistem PLTS Atap di provinsi, Menteri melalui Direktur Jenderal EBTKE memberikan akses aplikasi sistem pelayanan dan pelaporan terintegrasi Sistem PLTS Atap secara elektronik kepada gubernur.

Pasal 31

(1) Berdasarkan Peraturan Menteri ini, PT PLN (Persero) membangun:
a. aplikasi sistem pelayanan dan pelaporan terintegrasi Sistem PLTS Atap secara elektronik untuk pelanggan PT PLN (Persero);
b. aplikasi penggunaan Sistem PLTS Atap berbasis digital yang terintegrasi dengan sistem *Supervisory Control and Data Acquisition* (SCADA) atau *smart grid* distribusi; dan
c. membangun infrastruktur penunjang Sistem PLTS Atap.

(2) Aplikasi sebagaimana dimaksud pada ayat (1) huruf a dan huruf b terintegrasi dengan aplikasi sistem pelayanan dan pelaporan yang dibangun oleh Menteri melalui Direktur Jenderal EBTKE sebagaimana dimaksud dalam Pasal 30 ayat (1).

Pasal 32

(1) Aplikasi penggunaan Sistem PLTS Atap berbasis digital yang terintegrasi dengan sistem *Supervisory Control and Data Acquisition* (SCADA) atau *smart grid* distribusi sebagaimana dimaksud dalam Pasal 31 ayat (1) huruf b berfungsi untuk:
a. menjaga kestabilan dan keandalan Sistem Tenaga Listrik;
b. menjaga efisiensi penyaluran energi listrik; dan/atau
c. monitoring produksi energi Sistem PLTS Atap secara waktu nyata (*realtime*).

(2) Pembangunan aplikasi Sistem PLTS Atap sebagaimana dimaksud pada ayat (1) didahului dengan penyusunan peta jalan pembangunan aplikasi penggunaan Sistem PLTS Atap berbasis digital yang terintegrasi dengan sistem *Supervisory Control and Data Acquisition* (SCADA) atau *smart grid* distribusi.

(3) Peta jalan pembangunan aplikasi sebagaimana dimaksud pada ayat (2) wajib tersedia paling lambat 3 (tiga) bulan sejak Peraturan Menteri ini diundangkan.

(4) Peta jalan sebagaimana dimaksud pada ayat (3) paling sedikit memuat informasi:
a. konsep aplikasi;
b. tahapan pembangunan; dan
c. kebutuhan biaya pembangunan.

Pasal 33

Badan Usaha sebagaimana dimaksud dalam Pasal 21 ayat (1), menyediakan aplikasi sistem pemantauan produksi energi listrik Sistem PLTS Atap yang dapat terintegrasi dengan aplikasi sistem pelayanan dan pelaporan terintegrasi Sistem PLTS Atap secara elektronik.

Pasal 34

Dalam hal aplikasi sistem pelayanan dan pelaporan terintegrasi Sistem PLTS Atap secara elektronik sebagaimana dimaksud dalam Pasal 30 dan Pasal 31 belum tersedia, proses pelayanan dan pelaporan dilaksanakan secara manual.

Bagian Kelima
Pusat Pengaduan Sistem PLTS Atap

Pasal 35

(1) Menteri membentuk pusat pengaduan Sistem PLTS Atap untuk menerima dan menindaklanjuti pengaduan dari Pelanggan PLTS Atap atau Pemegang IUPTLU dalam pelaksanaan program Sistem PLTS Atap.
(2) Kedudukan atau lokasi pusat pengaduan Sistem PLTS Atap sebagaimana dimaksud pada ayat (1), berada di Direktorat Jenderal Energi Baru, Terbarukan, dan Konservasi Energi.
(3) Dalam mendukung pelaksanaan pusat pengaduan Sistem PLTS Atap sebagaimana dimaksud pada ayat (2), Menteri dapat membentuk tim pusat pengaduan Sistem PLTS Atap.
(4) Keanggotaan tim sebagaimana dimaksud pada ayat (3) terdiri atas perwakilan:
    a. Kementerian Energi dan Sumber Daya Mineral;
    b. Badan Pengawasan Keuangan dan Pembangunan; dan
    c. organisasi independen.
(5) Pusat pengaduan Sistem PLTS Atap sebagaimana dimaksud pada ayat (1) dan tim pusat pengaduan Sistem PLTS Atap sebagaimana dimaksud pada ayat (3) ditetapkan dengan Keputusan Menteri.

Bagian Keenam
Pelaporan

Pasal 36

(1) Pemegang IUPTLU wajib menyampaikan laporan penggunaan Sistem PLTS Atap kepada Menteri melalui Direktur Jenderal EBTKE dengan tembusan kepada Direktur Jenderal Ketenagalistrikan untuk setiap golongan tarif pada masing-masing wilayah Sistem Tenaga Listrik.

(2) Laporan sebagaimana dimaksud pada ayat (1) disampaikan secara berkala setiap bulan yang memuat paling sedikit:
   a. data jumlah Pelanggan PLTS Atap;
   b. data jumlah pengajuan permohonan Sistem PLTS Atap;
   c. total kapasitas Sistem PLTS Atap;
   d. total energi listrik yang disalurkan dari sistem instalasi Pelanggan PLTS Atap ke sistem jaringan Pemegang IUPTLU; dan
   e. total energi listrik yang diterima oleh sistem instalasi Pelanggan PLTS Atap dari sistem jaringan Pemegang IUPTLU.

Pasal 37

Pelanggan PLTS Atap dari golongan tarif untuk keperluan industri harus melaporkan rencana operasi Sistem PLTS Atap kepada Pemegang IUPTLU secara berkala sesuai dengan kebutuhan Pemegang IUPTLU.

BAB III
PEMBINAAN DAN PENGAWASAN

Pasal 38

Menteri melalui Direktur Jenderal EBTKE dan/atau Direktur Jenderal Ketenagalistrikan melakukan pembinaan dan pengawasan terhadap pelaksanaan Sistem PLTS Atap dalam:
a. penerapan keselamatan ketenagalistrikan;
b. penerapan standar dan mutu Sistem PLTS Atap;
c. pelaksanaan permohonan pembangunan dan pemasangan Sistem PLTS Atap;
d. pemenuhan persyaratan perizinan;
e. penerapan standar dan mutu pembangunan dan pemasangan Sistem PLTS Atap;
f. penerapan standar dan mutu pemeriksaan dan pengujian Sistem PLTS Atap;
g. pelaksanaan pelaporan Sistem PLTS Atap; dan
h. pelaksanaan pembangunan dan/atau persetujuan aplikasi penggunaan Sistem PLTS Atap berbasis digital yang dibuat oleh Pemegang IUPTLU.

Pasal 39

(1) Pembinaan sebagaimana dimaksud dalam Pasal 38, berupa:
   a. konsultasi;
   b. diseminasi;
   c. peningkatan kapasitas sumber daya manusia; dan/atau
   d. pembinaan lain sesuai dengan kebutuhan.

(2) Pengawasan sebagaimana dimaksud dalam Pasal 38, berupa:
   a. inspeksi pengawasan di lapangan;
   b. meminta laporan pelaksanaan Sistem PLTS Atap; dan/atau
   c. pelaksanaan penelitian dan evaluasi atas laporan pelaksanaan Sistem PLTS Atap.

BAB IV
KETENTUAN LAIN LAIN

Pasal 40

(1) Nilai ekonomi karbon dari penggunaan Sistem PLTS Atap dilaksanakan sesuai dengan ketentuan peraturan perundang-undangan.
(2) Dalam hal belum terdapat ketentuan peraturan perundang-undangan sebagaimana dimaksud pada ayat (1), nilai ekonomi karbon dari penggunaan Sistem PLTS Atap menjadi milik Pemerintah.

Pasal 41

Pelanggan PLTS Atap sebagaimana dimaksud dalam Pasal 17 ayat (1) dan Pasal 18 ayat (1), dilarang memperjualbelikan tenaga listrik yang dihasilkan dari Sistem PLTS Atap.

Pasal 42

Pelanggan PLTS Atap dari golongan tarif untuk keperluan industri dengan kapasitas Sistem PLTS Atap lebih besar dari 3 MW (tiga megawatt), wajib menyediakan pengaturan basis data prakiraan cuaca (*weather forecast*) yang terintegrasi dengan sistem *Supervisory Control and Data Acquisition* (SCADA) atau *smart grid* distribusi milik Pemegang IUPTLU.

Pasal 43

Khusus untuk PT PLN (Persero), biaya yang diperlukan dalam rangka pelaksanaan Peraturan Menteri ini sebagai dampak masuknya Sistem PLTS Atap diperhitungkan dalam biaya pokok penyediaan tenaga listrik PT PLN (Persero) sesuai dengan ketentuan peraturan perundang-undangan di bidang keuangan negara.

BAB V
SANKSI

Pasal 44

Menteri melalui Direktur Jenderal EBTKE mengenakan sanksi administratif berupa teguran tertulis kepada:
a. Pemegang IUPTLU yang melanggar ketentuan sebagaimana dimaksud dalam Pasal 7 ayat (1), Pasal 16 ayat (2), Pasal 28 ayat (1), Pasal 32 ayat (3), dan Pasal 36 ayat (1); dan/atau
b. Pelanggan PLTS Atap yang melanggar ketentuan Pasal 42.

Pasal 45

(1) Pelanggan PLTS Atap yang melanggar ketentuan sebagaimana dimaksud dalam Pasal 5 ayat (1), Pasal 6, Pasal 17 ayat (1), Pasal 18 ayat (1), Pasal 21 ayat (1), Pasal 24 ayat (1), Pasal 25 ayat (2), Pasal 25 ayat (5), dan Pasal 41 diberikan sanksi sesuai dengan ketentuan peraturan perundang-undangan di bidang ketenagalistrikan.
(2) Badan Usaha yang melanggar ketentuan sebagaimana dimaksud dalam Pasal 21 ayat (2) diberikan sanksi sesuai dengan ketentuan peraturan perundang-undangan di bidang ketenagalistrikan.

BAB VI
KETENTUAN PERALIHAN

Pasal 46

(1) Pada saat Peraturan Menteri ini mulai berlaku, Sistem PLTS Atap yang telah beroperasi secara terhubung dengan jaringan Pemegang IUPTLU sebelum Peraturan Menteri ini mulai berlaku dan belum dilaporkan kepada Pemegang IUPTLU, dalam jangka waktu paling lambat 3 (tiga) bulan sejak Peraturan Menteri ini diundangkan, Pelanggan PLTS Atap harus melaporkan kepada Pemegang IUPTLU dan memenuhi ketentuan peraturan perundang undangan di bidang ketenagalistrikan.
(2) Dalam hal Pelanggan PLTS Atap telah memenuhi ketentuan sebagaimana dimaksud pada ayat (1), Sistem PLTS Atap yang telah beroperasi secara terhubung dengan jaringan Pemegang IUPTLU dinyatakan telah sesuai dan berlaku ketentuan dalam Peraturan Menteri ini.
(3) Dalam hal Pelanggan PLTS Atap tidak memenuhi ketentuan sebagaimana dimaksud pada ayat (1), Pemegang IUPTLU menyampaian surat pemberitahuan sebagaimana dimaksud dalam Pasal 23 Peraturan Menteri ini.

Pasal 47

(1) Pada saat Peraturan Menteri ini mulai berlaku:
    a. Sistem PLTS Atap yang telah beroperasi secara terhubung dengan jaringan Pemegang IUPTLU sebelum Peraturan Menteri ini mulai berlaku yang telah menggunakan mekanisme perhitungan ekspor impor energi listrik dan ketentuan biaya kapasitas (*capacity charge*), dinyatakan tetap berlaku selama 10 (sepuluh) tahun sejak mendapatkan persetujuan dari Pemegang IUPTLU; atau
    b. Pelanggan PLTS Atap yang telah mendapatkan persetujuan dari Pemegang IUPTLU namun belum beroperasi sebelum Peraturan Menteri ini mulai berlaku, mekanisme perhitungan ekspor impor energi listrik dan ketentuan biaya kapasitasnya dinyatakan tetap berlaku selama 10 (sepuluh) tahun sejak mendapatkan persetujuan dari Pemegang IUPTLU.

(2) Dalam hal Pelanggan PLTS Atap sebagaimana dimaksud pada ayat (1) mengajukan perubahan kapasitas dari permohonan awal, Sistem PLTS Atap dilaksanakan sesuai dengan ketentuan dalam Peraturan Menteri ini.

Pasal 48

Calon Pelanggan PLTS Atap yang telah mengajukan permohonan kepada Pemegang IUPTLU sebelum Peraturan Menteri ini mulai berlaku namun belum mendapatkan persetujuan Pemegang IUPTLU, berlaku ketentuan yang diatur dalam Peraturan Menteri ini.

Pasal 49

Pada saat Peraturan Menteri ini mulai berlaku, aplikasi sistem pelayanan dan pelaporan terintegrasi Sistem PLTS Atap secara elektronik yang telah dibangun berdasarkan Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 26 Tahun 2021 tentang Pembangkit Listrik Tenaga Surya Atap yang Terhubung pada Jaringan Tenaga Listrik Pemegang Izin Usaha Penyediaan Tenaga Listrik untuk Kepentingan Umum (Berita Negara Republik Indonesia Tahun 2021 Nomor 948) berlaku sebagai aplikasi sistem pelayanan dan pelaporan terintegrasi Sistem PLTS Atap secara elektronik yang harus dibangun sebagaimana dimaksud dalam Pasal 30 ayat (1).

Pasal 50

Pada saat Peraturan Menteri ini mulai berlaku, pusat pengaduan Sistem PLTS Atap dan tim pusat pengaduan Sistem PLTS Atap yang telah dibentuk berdasarkan Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 26 Tahun 2021 tentang Pembangkit Listrik Tenaga Surya Atap yang Terhubung pada Jaringan Tenaga Listrik Pemegang Izin Usaha Penyediaan Tenaga Listrik untuk Kepentingan Umum (Berita Negara Republik Indonesia Tahun 2021 Nomor 948) berlaku sebagai pusat pengaduan Sistem PLTS Atap dan tim pusat pengaduan Sistem PLTS Atap yang harus dibentuk dengan Keputusan Menteri sebagaimana dimaksud dalam Pasal 35 ayat (5).

BAB VII
KETENTUAN PENUTUP

Pasal 51

Pada saat Peraturan Menteri ini mulai berlaku:

a. ketentuan operasi paralel sebagaimana dimaksud dalam Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 11 Tahun 2021 tentang Pelaksanaan Usaha Ketenagalistrikan (Berita Negara Republik Indonesia tahun 2021 Nomor 671), dinyatakan tidak berlaku sepanjang berkaitan dengan penggunaan Sistem PLTS Atap oleh Pelanggan PLTS Atap; dan

b. Peraturan Menteri Energi dan Sumber Daya Mineral Nomor 26 Tahun 2021 tentang Pembangkit Listrik Tenaga Surya Atap yang Terhubung pada Jaringan Tenaga Listrik Pemegang Izin Usaha Penyediaan Tenaga Listrik untuk Kepentingan Umum (Berita Negara Republik Indonesia Tahun 2021 Nomor 948), dicabut dan dinyatakan tidak berlaku.

Pasal 52

Peraturan Menteri ini mulai berlaku pada tanggal diundangkan.

Agar setiap orang mengetahuinya, memerintahkan pengundangan Peraturan Menteri ini dengan penempatannya dalam Berita Negara Republik Indonesia.

Ditetapkan di Jakarta
pada tanggal 29 Januari 2024

MENTERI ENERGI DAN SUMBER DAYA MINERAL
REPUBLIK INDONESIA,

ttd.

ARIFIN TASRIF

Diundangkan di Jakarta
pada tanggal 31 Januari 2024

DIREKTUR JENDERAL
PERATURAN PERUNDANG-UNDANGAN
KEMENTERIAN HUKUM DAN HAK ASASI MANUSIA
REPUBLIK INDONESIA,

ttd.

ASEP N. MULYANA

BERITA NEGARA REPUBLIK INDONESIA TAHUN 2024 NOMOR 70

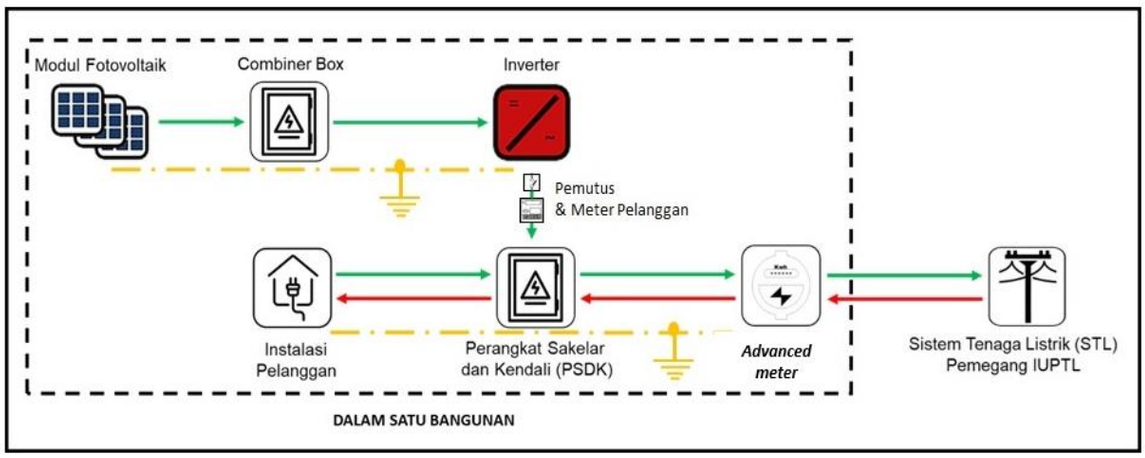
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KEPALA BIRO HUKUM,

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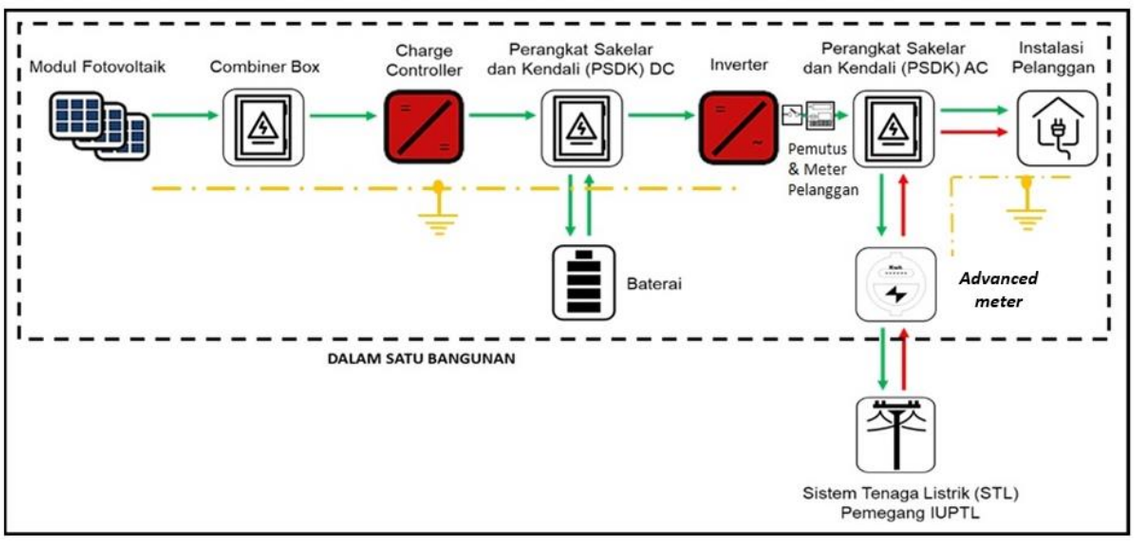
LAMPIRAN I
PERATURAN MENTERI ENERGI DAN SUMBER DAYA MINERAL
REPUBLIK INDONESIA
NOMOR 2 TAHUN 2024
TENTANG
PEMBANGKIT LISTRIK TENAGA SURYA ATAP YANG TERHUBUNG PADA JARINGAN TENAGA LISTRIK PEMEGANG IZIN USAHA PENYEDIAAN TENAGA LISTRIK UNTUK KEPENTINGAN UMUM

A. DIAGRAM INSTALASI SISTEM PLTS ATAP

1. Sistem PLTS Atap Tanpa Baterai



2. Sistem PLTS Atap dengan Baterai



B. STANDAR SPESIFIKASI TEKNIS SISTEM PLTS ATAP

Standar Spesifikasi Teknis yang harus dipenuhi oleh Sistem PLTS Atap adalah sebagai berikut:

No.	Peralatan	Standar Spesifikasi Teknis*)
1.	Modul Surya	Mengikuti a. SNI lEC 61215-1:2016 Modul Fotovoltaik (FV) terrestrial – Kualifikasi desain dan pengesahan jenis - Bagian 1 : Persyaratan uji (lEC 61215-1:2016, IDT); b. SNI lEC 61215-2:2016 Modul Fotovoltaik (FV) terestrial - Kualifikasi desain dan pengesahan jenis - Bagian 2 : Prosedur uji (lEC 61215-2:2016, IDT); dan c. SNI lEC 61215-1-1:2016 Modul Fotovoltaik (FV) terestrial- Kualifikasi desain dan pengesahan jenis - Bagian 1-1 : Persyaratan khusus untuk pengujian Modul Fotovoltaik (FV) silikon kristalin (lEC 61215-1-1:2016, IDT).
2.	Kotak dan Selungkup Untuk Lengkapan Listrik (*Combiner Box*)	Mengikuti SNI 0225 Tahun 2020 tentang Persyaratan Umum Instalasi Listrik
3.	*Inverter*	Minimum memiliki fungsi proteksi keselamatan: - Anti *Islanding* - *Over/under frekuensi* - *Over/under voltage* - *Over heat protection* - *Surge arrester* - Proteksi arus lebih - *DC ground fault detector*
4.	Saluran Penghantar AC	SNI 0225:2020 tentang Persyaratan Umum Instalasi Listrik (PUIL 2020)
5.	Saluran Penghantar DC	SNI 0225:2020 tentang Persyaratan Umum Instalasi Listrik (PUIL 2020)
6.	Gawai Proteksi	SNI 0225:2020 tentang Persyaratan Umum Instalasi Listrik (PUIL 2020)

No.	Peralatan	Standar Spesifikasi Teknis*)
7.	Perangkat Sakelar dan Kendali	SNI 0225:2020 tentang Persyaratan Umum Instalasi Listrik (PUIL 2020)
8.	Baterai	PLTS Atap yang terhubung dengan baterai harus tetap dapat beroperasi dengan proteksi *inverter* di angka 3
9.	Pembumian Sistem	SNI 0225:2020 tentang Persyaratan Umum Instalasi Listrik (PUIL 2020)
10.	*Advanced Meter*	tidak diatur

*) Standar Spesifikasi Teknis, termasuk perubahannya.

MENTERI ENERGI DAN SUMBER DAYA MINERAL
REPUBLIK INDONESIA,

ttd.

ARIFIN TASRIF

Salinan sesuai dengan aslinya
KEMENTERIAN ENERGI DAN SUMBER DAYA MINERAL
KEPALA BIRO HUKUM,

BAMBANG SUJITO

LAMPIRAN II
PERATURAN MENTERI ENERGI DAN SUMBER DAYA MINERAL
REPUBLIK INDONESIA
NOMOR 2 TAHUN 2024
TENTANG
PEMBANGKIT LISTRIK TENAGA SURYA ATAP YANG TERHUBUNG PADA JARINGAN TENAGA LISTRIK PEMEGANG IZIN USAHA PENYEDIAAN TENAGA LISTRIK UNTUK KEPENTINGAN UMUM

PERMOHONAN PEMBANGUNAN DAN PEMASANGAN
SISTEM PLTS ATAP OLEH CALON PELANGGAN PLTS ATAP

Nomor : ..... (tempat), (tanggal) (bulan) (tahun)
Lampiran : .....
Hal : Permohonan Pembangunan dan
Pemasangan Sistem PLTS Atap

Yang terhormat
General Manager/Direktur .....
(Pemegang IUPTLU)

Dalam rangka permohonan pembangunan dan pemasangan Sistem PLTS Atap, dengan ini kami sampaikan data sebagai berikut:

A. Data Administrasi:
   1. Nomor Identitas Pelanggan PLTS Atap :.....
   2. Nama Pelanggan PLTS Atap :.....
   3. Nomor Induk Kependudukan :.....
   4. NPWP :.....
   5. Alamat Pelanggan PLTS Atap
      a. Jalan :.....
      b. Desa/Kelurahan :.....
      c. Kecamatan :.....
      d. Kabupaten/Kota :.....
      e. Provinsi :.....
   6. Nomor Telepon :.....
   7. Alamat Email :.....

8. Mekanisme Pembayaran Tarif
   Tenaga Listrik Pelanggan PLTS Atap : ☐ pra bayar* ☐ pasca bayar

   *) *Jika mekanisme pembayaran tarif tenaga listrik Pelanggan PLTS Atap prabayar, maka surat permohonan ini berlaku juga sebagai permohonan Pelanggan PLTS Atap untuk perubahan mekanisme pembayaran tarif tenaga listrik prabayar menjadi pascabayar kepada Pemegang IUPTLU.*

9. Telah memiliki Perjanjian Jual Beli Tenaga Listrik dengan Pemegang izin Usaha Penyediaan Tenaga Listrik untuk Kepentingan Umum) : ☐ Ya * ☐ Tidak

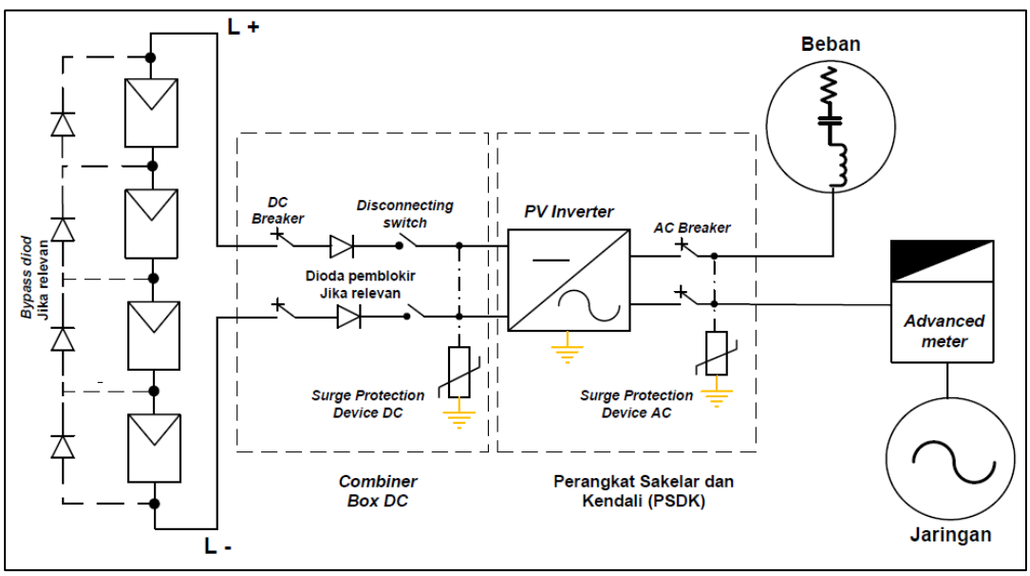
   *) *Jika Pelanggan PLTS Atap telah memiliki Perjanjian Jual Beli Tenaga Listrik dengan Pemegang IUPTLU, maka surat permohonan ini berlaku juga sebagai permohonan Pelanggan PLTS Atap untuk penyesuaian Perjanjian Jual Beli Tenaga Listrik kepada Pemegang IUPTLU.*

B. Data Teknis:

1. Besaran daya terpasang (VA) :.....
2. Badan Usaha yang ditunjuk :.....
3. Diagram satu garis :.....
4. Rencana operasi** :.....

   **) *hanya diperuntukan bagi Pelanggan PLTS Atap dari golongan tarif untuk keperluan industri.*

Contoh Diagram Satu Garis Sistem PLTS Atap Tanpa Baterai

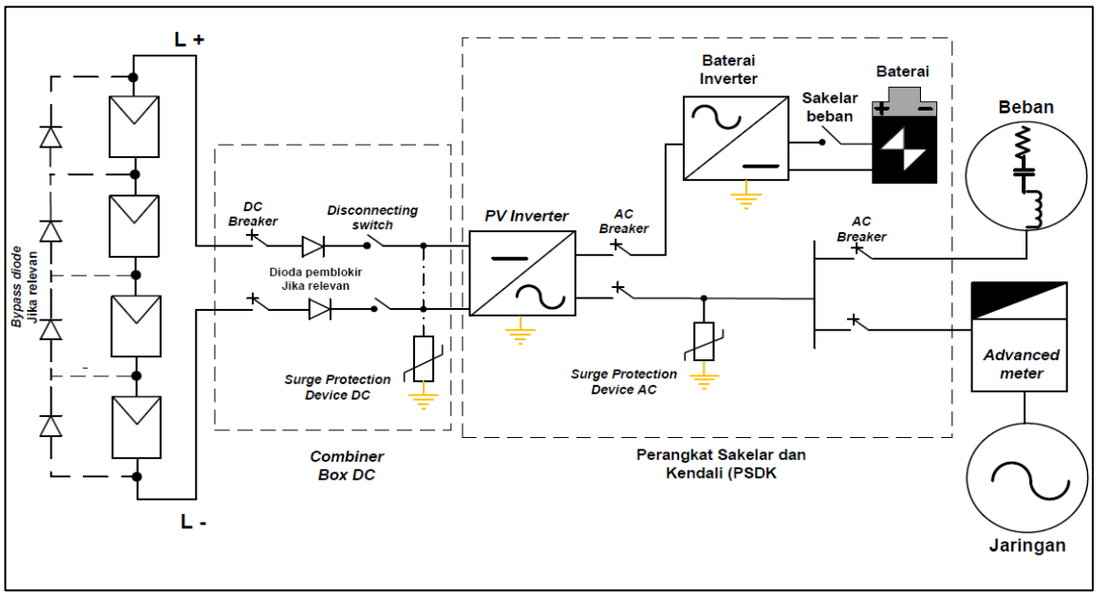


Catatan:

1. Semua Bagian Konduktif Terbuka (BKT) yang dibumikan harus terhubung secara *equipotensial* menjadi 1 (satu) titik.

2. Pembangunan dan pemasangan mengikuti ketentuan keselamatan ketenagalistrikan.

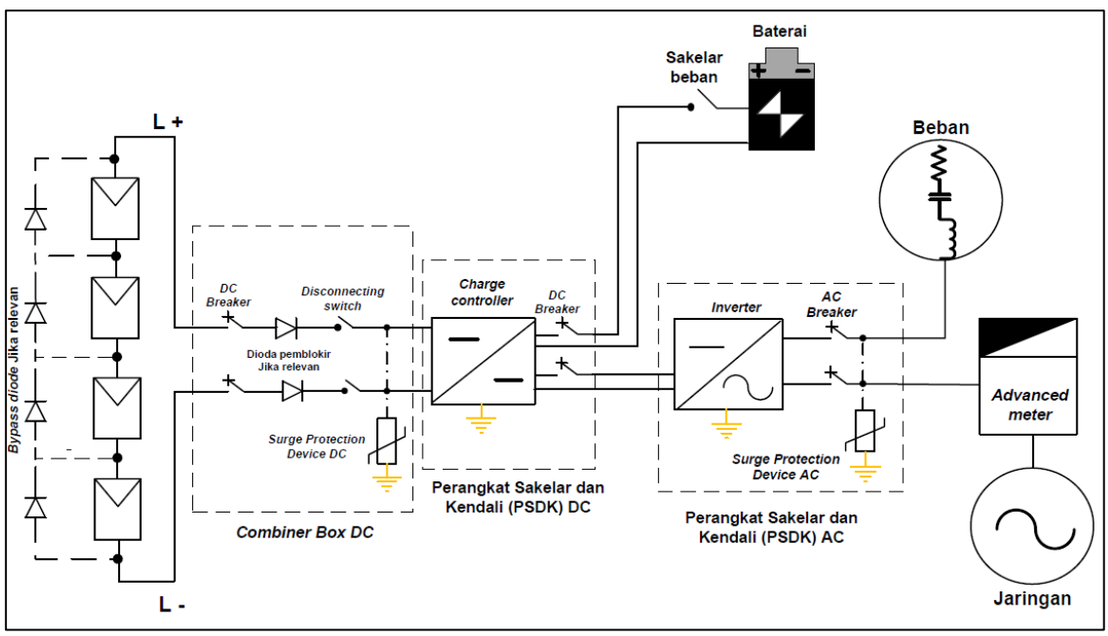
Contoh Diagram Satu Garis Sistem PLTS Atap
dengan Baterai - *AC Coupling*



Catatan:

1. Semua Bagian Konduktif Terbuka (BKT) yang dibumikan harus terhubung secara *equipotensial* menjadi 1 (satu) titik.
2. Pembangunan dan pemasangan mengikuti ketentuan keselamatan ketenagalistrikan.

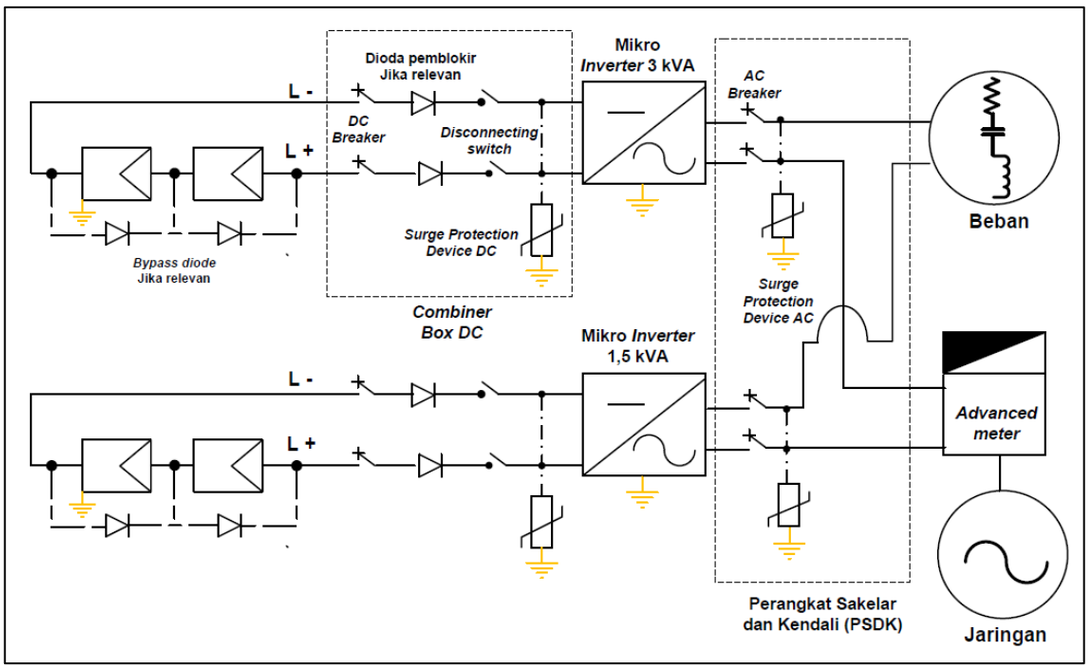
Contoh Diagram Satu Garis Sistem PLTS Atap
dengan Baterai - *DC Coupling*



Catatan:

1. Semua Bagian Konduktif Terbuka (BKT) yang dibumikan harus terhubung secara *equipotensial* menjadi 1 (satu) titik.
2. Pembangunan dan pemasangan mengikuti ketentuan keselamatan ketenagalistrikan.
3. Peralatan *inverter* harus memiliki fungsi anti-*islanding*.

Contoh Diagram Satu Garis Sistem PLTS Atap
dengan *Mikro Inverter*



Catatan:

1. Semua Bagian Konduktif Terbuka (BKT) yang dibumikan harus terhubung secara *equipotensial* menjadi 1 (satu) titik.
2. Pembangunan dan pemasangan mengikuti ketentuan keselamatan ketenagalistrikan.
3. Peralatan *inverter* harus memiliki fungsi anti-*islanding*.
4. Sistem PLTS Atap dengan total kapasitas *inverter* dan *Mikro Inverter* di bawah 10 kW (sepuluh kilowatt) dapat dinyatakan telah memenuhi ketentuan wajib SLO.
5. Spesifikasi teknis peralatan yang akan dipasang:

Data Peralatan	Modul Surya	*Inverter*	Baterai (alternatif jika ada)
Merek			
Tipe			

Data Peralatan	Modul Surya	*Inverter*	Baterai (alternatif jika ada)
Negara Produsen			
Tahun Produksi			
Kapasitas per unit			
Satuan	Wp	VA	Ah
Jumlah Unit			

6. Persyaratan teknis lainnya berupa dokumen perencanaan atau kajian berdasarkan besaran kapasitas PLTS Atap sesuai dengan tabel sebagai berikut:

No.	Persyaratan Dokumen	Kapasitas Sistem PLTS Atap (kWp)				
		<10	10 s.d 100	100 s.d 500	500 s.d 3000	>3000
1.	Dokumen perencanaan yang mencakup informasi: - sistem pembumian; - gawai proteksi arus lebih; - surja; dan - *over/under voltage.*	-	√	√	√	√
2.	Dokumen perencanaan yang mencakup informasi *data sheet* proteksi inverter dan fungsi Anti *Islanding*	√	√	√	√	√
3.	Dokumen perencanaan yang mencakup informasi *over/under* frekuensi	-	-	√	√	√
4.	Data proyeksi produksi kWh Sistem PLTS Atap	-	√	√	√	√
5.	Dokumen proyeksi beban harian	-	-	√	√	√
6.	Dokumen analisis hubung singkat	-	-	√	√	√
7.	Dokumen kajian *loadflow*	-	-	√	√	√
8.	Dokumen dampak harmonisa	-	-	√	√	√
9.	Dokumen kajian stabilitas	-	-	-	√	√

No.	Persyaratan Dokumen	Kapasitas Sistem PLTS Atap (kWp)				
		<10	10 s.d 100	100 s.d 500	500 s.d 3000	>3000
10.	Dokumen pengaturan basis data prakiraan cuaca (*weather forecast*)	-	-	-	-	√

Keterangan:

- : tidak dipersyaratkan

√ : dipersyaratkan

C. Perkiraan total biaya yang diperlukan untuk pembangunan dan pemasangan Sistem PLTS Atap adalah sebesar Rp .....

Demikian data ini disampaikan dan saya bertanggungjawab atas kebenaran data tersebut. Apabila di kemudian hari diketahui bahwa terdapat data atau dokumen yang tidak benar yang berdampak pada pengenaan sanksi, maka saya bersedia dikenai sanksi sesuai dengan ketentuan peraturan perundang-undangan.

Hormat kami,

Pelanggan PLTS Atap

(tanda tangan dan materai)

(Nama Lengkap)

MENTERI ENERGI DAN SUMBER DAYA MINERAL
REPUBLIK INDONESIA,

ttd.

ARIFIN TASRIF

Salinan sesuai dengan aslinya
KEMENTERIAN ENERGI DAN SUMBER DAYA MINERAL
KEPALA BIRO HUKUM,

BAMBANG SUJITO

LAMPIRAN III
PERATURAN MENTERI ENERGI DAN SUMBER DAYA MINERAL
REPUBLIK INDONESIA
NOMOR 2 TAHUN 2024
TENTANG
PEMBANGKIT LISTRIK TENAGA SURYA ATAP YANG TERHUBUNG PADA JARINGAN TENAGA LISTRIK PEMEGANG IZIN USAHA PENYEDIAAN TENAGA LISTRIK UNTUK KEPENTINGAN UMUM

FORMAT LAPORAN

SISTEM PLTS ATAP DENGAN TOTAL KAPASITAS SAMPAI DENGAN 500 KW

Nomor :
Lampiran :
Hal : Laporan Sistem PLTS Atap Dengan Total Kapasitas Sampai Dengan 500 kW

Yang terhormat,
Menteri Energi dan Sumber Daya Mineral
u.p. Direktur Jenderal Ketenagalistrikan/
Gubernur ... (provinsi)
u.p. Kepala Dinas ... (yang membidangi urusan ketenagalistrikan)

Dalam rangka usaha penyediaan tenaga listrik untuk kepentingan sendiri dengan total kapasitas pembangkit tenaga listrik sampai dengan 500 kW (lima ratus kilowatt), dengan ini kami sampaikan laporan sebagai berikut:

A. Data Administrasi:
   1. Nama (badan usaha/ Nonbadan usaha/perseorangan) :.....
   2. Alamat :.....
   3. Nomor Telepon/Faksimili/ Handphone :.....
   4. Nomor Induk Berusaha untuk badan usaha/Nomor Induk Kependudukan untuk perseorangan :.....
   5. Nomor Pokok Wajib Pajak :.....

B. Data Teknis

Data Peralatan	Modul Surya	*Inverter*	Baterai (alternatif jika ada)
Merek			
Tipe			
Negara Pembuat			
Tahun Pembuatan			
Kapasitas Satuan			
Jumlah Unit			

C. Lokasi Instalasi Sistem PLTS Atap

1. Jalan :.....
2. Desa/Kelurahan :.....
3. Kecamatan :.....
4. Kabupaten :.....
5. Provinsi :.....

Demikian laporan ini disampaikan dan saya bertanggungjawab atas kebenaran data tersebut. Apabila di kemudian hari diketahui bahwa terdapat data tidak benar yang berdampak pada pengenaan sanksi, maka saya atau badan usaha/nonbadan usaha yang saya wakili bersedia dikenai sanksi sesuai dengan ketentuan peraturan perundang-undangan.

(tempat), (tgl) (bulan) (tahun)

materai, tanda tangan, dan cap
(jika badan usaha/nonbadan usaha/perseorangan)

(Nama) (jabatan, jika badan usaha)

Tembusan:
Menteri Energi dan Sumber Daya Mineral

MENTERI ENERGI DAN SUMBER DAYA MINERAL
REPUBLIK INDONESIA,

ttd.

ARIFIN TASRIF

Salinan sesuai dengan aslinya
KEMENTERIAN ENERGI DAN SUMBER DAYA MINERAL
KEPALA BIRO HUKUM,

BAMBANG SUJITO

LAMPIRAN IV
PERATURAN MENTERI ENERGI DAN SUMBER DAYA MINERAL
REPUBLIK INDONESIA
NOMOR 2 TAHUN 2024
TENTANG
PEMBANGKIT LISTRIK TENAGA SURYA ATAP YANG TERHUBUNG PADA JARINGAN TENAGA LISTRIK PEMEGANG IZIN USAHA PENYEDIAAN TENAGA LISTRIK UNTUK KEPENTINGAN UMUM

FORMAT SURAT PERNYATAAN BERTANGGUNG JAWAB
TERHADAP ASPEK KESELAMATAN KETENAGALISTRIKAN

SURAT PERNYATAAN

Yang bertanda tangan di bawah ini:
Nama *Badan Usaha (BU)/non BU (perseorangan)* : .....
Alamat : .....
Nomor Induk Berusaha *(untuk usaha)*/
Nomor Induk Kependudukan *(untuk non BU)* : .....
menyatakan bertanggungjawab atas pemenuhan aspek keselamatan ketenagalistrikan pada instalasi:
Nama Instalasi : PLTS Atap
Lokasi Instalasi : .....
Nomor Seri Modul/Inverter [1)] : .....
Kapasitas : .....
Dokumen Pendukung:
a. sertifikat produk [2)];
b. hasil uji komisioning dari teknisi distributor; atau
c. dokumen pemeliharaan instalasi pembangkit tenaga listrik.

Demikan surat pernyataan ini dibuat dengan sebenar-benarnya dengan penuh kesadaran dan tanpa ada paksaan dari pihak manapun. Apabila di kemudian hari terjadi sesuatu yang menimbulkan bahaya akibat tidak melaksanakan ketentuan keselamatan ketenagalistrikan pada instalasi tersebut, maka saya atau badan usaha/non badan usaha yang saya wakili bersedia menanggung kerugian yang ditimbulkan dan dikenai sanksi sesuai dengan ketentuan peraturan perundang-undangan.

(tempat), (tanggal)(bulan)(tahun)

Yang Menyatakan,

Materai dan tanda tangan,
(dibubuhi cap, jika badan usaha)

(Nama) (jabatan, jika badan usaha)

Catatan:

1) disesuaikan dengan jenis pembangkit.

2) dipilih sesuai kepemilkan dokumen.

MENTERI ENERGI DAN SUMBER DAYA MINERAL
REPUBLIK INDONESIA,

ttd.

ARIFIN TASRIF

Salinan sesuai dengan aslinya
KEMENTERIAN ENERGI DAN SUMBER DAYA MINERAL
KEPALA BIRO HUKUM,

BAMBANG SUJITO

LAMPIRAN V
PERATURAN MENTERI ENERGI DAN SUMBER DAYA MINERAL
REPUBLIK INDONESIA
NOMOR 2 TAHUN 2024
TENTANG
PEMBANGKIT LISTRIK TENAGA SURYA ATAP YANG TERHUBUNG PADA JARINGAN TENAGA LISTRIK PEMEGANG IZIN USAHA PENYEDIAAN TENAGA LISTRIK UNTUK KEPENTINGAN UMUM

PERSYARATAN UJI KOMISIONING SISTEM PLTS ATAP

1) Sistem PLTS Atap yang termasuk kategori wajib SLO dianggap telah memenuhi persyaratan minimum komisioning.
2) Sistem PLTS Atap yang termasuk kategori memenuhi pemenuhan ketentuan wajib SLO maka:

No.	Persyaratan Komisioning	Kapasitas (kWp)		
		<10	10 s.d.100	100 s.d. 500
1.	Dokumen pemenuhan ketentuan wajib SLO yaitu surat pernyataan yang dilengkapi dengan dokumen berupa: - sertifikat produk; - garansi pabrikan yang masih berlaku; - hasil uji komisioning dari teknisi distributor atau Badan Usaha; atau - dokumen pemeliharaan instalasi pembangkit tenaga listrik.	√	√	√
2.	Dilakukan uji fungsi gawai sakelar dan gawai proteksi arus lebih	√	√	√
3.	Uji Anti *Islanding* Sistem PLTS Atap dan sinkron dengan jaringan	√	√	√
4.	Dilakukan uji tahanan pembumian dan tahanan isolasi sistem	√	√	√
5.	Minimal komisioning Sistem PLTS Atap terhadap pemeriksaan kesesuaian desain, pemeriksaan visual, uji peralatan dan sistem, pengujian unit merujuk pada mata uji sertifikasi instalasi pembangkit listrik tenaga surya. Mata uji sesuai dengan peraturan perundang-undangan terkait sertifikasi ketenagalistrikan.	-	-	√

Keterangan:

- : tidak dipersyaratkan

√ : dipersyaratkan

MENTERI ENERGI DAN SUMBER DAYA MINERAL
REPUBLIK INDONESIA,

ttd.

ARIFIN TASRIF

Salinan sesuai dengan aslinya
KEMENTERIAN ENERGI DAN SUMBER DAYA MINERAL
KEPALA BIRO HUKUM,

BAMBANG SUJITO

Public Disclosure Authorized

Public Disclosure Authorized

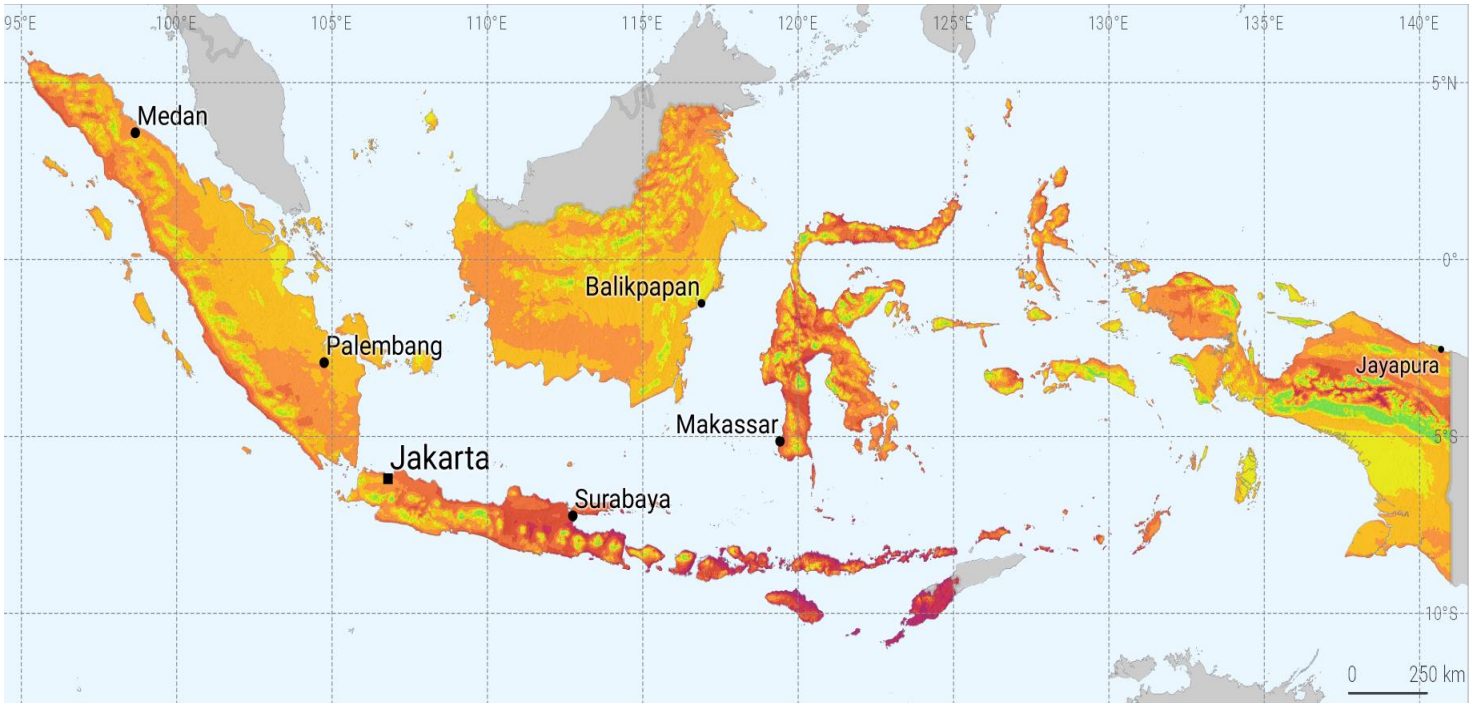
Public Disclosure Authorized

THE WORLD BANK
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ESMAP
Energy Sector Management Assistance Program

SOLAR RESOURCE AND PHOTOVOLTAIC POTENTIAL OF INDONESIA

May 2017



This report was prepared by Solargis, under contract to The World Bank.

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This report is an interim output from the above-mentioned project. Users are strongly advised to exercise caution when utilizing the information and data contained, as this has not been subject to validation using ground measurement data or peer review. The final output from this project will be a validated Indonesia Solar Atlas, which will be published once the project is completed.

To obtain additional maps and information on solar resources globally, please visit:

http://globalsolaratlas.info

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World Bank Group, Global ESMAP Initiative

Renewable Energy Resource Mapping and Geospatial Planning – Indonesia

Project ID: P7180885

Solar Resource and Photovoltaic Power Potential of Indonesia

May 2017



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Acronyms

AC	Alternating current
AERONET	The AERONET (AErosol RObotic NETwork) is a ground-based remote sensing network dedicated to measure atmospheric aerosol properties. It provides a long-term database of aerosol optical, microphysical and radiative parameters.
AOD	Aerosol Optical Depth at 670 nm. This is one of atmospheric parameters derived from MACC database and used in Solargis. It has important impact on accuracy of solar calculations in arid zones.
CFSR	Climate Forecast System Reanalysis. The meteorological model operated by the US service NOAA.
CFSv2	The Climate Forecast System Version 2. CFSv2 meteorological models operated by the US service NOAA (Operational extension of Climate Forecast System Reanalysis, CFSR).
CPV	Concentrated Photovoltaic systems, which uses optics such as lenses or curved mirrors to concentrate a large amount of sunlight onto a small area of photovoltaic cells to generate electricity.
CSP	Concentrated solar power systems, which use mirrors or lenses to concentrate a large amount of sunlight onto a small area, where it is converted to heat for heat engine connected to an electrical power generator.
DC	Direct current
DIF	Diffuse Horizontal Irradiation, if integrated solar energy is assumed. Diffuse Horizontal Irradiance, if solar power values are discussed.
DNI	Direct Normal Irradiation, if integrated solar energy is assumed. Direct Normal Irradiance, if solar power values are discussed.
ECMWF	European Centre for Medium-Range Weather Forecasts is independent intergovernmental organisation supported by 34 states, which provide operational medium- and extended-range forecasts and a computing facility for scientific research.
ESMAP	Energy Sector Management Assistance Program, a multi-donor trust fund administered by The World Bank
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites, intergovernmental organisation for establishing, maintaining and exploit European systems of operational meteorological satellites
GFS	Global Forecast System. The meteorological model operated by the US service NOAA.
GHI	Global Horizontal Irradiation, if integrated solar energy is assumed. Global Horizontal Irradiance, if solar power values are discussed.
GIS	Geographical Information System
GTI	Global Tilted (in-plane) Irradiation, if integrated solar energy is assumed. Global

	Tilted Irradiance, if solar power values are discussed.
KSI	Kolmogorov–Smirnov Index, a statistical index for comparing of functions or samples
MACC	Monitoring Atmospheric Composition and Climate – meteorological model operated by the European service ECMWF (European Centre for Medium-Range Weather Forecasts)
Meteosat IODC	Meteosat satellite operated by EUMETSAT organization. IODC: Indian Ocean Data Coverage
MERRA	Modern-Era Retrospective Analysis for Research and Applications, a NASA reanalysis for the satellite era using an Earth observing systems
MTSAT 2	Multifunctional Transport Satellite operated by Japan Meteorological Agency (JMA), also known as Himawari 7, positioned at 145° East
Himawari 8	Geostationary weather satellite operated by the Japan Meteorological Agency (JMA)
NASA	National Aeronautics and Space Administration organization
NOAA NCEP	National Oceanic and Atmospheric Administration, National Centre for Environmental Prediction
NOAA ISD	NOAA Integrated Surface Database with meteorological data measured by ground-based measurement stations
NOCT	The Nominal Operating Cell Temperature, is defined as the temperature reached by open circuited cells in a module under the defined conditions: Irradiance on cell surface = 800 W/m^2, Air Temperature = 20°C, Wind Velocity = 1 m/s and mounted with open back side.
PV	Photovoltaic
PVOUT	Photovoltaic electricity output calculated from solar resource and air temperature time series.
RSR	Rotating Shadowband Radiometer
SOLIS	Solar Irradiance Scheme, Solar clear-sky model for convert meteorological satellite images into radiation data
SRTM	Shuttle Radar Topography Mission, a service collecting topographic data of Earth's land surfaces
STC	Standard Test Conditions, used for module performance rating to ensure the same measurement conditions: irradiance of 1,000 W/m^2, solar spectrum of AM 1.5 and module temperature at 25°C.
TEMP	Air Temperature at 2 metres
UV	Ultraviolet radiation

Glossary

AC power output of a PV power plant	Power output measured at the distribution grid at a connection point.
Aerosols	Small solid or liquid particles suspended in air, for example desert sand or soil particles, sea salts, burning biomass, pollen, industrial and traffic pollution.
All-sky irradiance	The amount of solar radiation reaching the Earth's surface is mainly determined by Earth-Sun geometry (the position of a point on the Earth's surface relative to the Sun which is determined by latitude, the time of year and the time of day) and the atmospheric conditions (the level of cloud cover and the optical transparency of atmosphere). All-sky irradiance is computed with all factors considered
Bias	Represents systematic deviation (over- or underestimation) and it is determined by systematic or seasonal issues in cloud identification algorithms, coarse resolution and regional imperfections of atmospheric data (aerosols, water vapour), terrain, sun position, satellite viewing angle, microclimate effects, high mountains, etc.
Clear-sky irradiance	The clear sky irradiance is calculated similarly to all-sky irradiance but without considering the impact of cloud cover.
Fixed-mounted modules	Photovoltaic modules assembled on fixed bearing structure in a defined tilt to the horizontal plane and oriented in fixed azimuth.
Frequency of data (30-minute, hourly, daily, monthly, yearly)	Period of aggregation of solar data that can be obtained from the Solargis database.
Installed DC capacity	Total sum of nominal power (label values) of all modules installed on photovoltaic power plant.
Long-term average	Average value of selected parameter (GHI, DNI, etc.) based on multiyear historical time series. Long-term averages provide a basic overview of solar resource availability and its seasonal variability.
P50 value	Best estimate or median value represents 50% probability of exceedance. For annual and monthly solar irradiation summaries, it is close to average, since multiyear distribution of solar radiation resembles normal distribution.
P90 value	Conservative estimate, assuming 90% probability of exceedance (with the 90% probability the value should be exceeded). When assuming normal distribution, the P90 value is also a lower boundary of the 80% probability of occurrence. P90 value can be calculated by subtracting uncertainty from the P50 value. In this report, we apply a simplified assumption of normal distribution of yearly values.
PV electricity production	AC power output of a PV power plant expressed as percentage of installed DC capacity.
Root Mean Square Deviation (RMSD)	Represents spread of deviations given by random discrepancies between measured and modelled data and is calculated according to this formula: $$RMSD = \sqrt{\frac{\sum_{k=1}^{n}\left(X^{k}{}_{measured} - X^{k}_{modeled}\right)^{2}}{n}}$$ On the modelling side, this could be low accuracy of cloud estimate (e.g. intermediate clouds), under/over estimation of atmospheric input data, terrain,

	microclimate and other effects, which are not captured by the model. Part of this discrepancy is natural - as satellite monitors large area (of approx. 3 x 4 km), while sensor sees only micro area of approx. 1 sq. centimetre. On the measurement side, the discrepancy may be determined by accuracy/quality and errors of the instrument, pollution of the detector, misalignment, data loggers, insufficient quality control, etc.
Solar irradiance	Solar power (instantaneous energy) falling on a unit area per unit time [W/m^2]. Solar resource or solar radiation is used when considering both irradiance and irradiation.
Solar irradiation	Amount of solar energy falling on a unit area over a stated time interval [Wh/m^2 or kWh/m^2].
Spatial grid resolution	In digital cartography, the term applies to the minimum size of the grid cell or in the other words minimal size of the pixels in the digital map

Executive summary

This report presents results of the solar resource mapping and photovoltaic power potential evaluation, as a part of a technical assistance, implemented by the World Bank, for the renewable energy development in Indonesia.

The study has two objectives:

- Improve the awareness and knowledge of resources for solar energy technologies by producing a comprehensive countrywide data set and maps based on satellite and meteorological modelling. This report evaluates key solar climate features, and geographic and time variability of solar power potential in the country. The outcomes are supported by explanation of the methodology and evaluation of the data uncertainty.
- Provide support information for installation of meteorological stations in Indonesia by identifying and evaluating the most feasible areas. The data used in this report are based on the satellite and meteorological models. Due to insufficient number of high accuracy solar measurements in Indonesia, the data and the outcomes published in this study have higher uncertainty, compared to other regions. The uncertainty of the model outputs, in Indonesia, can be reduced by acquiring high quality measurements at several meteorological stations with specialised solar-measuring equipment.

Satellite-based and meteorological models are used for computing solar resource and meteorological data that are suitable for production of high-resolution maps and for use in Geographical Information Systems (GIS). A set of primary data parameters is discussed in the study. They are relevant for evaluation of energy yield and performance of the solar power plants, especially based on the use of photovoltaic technology:

- Global Horizontal Irradiation (GHI), Diffuse horizontal Irradiation (DIF), Global Tilted Irradiation (GTI) and Direct Normal Irradiation (DNI)
- Air temperature at 2 metres above ground
- Photovoltaic power potential (PVOUT).

The deliverables are designed to support effective development of solar energy strategies and projects in their first stages. This phase delivers data computed by Solargis model without considering regional measurements.

The model outcomes are delivered in two formats:

- Raster GIS data for the whole territory of the Republic of the Union of Indonesia, representing long-term monthly and yearly average values. This data layers are accompanied by geographical data layers in raster and vector format.
- Digital maps for high resolution poster printing and in medium resolution format

The report also provides an indicative analysis of regions and areas where deployment of solar measuring stations could take place. These stations would contribute to the validation of the models and reducing the data uncertainty. Once at least one year of measurements is available the data can be used for adaptation of solar and meteorological models and for detailed analysis of solar climate at representative sites.

This report addresses the following topics:

Chapter 1 evaluates existing data sets and studies and sets the current work into the broader perspective. Solar radiation basics and principles of photovoltaic power potential calculation are described in Chapter 2. Chapters 2.1 and 2.2. describe measuring and modelling approaches for developing reliable solar and meteorological data including information about the data uncertainty. Chapter 2.3 explains the relevance of solar resource and meteorological data for deployment of solar power technologies. An emphasis is given to photovoltaic (PV) technology, which has high potential for developing utility-scale projects close to larger load centres, as well as for deployment of off-grid, hybrid systems and mini-grids for electrification of small communities. Rooftop PV systems are considered as good option for covering electricity consumption at any place.

Chapter 3 presents analysis and evaluation of geographical, meteorological and solar resource data in Indonesia. Eight representative sites are selected to show potential regional geographical differences in the country through tables and graphs. Chapter 3.1 introduces support geographical data that influence deployment strategies and performance of solar power plants. Chapters 3.2 to 3.5 summarize geographical differences and seasonal variability of solar resource in Indonesia. Chapter 3.6 presents PV power generation potential of the country. The theoretical specific PV electricity output is calculated from the most commonly used PV technology: fixed system with crystalline-silicon (c-Si) PV modules optimally tilted and oriented towards the Equator. Chapter 3.7 delineates solar climate zones that are relevant for deployment of solar monitoring stations and PV power systems. Chapter 3.8 summarizes analytical information and brings conclusions.

In Chapter 4 the solar resource and meteorological conditions are evaluated in the context of possible deployment of solar meteorological stations for validation of the models, excluding areas that are not suitable for solar meteorological stations in Indonesia.

Chapter 5 provide an inventory of the technical features of the delivered data products.

This report, supported by the GIS data and maps, serves as an input for knowledge-based decisions targeting development of solar power in Indonesia. The outcomes show very good potential for exploitation of solar resources in Indonesia, indicating good opportunities for deployment of all type of photovoltaic applications.

1 Introduction

Solar electricity offers a unique opportunity to achieve long-term sustainability goals, such as development of modern economy, healthy and educated society, clean environment, and improvement of geopolitical stability. Solar power plants exploit local solar energy resources; they do not require heavy support infrastructure, they are scalable, and supply or improve electricity services. Important feature of solar electricity is that it is accessible also in remote locations, without access to electricity, thus providing development opportunities anywhere.

While solar resources are fuel to solar power plants, the local geographical and climate conditions determine the efficiency of their operation. Free fuel makes solar technology attractive; however effective investment and technical decisions require **detailed, accurate and validated solar and meteorological data**. Accurate data are also needed for the cost-effective operation of solar power plant. High quality solar resource and meteorological data can be obtained by satellite-based meteorological models and by instruments installed at the meteorological stations.

1.1 Inventory of previous solar resource projects

Several solar resource assessment initiatives are documented below, as publications and online data resources. The works show steady growing interest and different stages of development of solar resource assessment and energy modelling in the region.

Review and analysis of the global and diffuse solar radiations in Jakarta, Indonesia (1985)

The publication prepared by Mr. Parangtopo et al. from the Institute of Material Science and Energy, Faculty of Science, University of Indonesia, brings analysis based on the total solar energy radiation and sunshine duration data from the period 1965-1979 measured by Indonesian Institute of Meteorology and Geophysics. As a result, the diffuse solar radiation, clearness index histogram, space insolation distributions, daily, monthly and yearly diagrams are presented [1].

Solar radiation data for Indonesia (1992)

The publication by Mr. Graham Morrison from School of Mechanical and Manufacturing Engineering, University of New South Wales, Sydney, Australia, processed data measured in years 1969-1976 by Meteorological and Geophysics Centre, Jakarta, into a computer compatible form. As a result, irradiation conditions in Indonesia are presented in a map and compared to neighbouring countries [2].

Estimation of global solar radiation in the Indonesian climate region (2000)

The publication by Mr. Sugiyatno Halawa from the Research and Development Centre for Applied Physics in Bandung, Indonesia, presents monthly average daily global solar radiation correlation applicable to the Indonesian climatic region. The correlation developed is based on the meteorological data collected from seven meteorological stations and evolves from the Sayigh's "Universal Formula" with a slight modification to suit the Indonesian climatic conditions [3].

Mapping of solar energy potential in Indonesia using artificial neural network and geographical information system (2012)

The publication prepared by Mr. Meita Rumbayan, Mr. Asifujiang Abudureyimu, and Mr. Ken Nagasaka from Department of Electrical and Electronic Engineering, Tokyo University of Agriculture and Technology, Japan,

determine the theoretical potential of solar irradiation in Indonesia by using artificial neural networks method and visualize the solar irradiation by province as solar map for the entire of Indonesia [4]. The results are presented as monthly solar radiation maps of 30 provinces of Indonesia.

SWERA GIS data and maps

Monthly averages are available at SWERA web site as resource from NASA Surface meteorology and Solar Energy Release 6.0 Data Set (Jan 2008). The data consists of 22-year monthly & annual average (from July 1983 to June 2005), with resolution of approx. 110 km. The dataset is accessible from online source http://en.openei.org/datasets/dataset/solar-monthly-and-annual-average-global-horizontal-irradiance-gis-data-at-one-degree-resolution-of

PVGIS online tool

The tool is accessible from http://re.jrc.ec.europa.eu/pvgis/. The database is based on Meteosat satellite data calculation [5] and offers solar resource long-term monthly averages. The database is not validated in the region and it covers only Western part of Indonesia.

1.2 Evaluation of the existing data and studies

The previously developed solar and meteorological data sets (See Chapter 1.1) do not fulfil the requirements for accuracy and reliability needed for large-scale commercial development. The main features that differentiate Solargis database from the above-mentioned data sets (NASA, SWERA, etc.):

- The models are based on new and advanced algorithms, validated at different climate zones
- Use of modern and systematically updated input data for the models: satellite, atmospheric and meteorological
- Database has global coverage at very high resolution
- Historical subhourly time series data is updated in real time
- Data can be used for project development but also for monitoring and forecasting
- Data is systematically validated and quality controlled
- There is customer support and supporting consultancy services

The new data set from Solargis focuses on a supply of data and services for development and financing of large-scale solar power plants, worldwide, and in Indonesia. The main objective is to systematically supply reliable, validated and high-resolution data to solar industry with low uncertainty and systematic quality control.

Production of accurate solar and meteorological data requires elaborated models, outputs of which cover extensive territories at high level of detail. The long record of historical data should be produced by such models for representative characterization of the solar climate that is critical in the phase of project development and energy yield assessment. The solar and meteorological models should also be able to update the data in real time to support monitoring and forecasting of solar power plants.

At the country level, modern solar measuring stations are used for accuracy enhancement of such models. They are also needed for developing understanding of the regional and local patterns of weather. This knowledge helps to reduce risks and to improve performance of solar systems. A combination of the model data with modern solar and meteorological measurements is used to support solar energy development in all stages of its lifecycle.

Solar meteorological stations are typically installed at the sites where large solar power plants are developed. Such stations stay on the site, over the project lifetime, and provide data for monitoring, performance evaluation and forecasting of solar power. For improved accuracy and reliability of the measurements, it is a good practice to combine local measurements with solar and meteorological models.

High accuracy solar resource and meteorological data are needed for development and operation of commercial solar power plants. Typically, detailed data, describing the local climate, is needed for a site of interest. Existing meteorological stations are geographically dispersed, and they typically do not operate high-accuracy solar sensors. In majority of cases, high accuracy solar measurements for a site of interest are not available. Therefore, a procedure how solar and meteorological data is used in a project development is following:

- In the first stage, for energy yield and performance assessment of the power plants, the data from solar and meteorological models are used. This data has higher uncertainty as it has not been validated by local measurements.
- When the site is secured and the project development starts, a solar meteorological station is installed. The high accuracy meteorological equipment is used to collect local data for an initial period of at least one year. Such measurements are than used for site adaptation of solar models, and for delivering higher accuracy data that is used for energy yield assessment, financial calculations and for optimising the technical design.
- After solar power plant starts the operation, the solar and meteorological measurements are used in combination with models for monitoring, performance evaluation and forecasting of solar power.

At large power plants, solar measurements are collected over their all lifetime. To summarize, the solar and meteorological data is used for the following tasks related to solar power generation:

1. Country-level evaluation and strategical assessment
2. Prospection, selection of candidate sites for future power plants, and prefeasibility analysis
3. Project evaluation, solar and energy yield assessment, technical design and financing
4. Monitoring and performance assessment of solar power plants and forecasting of solar power
5. Quality control of solar measurements.

This report addresses the first topic, from the list above.

1.3 Objectives

This report offers a country-level evaluation of the solar resources, geographical conditions and photovoltaic power generation potential of Indonesia. The study also describes methods, and outcomes of solar resource mapping.

This analysis is based on the use of the Solargis model data. The solar model was validated by measurements only available in a wider region with similar geographical conditions. Because of limited validation one must expect higher uncertainty of the model outputs. To reduce this uncertainty and to improve understanding of the solar climate at local scale, it is proposed to install solar meteorological stations with high accuracy instruments. This report evaluates suitable areas for deployment of this type of solar meteorological stations.

2 Solargis methods and data

2.1 Solar resource data

2.1.1 Introduction

Solar resource (physical term solar radiation) is fuel to solar energy systems. The solar radiation available for solar energy systems at the ground level depends on processes in the atmosphere. This leads to a high spatial and temporal variability at the Earth's surface. The interactions of extra-terrestrial solar radiation with the Earth's atmosphere, surface and objects are divided into four groups:

1. Solar geometry, trajectory around the sun and Earth's rotation (declination, latitude, solar angle)
2. Atmospheric attenuation (scattering and absorption) by:
    2.1 Atmospheric gases (air molecules, ozone, NO_2, CO_2 and O_2)
    2.2 Solid and liquid particles (aerosols) and water vapour
    2.3 Clouds (condensed water or ice crystals)
3. Topography (elevation, surface inclination and orientation, horizon)
4. Shadows, reflections from surface or local obstacles (trees, buildings, etc.) and re-diffusion by atmosphere.

The atmosphere attenuates solar radiation selectively: some wavelengths are associated with high attenuation (e.g. UV) and others with a good transmission. Solar radiation called "short wavelength" (in practice, 300 to 4000 nm) is of main interest to solar power technology and is used as a reference. The component that is neither reflected nor scattered, and which directly reaches the surface, is called **direct radiation**; this is the component that produces shadows. Component scattered by the atmosphere, and which reaches the ground is called **diffuse radiation**. Small part of the radiation reflected by the surface and reaching an inclined plane is called the **reflected radiation**. These three components together create **global radiation**. A proportion of individual components at any time are given by Sun position and by the actual state of atmosphere – mainly occurrence of clouds, air pollution and humidity.

According to the generally adopted terminology, in solar radiation two terms are distinguished:

- **Solar irradiance** indicates power (instant energy) per second incident on a surface of 1 m^2 (unit: W/ m^2).
- **Solar irradiation**, expressed in MJ/ m^2 or Wh/m^2 it indicates the amount of incident solar energy per unit area during a lapse of time (hour, day, month, etc.).

Often, the term *irradiance* is used by the authors of numerous publications in both cases, which can be sometimes confusing.

In **solar energy applications**, the following three solar resources are relevant:

- **Direct Normal** Irradiation/Irradiance (DNI): it is the direct solar radiation from the solar disk and the region closest to the sun (circumsolar disk of 5° centred on the sun). DNI is the component that is important to concentrating solar collectors used in Concentrating Solar Power (CSP) and high-performance cells in Concentrating Photovoltaic (CPV) technologies.
- **Global Horizontal** Irradiation/Irradiance (GHI): sum of direct and diffuse radiation received on a horizontal plane. GHI is a reference radiation for the comparison of climatic zones; it is also the essential parameter for calculation of radiation on a flat plate collector.
- **Global Tilted** Irradiation/Irradiance (GTI) or total radiation received on a surface with defined tilt and

azimuth, fixed or sun-tracking. This is the sum of the scattered radiation, direct and reflected. A term Plan of Array (POA) irradiation//irradiance is also used. In the case of photovoltaic (PV) applications, GTI can be occasionally affected by shading from surrounding terrain or objects, and GTI is then composed only from diffuse and reflected components. This happens usually for sun at low angles over the horizon.

Solar radiation data can be acquired by two complementary approaches:

1. **Ground-mounted sensors** are good in providing high frequency and accurate data (for well-maintained, high accuracy measuring equipment) for a specific location.
2. **Satellite-based models** provide data with lower frequency of measurement, but representing long history over lager areas. Satellite-models are not capable of producing instantaneous values at the same accuracy as ground sensors, but can provide robust aggregated values.

This Chapter summarizes approaches for measuring and computing these parameters, and the main sources of uncertainty. Methods for combination of data acquired by these two complementary approaches with the aim to get maximum from their benefits were developed. The most effective approach is to correlate multiyear satellite time series with data measured locally over short periods of time (at least one year) to reduce uncertainty and achieve more reliable long term estimates.

2.1.2 Solar radiation measurements

Global irradiance for horizontal and tilted plane is most often measured by (i) *pyranometers* using thermocouple junction or (ii) silicon *photodiode cells*. **Diffuse irradiance** is measured with the same sensors as global irradiance, except that the sun is obscured with a sun-tracking disk or rotating shadow band to block the direct component. **Direct Normal Irradiance** is commonly measured by *pyrheliometers*, where the instrument always aims directly at the sun using a continuously sun tracking mechanism.

A variety of instruments exists, with different properties and achievable accuracy of measurements (Table 2.1). Due to required accuracy in the solar industry, it is recommended to measure solar radiation with the highest-accuracy instruments:

- **Secondary standard pyranometers** for Global Horizontal Irradiation (GHI) and (with shading ball/disc on a tracker) also for Diffuse Horizontal Irradiation (DIF)
- **First class pyrheliometer** for Direct Normal Irradiation (DNI).

This instrumentation is more expensive, and it is also more susceptible to soiling, thus it is more demanding for maintenance. However, if professional cleaning and operation are rigorously followed, the measuring set-up works reliably, delivering data with the lowest possible uncertainty.

Accuracy of Global Horizontal irradiance, measured with a thermopile **pyranometer**, is affected by two sources of error: the thermal imbalance problem and the cosine error of the sensor, resulting in a minimum uncertainty (for the most accurate sensor) of daily sums at about ±2%.

Direct Normal Irradiance, if measured by **pyrheliometers**, may be measured at daily uncertainty of about ±1% for a freshly calibrated high-accuracy pyrheliometer under ideal conditions. This uncertainty can more than double in case of rapid fluctuations of radiation, when using older instruments, or after prolonged exposure to challenging weather.

Table 2.1: Theoretically-achievable uncertainty of pyranometers at 95% confidence level

ISO 9060 class	Hourly totals	Daily totals
Secondary standard	±3%	±2%
First class	±8%	±5%
Second class	±20%	±10%

Global and diffuse components can also be measured by a *Rotating Shadowband Radiometer* (RSR) or by an integrated pyranometer such *Sunshine Pyranometer* (e.g. by SPN1). In such a case, DNI is calculated from global and diffuse irradiance.

Rotating Shadowband Radiometer (RSR) instruments can be installed as an alternative to the above-mentioned instruments, if measurements take place in a more challenging and remote environment with limited possibilities for cleaning and maintenance. However, if RSR is to be used, it is proposed to add one redundant measurement using a thermopile-type instrument for crosschecking the accuracy of RSR measurements.

The photodiodes and RSR devices are also affected by cosine error and temperature. Empirical functions are used to correct the raw data, but theoretical daily uncertainty is around ±4% to 5%. These instruments have narrower spectral sensitivity, thus operating these instruments in very different environmental conditions from those used for calibration may lead to increased uncertainty.

Utilization of the state-of-the-art instruments does not alone guarantee good results. The lowest possible uncertainties of solar measurements are essential for accurate determination of the solar resource. **Uncertainty of measurements in outdoor conditions is always higher than the one declared in the technical specifications of the instrument** (Table 2.1). The uncertainty may dramatically increase in extreme operating conditions and in cases of limited or insufficient maintenance.

Solar radiation measurements are not only subject to errors, as regards the instant values. The radiometric response of the instruments also undergoes seasonal variability and longterm drift. Without careful maintenance, periodical check-up and calibration, the measured values can significantly differ from the “true” ones.

Rigorous on-site maintenance is crucial for sustainable quality of the longterm measuring campaign. Not only regular care of instruments is necessary, but also documenting all changes in instrumentation, calibration, cleaning and variations of the instruments’ behaviour.

Measuring solar radiation is sensitive to imperfections and errors, which result in visible and hidden anomalies in the output data. The errors may be introduced by measurement equipment, system setup or operation-related problems. Errors in data can severely affect derived data products and subsequent analyses; a thorough quality check is needed prior the data use.

2.1.3 Solargis satellite-based model

Numerical models using satellite and atmospheric data have become a standard for calculating solar resource time series and maps. The same models are also used for real-time data delivery for system monitoring and solar resource forecasting. Data from reliable operational solar models are routinely used by solar industry.

In this study, we applied a model developed and operated by the company Solargis. This model operationally calculates a high-resolution solar resource data and other meteorological parameters. Its geographical extent covers most of the land surface between 60º North and 55º South latitudes. A comprehensive overview of the Solargis model was made available in several publications [6, 7, 8, 9]. The related uncertainty and requirements for bankability are discussed in [10, 11].

In Solargis approach, solar irradiance is calculated in 5 steps:

1. Calculation of clear-sky irradiance, assuming all atmospheric effects except of clouds,
2. Calculation of cloud properties from satellite data,
3. Integration of clear-sky irradiance and cloud effects and calculation of global horizontal irradiance (GHI)
4. Calculation of direct normal irradiance (DNI) from GHI and clear-sky irradiance.
5. Calculation of global tilted irradiance (GTI) from GHI and DNI.

Models used in individual calculation steps are parameterized by a set of inputs characterizing the cloud properties, state of the atmosphere and terrain conditions.

The **clear-sky irradiance** is calculated by the simplified SOLIS model [12]. This model allows fast calculation of clear-sky irradiance from the set of input parameters. Sun position is deterministic parameter, and it is described by the algorithms with satisfactory accuracy. Stochastic variability of clear-sky atmospheric conditions is determined by changing concentrations of atmospheric constituents, namely aerosols, water vapour and ozone. Global atmospheric data, representing these constituents, are routinely calculated by world meteorology data centres:

- In Solargis, the new generation **aerosol data set** representing Atmospheric Optical Depth (AOD) is used. The core data set is from MACC-II/CAMS project (ECMWF) [13, 14]. An important feature of this data set is that it captures daily variability of aerosols and allows simulating more precisely the events with extreme atmospheric load of aerosol particles. Thus, it reduces uncertainty of instantaneous estimates of GHI and especially DNI, and it allows for improved statistical distribution of irradiance values [15, 16]. For years 1999 to 2002, data from the MERRA-2 model (NASA) [17] homogenized with MACC-II/CAMS model are used. The Solargis calculation accuracy of the clear-sky irradiance is especially sensitive to the information on aerosols.
- **Water vapour** is also highly variable in space and time, but it has lower impact on the values of solar radiation, compared to aerosols. The daily GFS and CFSR values (NOAA NCEP) are used in Solargis, thus representing the daily variability from 1999 to the present [18, 19, 20].
- **Ozone** absorbs solar radiation at wavelengths shorter than 0.3 μm, thus having negligible influence on the broadband solar radiation.



Map 2.1: Coverage of solar geostationary satellite data in Indonesia

The **clouds** are the most influencing factor, modulating clear-sky irradiance. Effect of clouds is calculated from the satellite data in the form of cloud index (cloud transmittance). The cloud index is derived by relating irradiance recorded by the satellite in several spectral channels and surface albedo to the cloud optical properties. In this study, a data from the Meteosat MFG IODC (Eumetsat), MTSAT and Himawari 8 satellite (JMA) satellites are used. Data from Meteosat *IODC* mission is available for a period from 1999 till the last day in a time step of 30 minutes. Data from the *Pacific* satellite mission is available from 2007 to 2015 (MTSAT) in a time step of 30 minutes, and for a period 2016 onwards in a time step of 10 minutes (Map 2.1). In Solargis, the modified calculation scheme by Cano has been adopted to retrieve cloud optical properties from the satellite data [21]. A number of improvements have been introduced to better cope with specific situations such as snow, ice, or high albedo areas (arid zones and deserts), and with complex terrain.

To calculate **Global Horizontal Irradiance** (GHI) for all atmospheric and cloud conditions, the clear-sky global horizontal irradiance is coupled with the cloud index.

From GHI, other solar irradiance components (direct, diffuse and reflected) are calculated. **Direct Normal Irradiance** (DNI) is calculated by the modified Dirindex model [22]. Diffuse horizontal irradiance is derived from GHI and DNI according to the following equation:

$$DIF = GHI - DNI * \cos Z \quad (1)$$

Where Z is the zenith angle between the solar position and the Earth's surface.

Calculation of **Global Tilted Irradiance (GTI)** from GHI deals with direct and diffuse components separately. While calculation of the direct component is straightforward, estimation of diffuse irradiance for a tilted surface is more complex, and is affected by limited information about shading effects and albedo of nearby objects. For converting diffuse horizontal irradiance for a tilted surface, the Perez diffuse transposition model is used [23]. The reflected component is also approximated considering that knowledge of local conditions is limited.

Model for simulation of **terrain** effects (elevation and shading) based on high-resolution elevation and horizon data is used in the standard Solargis methodology [24]. Model by Ruiz Arias is used to achieve enhanced spatial representation – from the resolution of satellite (several km) to the resolution of digital terrain model.

Solargis model version 2.1 has been used for computing the data. Table 2.2 summarizes technical parameters of the model inputs and of the primary outputs.

Table 2.2: Input data used in the Solargis solar radiation model and related GHI and DNI outputs

Inputs into the Solargis model	Source of input data	Time representation	Original time step	Approx. grid resolution
Cloud index	Meteosat IODC (EUMETSAT)*	1999 to date	30 minutes	2.7 to 4.6 km
	MTSAT (JMA)	2007 to 2015	30 minutes	4.0 to 8.0 km
	Himawari 8 (JMA) **	2016 to date	10 minutes	2.0 to 5.0 km
Atmospheric optical depth (aerosols)	MACC/CAMS (ECMWF)	2003 to date	3 hours	75 km and 125 km
	MERRA-2 (NASA)	1999 to 2002	1 hour	50 km
Water vapour	CFSR/GFS (NOAA)	1999 to date	1 hour	35 and 55 km
Elevation and horizon	SRTM-3 (SRTM)	-	-	250 m
Solargis primary data outputs (GHI and DNI) supplied for Myanmar	-	1999 to 2016***	30 minutes	250 m

* *Data from IODC is used on Sumatra only*

** *Data from MTSAT and Himawari-8 in all territories except for Sumatra*

*** *Solargis operational model provides the data updates **in real time**. The deliverables within this project cover complete calendar years from 1999 (Meteosat IODC) and 2007 (MTSAT) till 2015 (see Chapter 5.1)*

The achievable uncertainty of the solar irradiance derived from the satellite-based models depends on performance and limits of partial models as well as on the quality and the model inputs (mostly aerosols and satellite data). The modelling of solar irradiance in variable geographical conditions of Indonesia is challenging and several features influencing final data uncertainty should be considered:

1. Aerosols: there is a limited knowledge available on aerosols (pollution, burning biomass, forest fires etc.). Some of satellite based aerosol datasets are inherent part of AOD databases used in Solargis model, but local sources of pollution may not be accurately recorded in Solargis model inputs.
2. Regional effect of extreme events such as forest fires and volcano eruptions, which may significantly increase amount of pollutants (reducing solar radiation) in the atmosphere. Modelling of such features is difficult as it is usually represented in the input aerosol databases with insufficient accuracy.

Moreover, the knowledge on effects of such extreme situations is low and not adequately represented in traditional solar radiation models.

3. Persistent cloudy weather and monsoons: for this type of weather conditions the identification accuracy of cloud properties (their effect on amount of irradiance at ground level) from satellite data is in general lower.
4. Specific satellite data features. Indonesia is located between two geostationary satellite missions: IODC (Meteosat MFG) and Pacific (MTSAT and Himawari). In both satellite missions, Indonesia is located at the edge of satellite images, where the identification of clouds has higher uncertainty. Moreover, data from the older satellite platforms (e.g. MTSAT) have lower positional accuracy (images may be slightly shifted). Even though the Solargis model uses advanced methods to correct image geometry, the identification of clouds has higher uncertainty in a contrast areas such as coastlines and ocean.
5. High mountains are very challenging for solar radiation modelling. The main problem is the identification of clouds using satellite images. Presence of terrain shading makes the cloud identification erroneous, and the clouds and snow have similar reflectivity in visible wavelengths. The use of satellite data acquired in the infrared spectrum helps in the cloud identification, but the resulting uncertainty remains higher.

2.1.4 Measured vs. satellite data – adaptation of solar model

For qualified solar resource assessment, it is important to understand characteristics of ground measurements and satellite-modelled data (Table 2.3). In general, top-quality and well-maintained instruments provide data with lower uncertainty than the satellite model. However, such data are rarely available for the required location and extrapolation of measured information from nearby station is limited only to short distances. Moreover, the period of measurements is usually too short to describe longterm weather conditions. On the other hand, the satellite data can provide long climatic history – more than 18 (10) years in Indonesia – for any location, but may not accurately represent the micro-climatic conditions of a specific site.

The ground measurements and satellite data complement each other and it is beneficial to correlate them and to adapt the satellite model for the specific site of interest. Site-adapted satellite model data provide long history time series with lower uncertainty. The **model adaptation** has two steps:

1. Identification of systematic differences between hourly satellite data and local measurements for the period when both data sets overlap;
2. Development of a correction method that is applied for the whole period represented by the satellite time series.

The improvements of such site-adapted data depend on the quality and accuracy of measured and satellite data. In the most favourable cases, the resulting uncertainty is still slightly higher than uncertainty of ground measurements. In general, site adaptation of satellite data by local measurements will result in lower uncertainty under the following conditions:

- At least one year of ground-measured data is available (preferably two years or more) to cover all seasons;
- The solar measuring station is equipped with more than one instrument, allowing redundancy checks for GHI, DNI and DIF values;
- Ground measurements are of high quality, which should be traceable in the cleaning, maintenance and calibration logs.
- High quality satellite data are used, with good representation of irradiance variability, extreme situations and with consistent longterm quality.
- Advanced site-adaptation methods are used, capable to address specific sources of satellite-ground data differences (e.g. correction of aerosols, reduction of cloud identification problems). Besides

reduced uncertainty of longterm estimate (lower bias), the model adaptation method should also improve random deviations (lower RMSD) and should provide more representative (sub) hourly values (lower KSI).

The **site-adaptation of the model** data is typically performed for locations where large-scale solar power plants are planned. During the project development phase a meteorological station with high-accuracy instruments is installed on the site and operated for at least one year, to get good understanding of local conditions. Local measurements are then used for site-adaptation of satellite model. The site-adapted long-term data are crucial for local solar resource evaluation and for accurate simulation of performance of various solar energy technologies with low uncertainty.

The ground measurements can be correlated with satellite data also at a regional level – within so called **regional model adaptation**, focused on broader territory rather than a single site. In the case of regional adaptation, the method aims to identify and reduce regional systematic deviations of the model typically driven by insufficient characterization of aerosols or specific cloud patterns. The regional adaptation requires measurements from several stations, which allows distinguishing the systematic model issues relevant to a large region, from the features related to a microclimate. The result of regional adaptation is improved solar resource database in the regional context with overall reduction of systematic errors.

Table 2.3: Comparing solar data from solar measuring stations and from satellite models

	Data from solar measuring stations	Data from satellite-based models
Availability/ accessibility	Available only for limited number of sites. Most often, data cover only recent years.	Data are available for any location within latitudes 60N and 55S. Data cover long period, in Indonesia more than 18 (10) years.
Original spatial resolution	Data represent the microclimate of a site.	Satellite models represent area with complex spatial resolution: clouds are mapped at approx. 2.0-8.0 km, aerosols at 50-125 km and water vapour at 34 km. Terrain can be modelled at spatial resolution of up to 90 metres. Methods for enhancement of spatial resolution are often used.
Original time resolution	Seconds to minutes	10 minutes (Himawari) and 30 minutes (MTSAT and IODC) in Southeast Asia, depending on the satellite platform
Quality	Data need to go through rigorous quality control, gap filling and cross-comparison.	Quality control of the input data is necessary. Outputs are regularly validated. Under normal operation, the data have only few gaps, which are filled by intelligent algorithms.
Stability	Instruments need regular cleaning and control. Instruments, measuring practices, maintenance and calibration may change over time. Thus, regular calibration is needed. Longterm stability is typically a challenge.	If data are geometrically and radiometrically pre-processed, a complete history of data can be calculated with one single set of algorithms. Data computed by an operational satellite model may change slightly over time, as the model and its input data evolve. Thus, regular reanalysis and temporal harmonization of inputs is used in state-of-the-art models.
Uncertainty	Uncertainty is related to the accuracy of the instruments, maintenance and operation of the equipment, measurement practices, and quality control.	Uncertainty is given by the characteristics of the model, resolution and accuracy of the input data. Uncertainty of models is higher than high quality local measurements. The data may not exactly represent the local microclimate, but are usually stable and may show systematic deviation, which can be reduced by good quality local measurements (site-adaptation of the model).

2.1.5 Validation of solar radiation model data and uncertainty

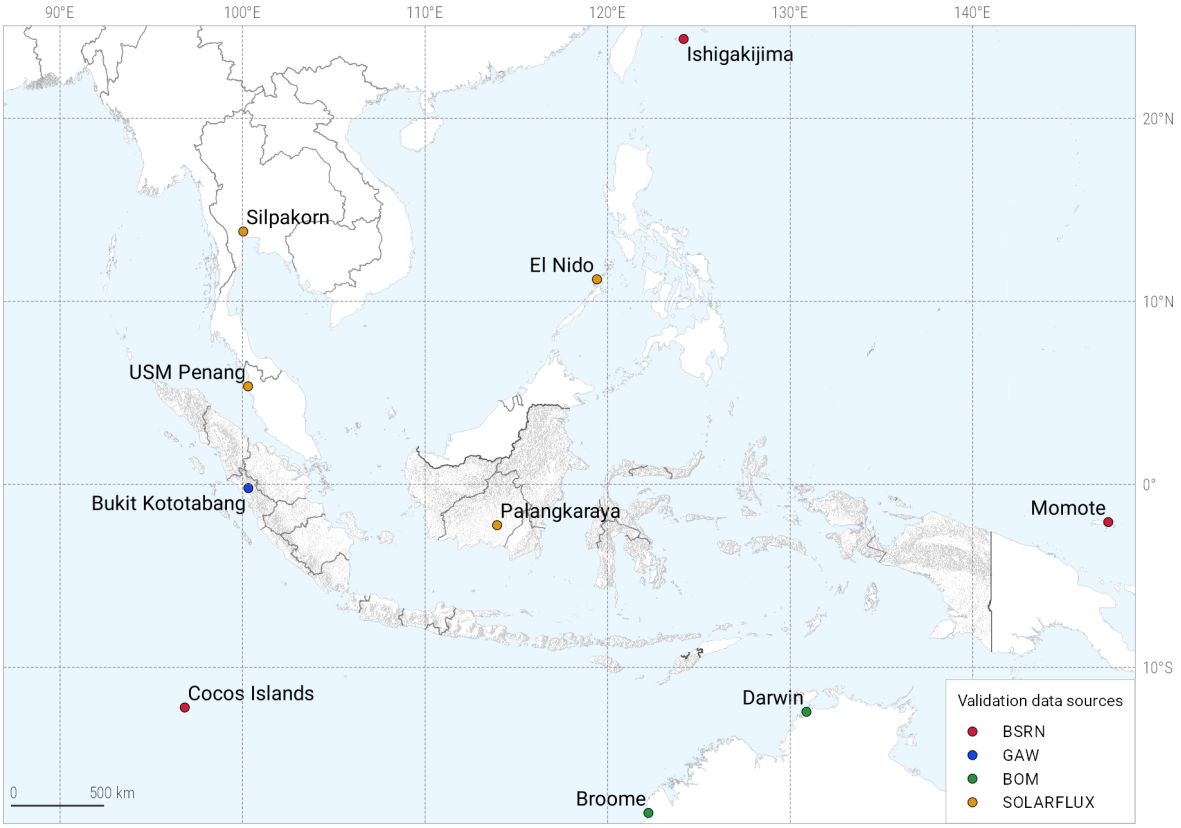
Accuracy of Solargis data has been compared with high-quality solar measurements at 220+ meteorological stations, distributed worldwide. Map 2.2 and Table 2.4 show selected validation sites in the broader region,

fulfilling the minimum requirements of measured data quality. Tables 2.5 and 2.6 show the Solargis model quality indicators for solar primary parameters: DNI and GHI.

Table 2.4: Selected validation sites in the region

Site name	Country	Latitude [°]	Longitude [°]	Elevation [m]	Source
Silpakorn	Thailand	13.8188	100.0408	72	SOLARFLUX
USM Penang*	Malaysia	5.358	100.302	51	SOLARFLUX
Bukit Kototabang	Indonesia	-0.2019	100.3181	864	GAW
Palangkaraya*	Indonesia	-2.228	113.946	27	SOLARFLUX
El Nido airport*	Philippines	11.205	119.413	4	SOLARFLUX
Ishigakijima	Japan	24.3367	124.1633	11	BSRN
Cocos (Keeling) Islands	Australia	-12.1892	96.8344	3	BSRN
Momote	Papua New Guinea	-2.058	147.425	6	BSRN
Darwin	Australia	-12.4239	130.8925	30	BOM
Broome	Australia	-17.9475	122.2353	7	BOM

** Less than one year of measurements*



Map 2.2: Solar radiation validation sites

Comparison of the validation statistics, computed for the solar meteorological sites in the region, shows overall stability of the Solargis model and of the underlying input data. Locally increased bias was identified in some

sites, that may be effect of the specific local conditions (e.g. anthropogenic pollution, forest fires), limited accuracy of model and its input data as well as properties of ground measurements (short period of available data, lower accuracy of instruments).

Table 2.5: Global Horizontal Irradiance – quality indicators in the region

Global Horizontal Irradiance, GHI	Bias		Root Mean Square Deviation, RMSD		
	[W/m^2]	[%]	Hourly [%]	Daily [%]	Monthly [%]
Silpakorn	-9	-1.9	23.6	12.2	5.0
USM Penang*	24	6.1	32.4	13.8	7.1
Bukit Kototabang	2	0.6	31.6	14.8	2.5
Palangkaraya*	-20	-4.6	21.7	9.8	8.0
El Nido airport*	-13	-3.1	26.4	10.7	5.7
Ishigakijima	-5	-1.3	24.2	14.3	2.3
Cocos (Keeling) Islands	-20	-4.1	18.3	8.4	4.9
Momote	-13	-2.9	25.9	12.4	3.8
Darwin	11	2.1	18.3	8.5	2.9
Broome	1	0.1	11.7	6.0	2.1

** Less than one year of measurements*

Table 2.6: Direct Normal Irradiance – quality indicators in the region

Direct Normal Irradiance, DNI	Bias		Root Mean Square Deviation, RMSD		
	[W/m^2]	[%]	Hourly [%]	Daily [%]	Monthly [%]
Bukit Kototabang	18.7	8.9	72.6	42.1	11.0
Ishigakijima	2.3	0.7	43.7	25.7	4.9
Cocos (Keeling) Islands	-29	-7.1	38.4	20.6	8.9
Momote	5.3	1.5	49.2	24.1	5.2
Darwin	11.3	2.2	29.4	14.9	3.2
Broome	13.6	2.1	21.2	12.7	4.6

The ground measurement sites (Table 2.5, Map 2.2) are selected from the wider region and only two of them are in Indonesia (one of them has data available only for few months). The available ground measurements are not sufficient to analyse the model performance, rather they give only indication of model performance in a broader context. With assumption of the Solargis model performance stability over the lager territories with the similar geographical conditions, confirmed in other regions, we estimate the **expected uncertainty of yearly solar radiation summaries of the Solargis data for Indonesia**. In Indonesia, we recognise three main regions with different expected uncertainty (Map 2.3, Table 2.7).

Table 2.7: Uncertainty of long-term yearly estimates for GHI, GTI and DNI values in Indonesia

	Global Horizontal Irradiation (GHI)	Global Tilted Irradiation (GTI)	Direct Normal Irradiation (DNI)
I. Northern Java, southern Sulawesi, southern islands, low lands of New Guinea	5 to 6.5%	6 to 7.5%	10 to 18 %
II. Eastern Sumatra, central part of Kalimantan, parts of New Guinea, Maluku	±6 to 8%	±7 to 9%	±12 to 18%
III. High mountains, western coast of Sumatra	±7 to 10%	±8 to 11%	±14 to 22%

In the data comparison exercise run for Europe and North Africa, Solargis has been identified as the best performing satellite-based solar database [25].



Map 2.3: Regions of solar resource uncertainty in Indonesia
Source: SRTM-3

2.2 Meteorological data

2.2.1 Measured vs. modelled data – features and uncertainty

Meteorological parameters are an important part of a solar energy project assessment as they determine the operating conditions and effectiveness of operation of solar power plants. The most important meteorological parameter for the operation of photovoltaic power plants is air temperature, which directly impact power production (energy yield is decreasing when temperature is increasing). Meteorological data can be collected by two approaches: (1) by measuring at meteorological sites and (2) computing by meteorological models.

The requirements for the meteorological data for solar energy projects are:

- Long and continuous record of data, preferably covering the same period as satellite-based solar resource data,
- Data should reliably represent the local climate,

- Data should be accurate, quality-controlled and without gaps.

The best option would be to have continuous measurements from high-accuracy sensors installed on the site in a **meteorological station**. However, except for sites where long-term meteorological observations are operated as part of national meteorological service or some other observation network, this option is typically not available. Even if some measurements are available, often the time series are incomplete or not reliable.

Most often, the only alternative is to derive historical meteorological data from **meteorological models**. Several models are available; a good option is to use Climate Forecast System Reanalysis (CFSR) and its operational extension the Climate Forecast System Version 2 (CFSv2) models (source NOAA, NCEP, USA) covering long period of time with continuous data [19, 20]. The results of these models are implemented in Solargis.

The ground measurements play an important role in the assessment of local climate conditions as they determine the efficiency of photovoltaic power production. The role of the measurements in solar energy development is twofold:

- Measurements are used for validation and accuracy enhancement of historical data derived from the solar and meteorological models
- The high frequency measurements (typically one-minute data) are used for improved understanding of the microclimate of the site, especially for capturing the extremes.

Data inputs and method

In this delivery, the air temperature, wind speed and relative humidity is derived from the meteorological models: CFSR and CFSv2 (Table 2.8). The original spatial resolution of the models is enhanced to 1 km for air temperature by spatial disaggregation and use of the Digital Elevation Model SRTM-3.

Important note: the numerical weather model has lower spatial and temporal resolution compared to the solar resource data. **Local microclimate of the site may deviate from the values derived from the numerical models.**

Table 2.8: Original source of Solargis meteorological data for Indonesia: models CFSR and CFSv2.

	Climate Forecast System Reanalysis (CFSR)	Climate Forecast System (CFSv2)
Period	1999 to 2010	2011 to date*
Original spatial resolution	30 x 35 km	20 x 22 km
Original time resolution	1 hour	1 hour

** Solargis generates data updates from CFSv2 model in real time. The deliverables within this project cover complete calendar years from 1999 (compatible with Meteosat IODC region) and 2007 (compatible with MTSAT/Himawari satellite region) till 2016.*

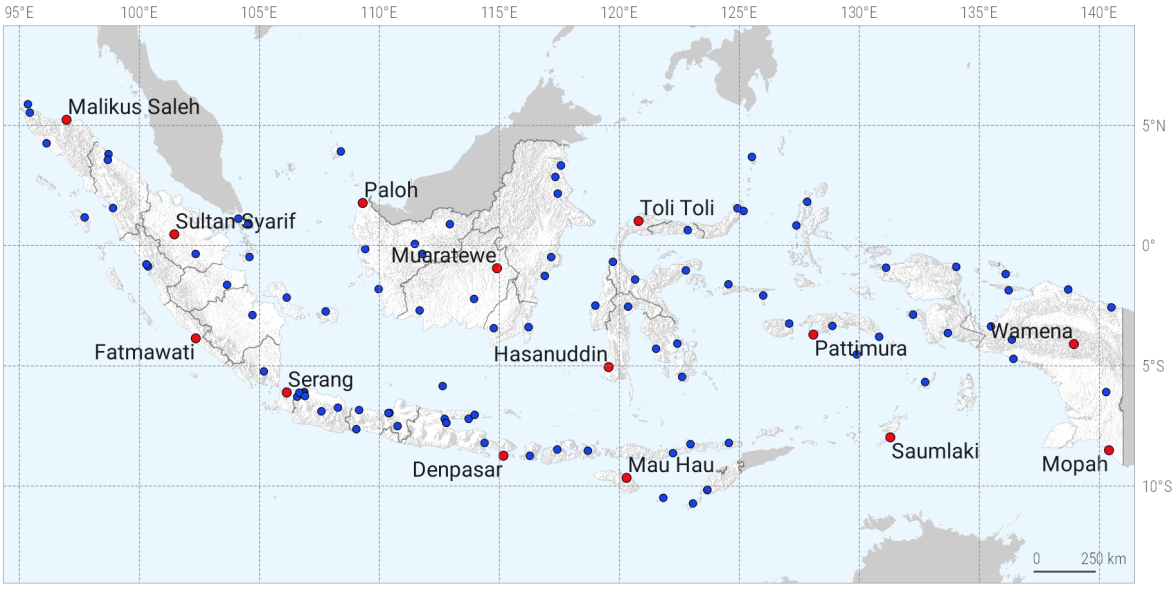
Data from the two sources described above have their advantages and disadvantages (Table 2.9). Air temperature, wind speed and relative humidity retrieved from the meteorological models have lower spatial and temporal resolution compared to on-site meteorological measurements, and they have lower accuracy. Thus, modelled parameters may characterize only regional climate patterns rather than local microclimate; especially extreme values may be smoothed and not well represented.

Table 2.9: Comparing data from meteorological stations and weather models

	Meteorological station data	Data from meteorological models
Availability/ accessibility	Available only for selected sites. Data may cover various periods of time	Data are available for any location. Data cover long period of time (decades)
Original spatial resolution	Local measurement representing microclimate with all local weather occurrences	Regional simulation, representing regional weather patterns with relatively coarse grid resolution. Therefore, the local values may be smoothed, especially the extreme values.
Original time resolution	From 1 minute to 1 hour	1 hour
Quality	Data need to go through rigorous quality control, gap filling and cross-comparison.	Only basic quality control is needed. No gaps. Relatively stable outputs if data processing is systematically controlled.
Stability	Sensors, measuring practices, maintenance and calibration may change over time. Thus, long-term stability is often a challenge.	In case of reanalysis, long history of data is calculated with one single stable model. Data for operational forecast model may slightly change over time, as model development evolves
Uncertainty	Uncertainty is related to the quality and maintenance of sensors and measurement practices, usually sufficient for solar energy applications.	Uncertainty is given by the resolution and accuracy of the model. Uncertainty of meteorological models is higher than high quality local measurements. The data may not exactly represent the local microclimate, but are usually sufficient for solar energy applications.

2.2.2 Validation of air temperature data

The validation was carried out to compare the modelled data with measurements available at selected meteorological stations in Indonesia, available through NOAA ISD network (Table 2.10 and Map 2.4). In general, the data from the meteorological models represent larger area, and it may not be capable to represent accurately the microclimate, especially in mountains. The validation was made on larger number of power plants (109 stations in total) but only selected stations (14 stations) results are presented in the tabular form.



Map 2.4: Position of meteorological stations considered in the validation.
Validation results of stations depicted in red colour are presented in tables below

Table 2.10: Meteorological stations and time periods considered in the model validation

Meteorological station	Data source	Validation period	Latitude* [°]	Longitude* [°]	Elevation* [m a.s.l.]
Mopah	NOAA ISD	01/2008 – 12/2015	-8.5200	140.4180	3
Saumlaki	NOAA ISD	01/2008 – 12/2015	-7.9830	131.3000	24
Pattimura	NOAA ISD	01/2008 – 12/2015	-3.7100	128.0890	10
Wamena	NOAA ISD	01/2008 – 12/2015	-4.1030	138.9570	1550
Mau Hau	NOAA ISD	01/2008 – 12/2015	-9.6690	120.3020	12
Denpasar Ngurah Rai	NOAA ISD	01/2008 – 12/2015	-8.7480	115.1670	4
Hasanuddin	NOAA ISD	01/2008 – 12/2015	-5.0620	119.5540	14
Toli Toli Lalos	NOAA ISD	01/2008 – 12/2015	1.0170	120.8000	2
Serang	NOAA ISD	01/2008 – 12/2015	-6.1170	106.1330	40
Muaratewe Beringin	NOAA ISD	01/2008 – 12/2015	-0.9500	114.9000	60
Paloh	NOAA ISD	01/2008 – 12/2015	1.7670	109.3000	15
Fatmawati Soekarno	NOAA ISD	01/2008 – 12/2015	-3.8640	102.3390	15
Sultan Syarif Kasim	NOAA ISD	01/2008 – 12/2015	0.4610	101.4450	31
Malikus Saleh	NOAA ISD	01/2008 – 12/2015	5.2270	96.9500	27

*Remark: the position of meteorological stations from the ISD network can be less accurate

Air temperature is derived from both meteorological models and post-processed to the spatial resolution of 1 km by post-processing and disaggregation (Table 2.11). Considering spatial and time interpolation, for hourly values the deviation of the model to the ground observations can occasionally reach several degrees Celsius.

Table 2.11: Air temperature at 2 m: accuracy indicators of the model outputs [°C].

Meteorological station	CFSR and CFSv2 models			
	Bias	RMSD hourly	RMSD daily	RMSD monthly
Mopah	-0.4	1.5	1.1	0.5
Saumlaki	-0.2	1.4	0.9	0.3
Pattimura	0.6	2.0	1.0	0.6
Wamena	-4.3	4.7	4.6	4.3
Mau Hau	-0.8	2.0	1.4	0.9
Denpasar Ngurah Rai	-0.6	1.4	0.9	0.6
Hasanuddin	-0.8	1.9	1.2	0.9
Toli Toli Lalos	-1.7	2.4	2.0	1.7
Serang	-0.3	1.8	1.4	0.4
Muaratewe Beringin	0.0	2.8	2.4	0.5
Paloh	-0.3	1.9	1.3	0.4
Fatmawati Soekarno	-0.9	1.9	1.5	0.9
Sultan Syarif Kasim	-1.4	2.7	2.3	1.5
Malikus Saleh	0.5	2.0	1.3	0.6

The modelled air temperature in Indonesia fits quite well the measured data, regarding average values. Daily temperature amplitude is often reduced for the stations located on the coast due to limited resolution of the meteorological model. For the same reason for the stations located in complex mountainous regions there can

be higher bias in the annual values. Wamena airport is an example of such a station exhibiting high negative bias, -4.3°C (model underestimates the air temperature). There are not many stations in the mountains, so the actual quality of the model data is difficult to estimate is such areas. For the stations located in a flat land the quality of model data is quite good with small negative annual bias between -1.5°C to 0°C (85 out of 109 stations). Average hourly RMSE data is low (2.2°C) due to small daily amplitude of temperature in Indonesia.

2.2.3 Validation of wind speed and relative humidity data

Beside air temperature, the wind speed and relative humidity are the most important meteorological parameters having impact on PV energy production. Similar validation procedure was carried out for wind speed and humidity. The results for selected 14 stations are presented in Tables 2.12 and 2.13. It was found that quality of wind speed data is quite good with 42, 72 and 94 stations, respectively, out of analysed 109 having bias lower then ±0.5 m/s, ±1.0 m/s and ±1.5 m/s.

Table 2.12: Wind speed at 10 m: accuracy indicators of the model outputs [m/s].

Meteorological station	CFSR and CFSv2 models			
	Bias	RMSD hourly	RMSD daily	RMSD monthly
Mopah	0.0	2.0	1.0	0.4
Saumlaki	1.3	2.3	1.8	1.4
Pattimura	1.5	2.5	2.2	1.7
Wamena	-2.4	3.5	2.9	2.5
Mau Hau	-1.0	2.1	1.5	1.1
Denpasar Ngurah Rai	0.0	1.6	1.0	0.3
Hasanuddin	-0.1	1.6	0.6	0.3
Toli Toli Lalos	0.1	1.1	0.7	0.2
Serang	-0.1	1.5	1.0	0.3
Muaratewe Beringin	-0.9	1.5	1.5	0.9
Paloh	0.5	1.5	1.1	0.5
Fatmawati Soekarno	-0.9	2.0	1.4	1.0
Sultan Syarif Kasim	-1.8	2.2	2.1	1.8
Malikus Saleh	0.0	1.4	0.8	0.1

The climate of Indonesia is tropical. Relative humidity ranges between 60% and 100%. Meteorological model data fit quite well the measured values with 59 and 97 stations, respectively, out of analysed 109, having bias lower then ±5% and ±10%. This accuracy should be sufficient for solar energy applications.

Table 2.13: Relative humidity at 2 m: accuracy indicators of the model outputs [%].

Meteorological station	CFSR and CFSv2 models			
	Bias	RMSD hourly	RMSD daily	RMSD monthly
Mopah	-4	9	7	4
Saumlaki	-6	9	8	6
Pattimura	-9	12	10	9
Wamena	23	25	25	23
Mau Hau	-2	10	7	4
Denpasar Ngurah Rai	-5	9	6	5
Hasanuddin	-6	12	9	7
Toli Toli Lalos	0	9	5	1
Serang	-5	10	9	6
Muaratewe Beringin	-8	16	15	9
Paloh	-7	11	9	7
Fatmawati Soekarno	-6	12	9	6
Sultan Syarif Kasim	4	13	11	5
Malikus Saleh	-13	17	15	13

2.2.4 Expected uncertainty of meteorological model data model

The meteorological parameters summarised in this report are derived from two similar numerical meteorological models covering periods from 1999 to 2010 (CFSR model) and 2011 to date (CFSv2). Taking into account the validation results, the uncertainty of the estimate for the main meteorological parameters is summarised in Table 2.14.

It must be noted that despite relatively large number of meteorological stations used in this validation there are regions (like mountains, tropical rain forests) where there are no stations at all. As a result the validation in these regions ma not show full picture.

Table 2.14: Expected uncertainty of modelled meteorological parameters in Indonesia.

	Unit	Annual	Monthly	Hourly
Air temperature at 2 m	°C	±2.0	±2.0	±3.0
Wind speed at 10 m	m/s	±1.0	±1.0	±2.5
Relative humidity at 2 m	%	±5	±5	±10

2.3 Solar power systems: technical options and energy simulation

2.3.1 Photovoltaic systems

Solar radiation is the most important parameter for PV power simulation, as it is fuel for solar power plants. The intensity of global irradiance received by tilted surface of PV modules (GTI) is calculated from two primary parameters stored in the Solargis database and delivered in this project:

- Global Horizontal Irradiance (GHI)
- Direct Normal Irradiance (DNI)

There are two main types of solar energy technologies: photovoltaic (PV) and concentrating solar power (CSP).

Photovoltaics exploits global horizontal or tilted irradiation, which is the sum of direct and diffuse components (see equation (1) in Chapter 2.1.3). To simulate power production from a PV system, global irradiance received by a flat surface of PV modules must be correctly calculated. Due to clouds, PV power generation reacts to changes of solar radiation in the matter of seconds or minutes (depending on the size of a module field), thus intermittency (short-term variability) of the PV power production is to be considered. Similarly, the effect of seasonal variability is important as well.

PV technology will become an important part of energy mix in Indonesia. It is also an attractive option for small-scale provision of electricity, particularly in remote areas of eastern Indonesia. In many areas, local minigrids or off-grid systems are less costly solution than grid extension to the households remaining to be electrified [26]. Possible configurations range from small solar home systems, through local mini-grid systems (hybrid systems, where PV is support for diesel, micro-hydroelectric or home biogas generators) to ground mounted large scale grid connected systems in range of tens or hundreds of MWp [27]. For PV applications, several technical options are briefly described below.

Two types of mounting of PV modules are considered:

- Build in an open space, where PV modules are ground-mounted in a fixed position or on sun-trackers
- Mounted on roofs or façades of buildings.

Three types of a PV system are considered for Indonesia:

- Grid-connected PV power plants
- Mini-grid PV systems
- Off-grid PV systems

Most large-scale PV power plants are built in **open space** and have **PV modules mounted at a fixed position**. Fixed mounting structures (often mounted at an optimum tilt) offer a simple and efficient choice for implementing the PV power plants. A well-designed structure is robust and ensures long-life performance at low maintenance costs. **Sun-tracking systems** offer an alternative. Solar trackers adjust the orientation of the PV modules during a day to a more favourable position in relation to the sun, so the PV modules collect more solar radiation.

Roof or façade mounted PV systems are typically small to medium size, i.e. ranging from hundreds of watts to hundreds of kilowatts. Modules can be mounted on roofs (flat or tilted), façades or can be directly integrated as part of a building structure. PV modules in these systems are often installed in a suboptimal position (deviating from the optimum angle), and this results in a lower performance, compared to open space systems. PV modules, which are mounted at very low tilt (less than 10 degrees), may be affected by higher surface pollution due to limited natural cleaning. Another reduction of PV power output is often determined by nearby shading structures. Trees, masts, neighbouring buildings, roof structures or self-shading of crystalline silicon modules especially have some influence on reduced PV system performance.

The main characteristic of **grid-connected systems** is their geographic dispersion and connection into a distribution grid. Direct connection into grid also means that the inverter must provide support functions to the electrical grid, required by regulations (voltage, frequency, isolation check, etc.). For comparison, a utility scale

power plant has its own protection equipment, separated from the inverter and assembled typically on the high-voltage side. Inverters can reach higher efficiencies, and are required to have anti-islanding protection, which means that they work only if grid voltage is present (due to safety reasons). Other connection options, combined with batteries, are also used.

Mini-grid PV systems provide small isolated distribution grid for local consumers, usually in remote areas. Typical size of installed PV systems is in the range of several hundreds of kWp. Mini-grid may be adapted to meet requirements of local needs, sometimes with several types of electricity generators (hybrid systems) and battery storage. This type of electrification gives prospects for development to remote and rural communities, because it is often the only economically-viable option for supply of electricity.

Off-grid PV systems are small systems, not connected into distribution grid. They are usually equipped with energy storage (classic lead acid or modern-type batteries) and/or connected to diesel generators. Batteries are maintained through charge controllers for protection against overcharging or deep discharge. Depending on size and functionality of the off-grid PV system, it can work with AC (together with inverter) or DC voltage source.

2.3.2 Solar concentrating power systems

Solar concentrating technologies can only exploit direct normal irradiance (DNI), as diffuse irradiance cannot be concentrated. Instant (short-term) variability of DNI is very high, especially in equatorial tropics. Advantage of solar thermal power plants, often denoted as Concentrating Solar Power technology, is that they have means to control short-term and daily variability due to the inertia of the whole system (solar field, heat transfer and storage), which in addition can be supported by fossil fuels. This type of technology is mentioned briefly below, for the sake of completeness, although it is not expected that solar concentrators are implemented in Indonesia.

CSP (Concentrated Solar Power) technologies concentrate DNI onto a small area through mirrors or lenses. Focused light is then converted to heat which drives a heat engine like a steam turbine, connected to an electrical power generator. There are three main CSP systems:

- Parabolic trough systems: U-shaped mirrors with oil-filled pipes running along their centre
- Power tower systems: they include large number of flat mirrors tracking the sun and focusing irradiance onto a receiver in tower
- Dish engine systems: they include stand-alone parabolic reflector that concentrates light onto a focal point with a Stirling engine to generate power.

CSP generators are most effective in arid or semiarid countries with high intensities of DNI and low atmospheric pollution i.e. low diffuse irradiation (DIF).

Another type of technology converting DNI into electricity is **Concentrated Photovoltaic (CPV).** This technology is based on the use of lenses or curved mirrors to concentrate sunlight onto a small area of high-efficiency PV cells. High concentration CPV has to use very precise solar trackers. The advantage of CPV over flat plate PV is a potential for cost reduction due to the smaller area of photovoltaic material. The necessity of sun tracking partially balances out the smaller price of semiconductor material used. CPV technology requires also more maintenance during the lifetime of the power plant. Power production from CPV may be more sensitive to changing weather conditions. The advantage of CPV over CSP is full scalability, similar to flat plate PV modules.

There is regionally limited potential for CSP and CPV in Indonesia, and therefore this report focuses mainly on photovoltaic technology. Its potential is studied for **a system with fixed-mounted PV modules**, considered here as the mainstream technology. Installed capacity of a PV power plant is usually determined by the available space and options to maintain the stability of the power grid.

2.3.3 Principles of photovoltaic power simulation

PV energy simulation results, presented in Chapter 3.6, are based on software developed by Solargis. This Chapter summarizes key elements of the simulation chain.

Table 2.15: Specification of Solargis database used in the PV calculation in this study

Data inputs for PV simulation	Global tilted irradiation (GTI) for optimum angle towards South (0° to 4°) or towards North (0° to 15°), derived from GHI and DNI; air temperature at 2 m (TEMP).
Spatial grid resolution (approximate)	Approx. 275 metres (9 arc-sec)
Time resolution	30-minute
Geographical extent (this study)	Republic of Indonesia
Period covered by data (this study)	01/1999 to 12/2016

The Solargis PV software is based on the implementation of scientifically proven methods [28 to 35] and uses Solargis time series of solar radiation and air temperature data on the input (Table 2.15). Data and model quality are checked using field tests and ground measurements.

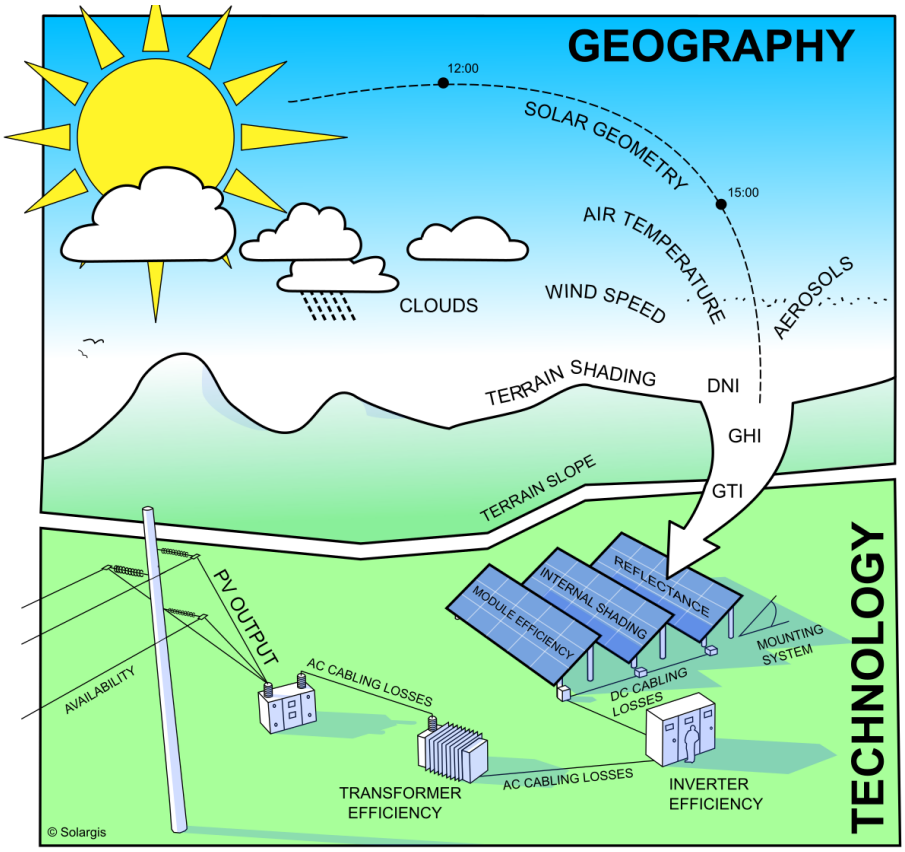


Figure 2.1: Simplified Solargis PV simulation chain

In PV energy simulation procedure, there are several energy losses occurring in the individual steps of energy conversion (Figure 2.1):

1. **Losses due to terrain shading** caused by far horizon**.** Shading of local features such as nearby building, structures or vegetation is not considered in the calculation,
2. Energy conversion in PV modules is reduced by **Losses due to angular reflectivity**, which depends on relative position of the sun and plane of the module and **Temperature Losses,** caused by performance of PV modules working outside of STC conditions defined in datasheets,
3. DC output of PV array is further reduced by **Losses due to dirt, soiling or snow** depending mainly on the environmental factors and module cleaning**, Losses by inter-row shading** caused by preceding rows of modules and **Mismatch** and **DC cabling losses**, which are given by slight differences between nominal power of each module and small losses on cable connections,
4. DC to AC energy conversion is performed by inverter. Efficiency of this conversion step is reduced by **Inverter losses**, given by inverter efficiency function. Further factors, reducing AC energy output, are **Losses in AC cabling** and **Transformer losses** (apply only for large–scale open space systems),
5. **Availability.** This empirical parameter quantifies electricity losses incurred by shutdown of a PV power plant due to maintenance or failures, including issues in the power grid. Availability of well operated PV system is approximately 99%.

According to experience in many countries, the crystalline silicon PV modules show low performance degradation (reduction of conversion efficiency) over time. The rate of the performance degradation is higher at the beginning of the exposure, and then stabilizes at a lower level. Initial degradation may be close to value of 0.8% for the first year and 0.5% or less for the next years [32]. Degradation of PV modules is not considered in this study.

Results of calculation of PV power potential for Indonesia are shown in Chapter 3.6.

2.3.4 Configuration of a reference PV system considered in this study

Photovoltaic power production has been calculated using numerical models developed and implemented in-house by Solargis. As introduced in Chapter 2.1, 30-minute **time series of solar radiation and air temperature**, representing last 18 and 10 years, respectively are used as an input to the simulation. The models are developed based on the advanced algorithms, expert knowledge and recommendations given in [34] and tested using monitoring results from existing PV power plants. Table 2.17 summarize losses and related uncertainty throughout the PV computing chain.

Table 2.16: Reference configuration - photovoltaic power plant with fixed-mounted PV modules

Feature	Description
Nominal capacity	Configuration represents a typical PV power plant of 1 MW-peak or higher. All calculations are scaled to 1 kWp, so that they can be easily multiplied for any installed capacity.
Modules	Crystalline silicon modules with positive power tolerance. NOCT 46°C and temperature coefficient of the Pmax -0.45 %/K
Inverters	Central inverter with Euro efficiency 97.5%
Mounting of PV modules	Fixed mounting structures facing towards equator with optimum tilt (the range from 0° to 15°). Relative row spacing 2.5 (ratio of absolute spacing and table width)
Transformer	Medium voltage power transformer

Map 3.18 shows theoretical potential power production of a PV system installed with a typical technology configuration, for large-scale open space PV power plants. The technical parameters are described in Table 2.16.

In this study, the reference configuration for the PV potential calculation is a PV system with crystalline-silicon (c-Si) modules mounted in a fixed position on a table facing towards equator and inclined at an angle close to optimum, i.e. at the angle at which the yearly sum of global tilted irradiation received by PV modules is maximized (0° to 4° on a northern hemisphere and 0° to 15° on a southern hemisphere, depending on a geographical region). The fixed-mounting of PV modules is very common and provides a robust solution with a minimum maintenance effort. Geographical differences in potential PV production are shown on the example of eight selected sites (see Chapters 3.1 and 3.6).

Table 2.17: Yearly energy losses and related uncertainty in PV power simulation

Simulation step		Losses [%]	Uncertainty [± %]	Notes
1	Global Tilted Irradiation (model estimate with terrain shading)	N/A	6.0 to 11.0	Annual Global Irradiation falling on the surface of PV modules
2	Module surface angular reflectivity (numerical model)	-2.7 to -3.4	1.0	Medium polluted surface of PV modules is considered
	Temperature losses (numerical model)	-1.5 to -13.0	3.5	Depends on the temperature and irradiance. NOCT of 46°C is considered
3	Polluted surface of modules (empirical estimate)	-3.5	1.5	Losses due to dirt, dust, soiling, snow and bird droppings
	Module inter-row shading (model estimate)	-0.1 to -0.3	0.3	Partial shading of strings by modules from the preceding rows
	Mismatch between modules (empirical estimate)	-0.5	0.5	Well-sorted modules and lower mismatch are considered.
	DC cable losses (empirical estimate)	-2.0	1.5	This value can be calculated from the electrical design
4	Conversion in the inverter (value from the technical data sheet)	-2.5	0.5	Given by the Euro efficiency of the inverter, which is considered at 97.5%
	AC cable losses (empirical estimate)	-0.5	0.5	Standard AC connection is assumed
	Transformer losses (empirical estimate)	-1.0	0.5	Standard transformer is assumed
5	Availability	0.0	0.0	A theoretical value of 100% technical availability is considered
	Range of cumulative losses and indicative uncertainty	**-13.5 to -24.3**	**7.4 to 11.8**	These values are indicative and do not consider project specific features and performance degradation of a PV system over its lifetime

PV electricity potential is calculated based on a set of assumptions shown in Tables 2.16 and 2.17. These assumptions are approximate, and they may differ in various parameters, in real projects. As can be seen, the uncertainty of solar resource is the highest element of energy simulation.

The results presented in Chapter 3.6 do not consider performance degradation of PV modules due to aging. They also lack a detail: these results cannot be used for financial assumptions of any particular project. Detailed assessment of energy yield of a specific power plant is offered within a scope of site-specific bankable expert study.

3 Solar resource and PV potential of Indonesia

3.1 Geography

This report analyses solar and meteorological data for Indonesia that determine photovoltaic power production and influence its performance efficiency. We analyse also other geographical factors that influence development and operation of solar photovoltaic power plants.

Indonesia is located in South Asia between latitudes 6° North and 11° South and longitudes 91° and 145° East. We demonstrate the variability of solar potential in two forms:

- At the **country level** in the form of maps
- In the form of graphs and tables for **eight selected sites** that represent the geographical variability of solar power production in Indonesia. While trying to address the geographical diversity, these sites are also chosen in regions where majority of PV systems will be very likely deployed.

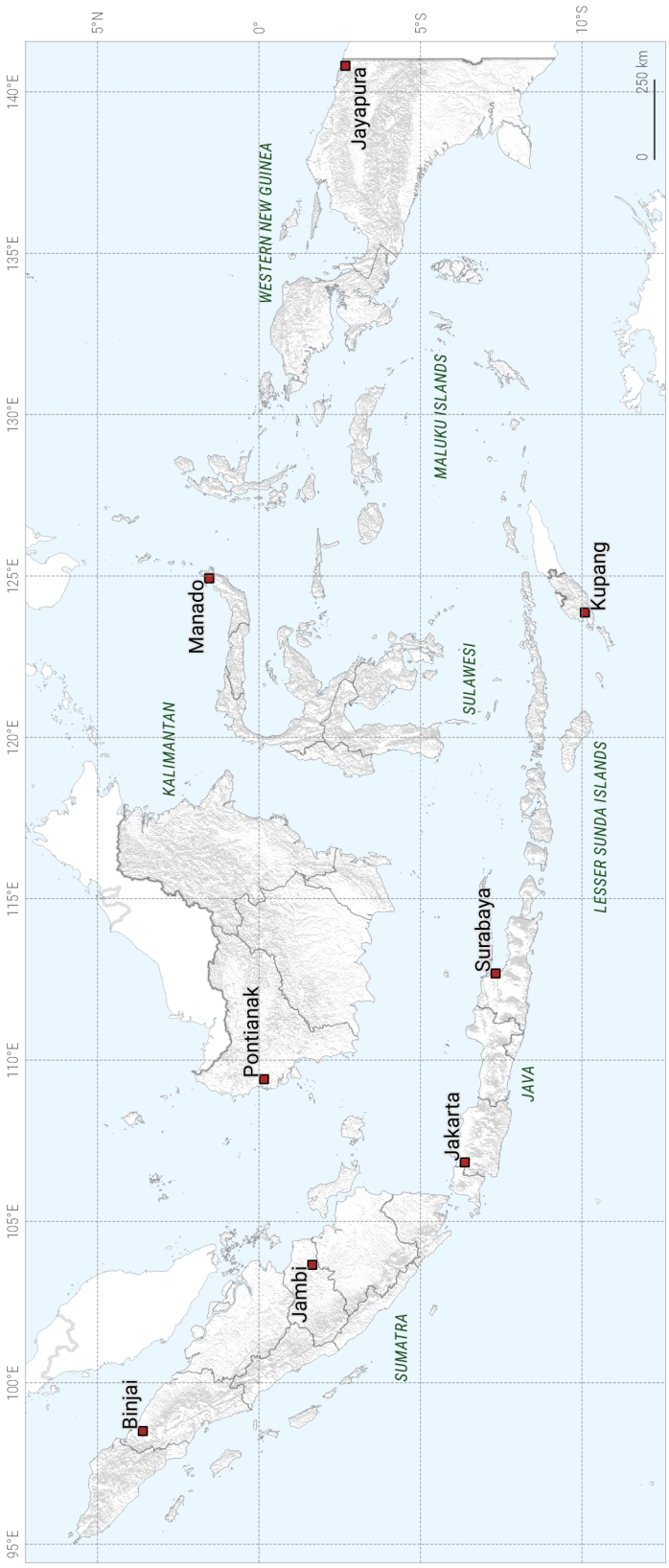
The position of selected sites is summarised in Table 3.1 and Map 3.1. All the data in tables and graphs, shown in this Chapter 3, relate to these eight sites.

Table 3.1: Position of eight selected sites in Indonesia

ID	Site name	Island	Latitude [°]	Longitude [°]	Elevation [metres a.s.l.]
1	Binjai	Sumatra	3.60127	98.50460	33
2	Jambi airport	Sumatra	-1.64575	103.65354	19
3	Jakarta, University of Indonesia	Java	-6.36808	106.82845	76
4	Pontianak airport	Kalimantan	-0.14988	109.40488	1
5	Surabaya	Java	-7.32250	112.68213	3
6	Kupang	Timor	-10.08692	123.86587	31
7	Manado airport	Sulawesi	1.54684	124.92397	83
8	Jayapura	Papua	-2.67182	140.80187	6

Geographic information and maps bring additional value to the solar data. Geographical characteristics of the country, from regional to local scale may represent technical and environmental prerequisites, but also constraints for solar energy development. In this report, we collected the following data that have relevance to development of photovoltaic solar power plants, focusing on large (utility-scale) ground-mounted systems (rooftop systems have almost no limitations and can be installed anywhere):

- Terrain: physical limitation for development (Maps 3.2 and 3.3)
- Land cover: defines use of land for settlements and economic activities (Map 3.4)
- Main road network: defining accessibility of sites (Map 3.5)
- Protected areas may pose limits to the size of power plants and the related infrastructure (Map 3.6)
- Population density (Map 3.7)
- Forest fires (creating air pollution and haze) and volcanic eruptions (Map 3.8 and 3.9)
- Rainfall (precipitation) has impact on cleaning of PV modules (Map 3.10)
- Air temperature has impact on performance efficiency of PV (Map 3.11).



Map 3.1: Position of eight selected representative sites in Indonesia.

Eight sites are selected with an aim to have balanced perspective of solar power generation by respecting the geographical diversity and population distribution in Indonesia.

To some extent, **terrain elevation and slope** (Maps 3.2 and 3.3) represents limiting factor for locating large-scale solar power facilities. High elevation and steep slopes (higher than approx. 7 to 10 degrees) pose extra challenges to the development of large scale PV. Small solar power installations (residential, off-grid stand-alone or mini-grids) in Indonesia can be installed in any populated area: they play crucial role for development especially in remote communities.

Land cover map (Map 3.4) shows that the most of settlements and economic activities (industry, agriculture and transport) – that require access to electrical power – are developed in areas with elevation up to 1000 m a.s.l. with terrain slopes below 10 degrees. Settlements are dispersed in highlands and remote areas as well.

Urbanisation and transport infrastructure is the most developed in Java and Sumatra islands, where also electricity demand is the highest (Map 3.5). The most densely populated areas coincide, to a large degree, with areas most suitable for solar investments (Map 3.7).

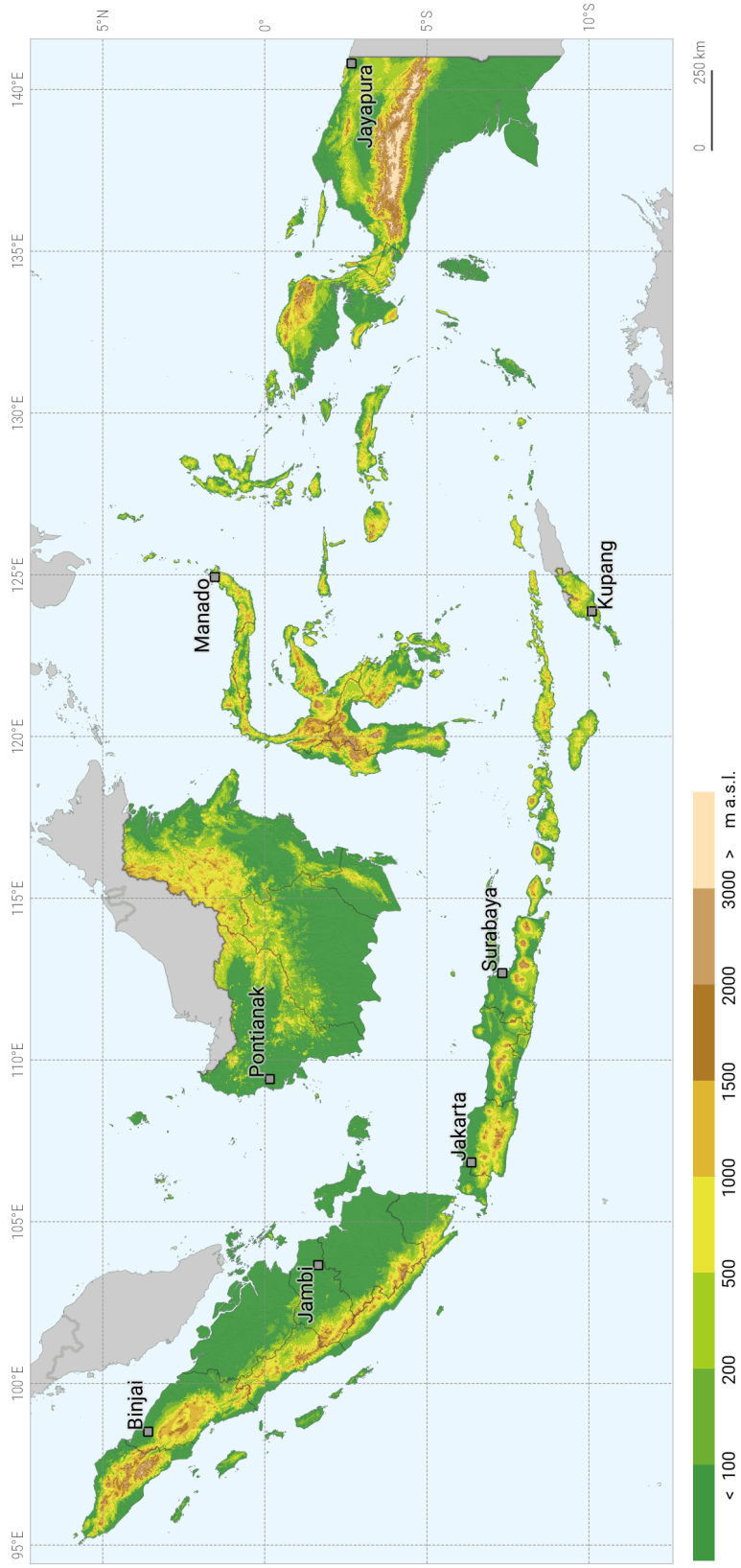
Nature protection areas (Map 3.6) represent limitation for deployment of large scale solar power plants. They are dispersed across all the islands of Indonesia. However, having just a local impact, it is not difficult to manage planning and development with the knowledge of these constrains.

Increasing economic activity has brought numerous challenges and changes to ecosystems. One of these challenges is deforestation. Deforestation, driven mainly by agricultural expansion is the main culprit for **forest fires** in Indonesia. These fires occur regularly during the dry season, mainly on the islands of Sumatra and Kalimantan (Borneo), and are the main driver behind increased aerosols in the atmosphere of the region. Regarding solar irradiance, aerosols could substantially affect solar irradiance. They hinder direct solar irradiation (DNI), while slightly increasing diffused horizontal irradiance. According to Global Forest Watch dataset of forest fires [39], in the period of 2001 to 2015 the year 2015 was particularly severe (Map 3.8). In Solargis data, particularly for Pontianak airport in West Kalimantan, we can see a drop in direct solar irradiation (DNI) by 5% in September 2015, when compared to the long-term average for this site (see Chapter 3.4).

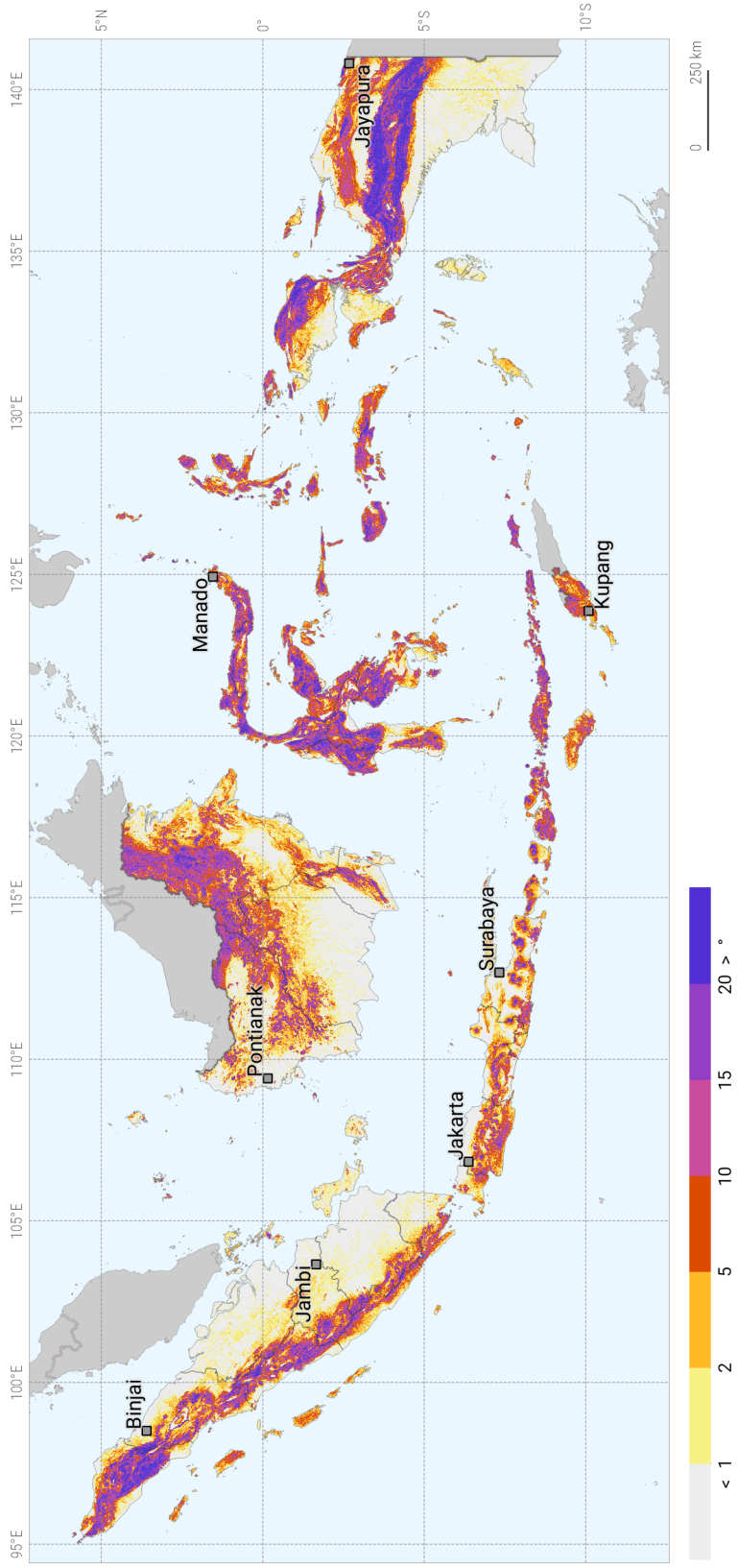
Indonesia is affected also by almost constant **volcanic activity** (Map 3.9), since it lies in the volcanic region called “The Ring of Fire” [41]. This activity should be also considered for evaluation of large scale PV. Volcanic activity is assessed by Volcanic Explosivity Index (VEI), mainly by the international community and by the United States Geographical Survey [41]. The frequency of volcanic eruptions in Southeast Asia is historically given as 95% of VEI 3 every 11 years and VEI 4 every 16 years. VEI 1 and above has the strength to effect local climate, while VEI above 3 to 4 can affect the whole region. Closer look in the data from the Global Volcanism program has given evidence for higher occurrence of explosions in Indonesia: there are eruptions somewhere in Indonesia of any intensity (VIE 0 to VIE 8) every two months, with the data showing 62 occurrences of VEI 2, 15 occurrences of VEI 3 and 3 of VEI 4 in the last 18 years. These explosions can last for years with varying intensity. The most recent explosions are: the 2010 Mount Merapi explosion (VEI 4), Mount Kelut in 2014 (VEI 4) and numerous explosion of Mount Soputan between 2011 and 2016 (all VEI 3).

Ash cloud from these eruptions, depending on the distance from its source, can accumulate from few mm to few cm on the ground and any object, as well as the energy transmission infrastructure. This results in breakage of lines, outages and hindering the PV production of solar panels. Aerosols ejected from vents which reach significant height can disperse in the atmosphere, even stratosphere and travel hundreds and thousands of kilometres, lowering solar irradiance depending. Moreover, the SO_2 (as well as other components) emitted into the atmosphere can lower local and even global temperature.

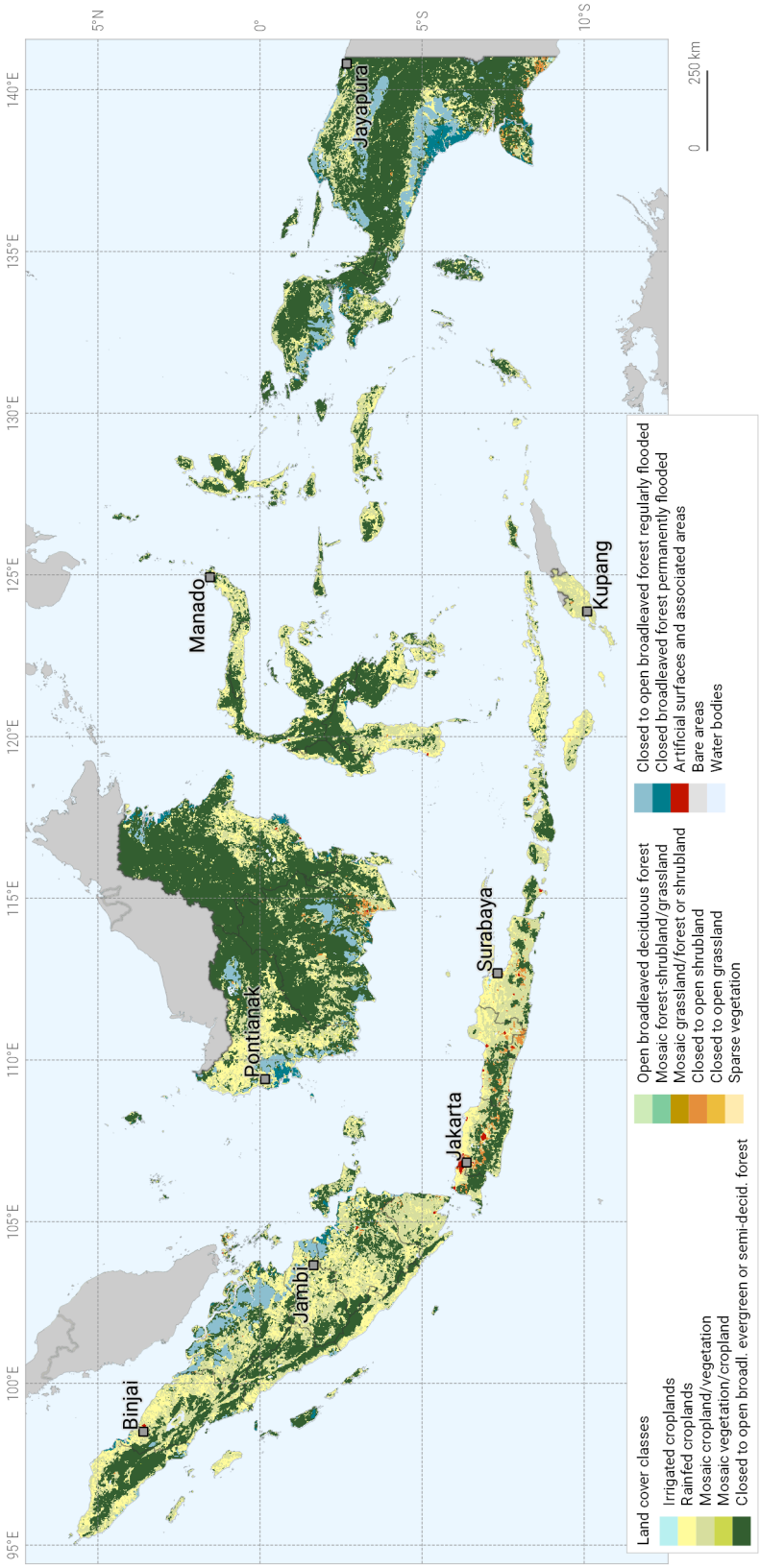
Rainfall has importance from the view point of cleaning of the surface of PV modules. Excessive rainfall (especially high intensities) may pose a risk to development and operation of solar power plants (Map 3.10).



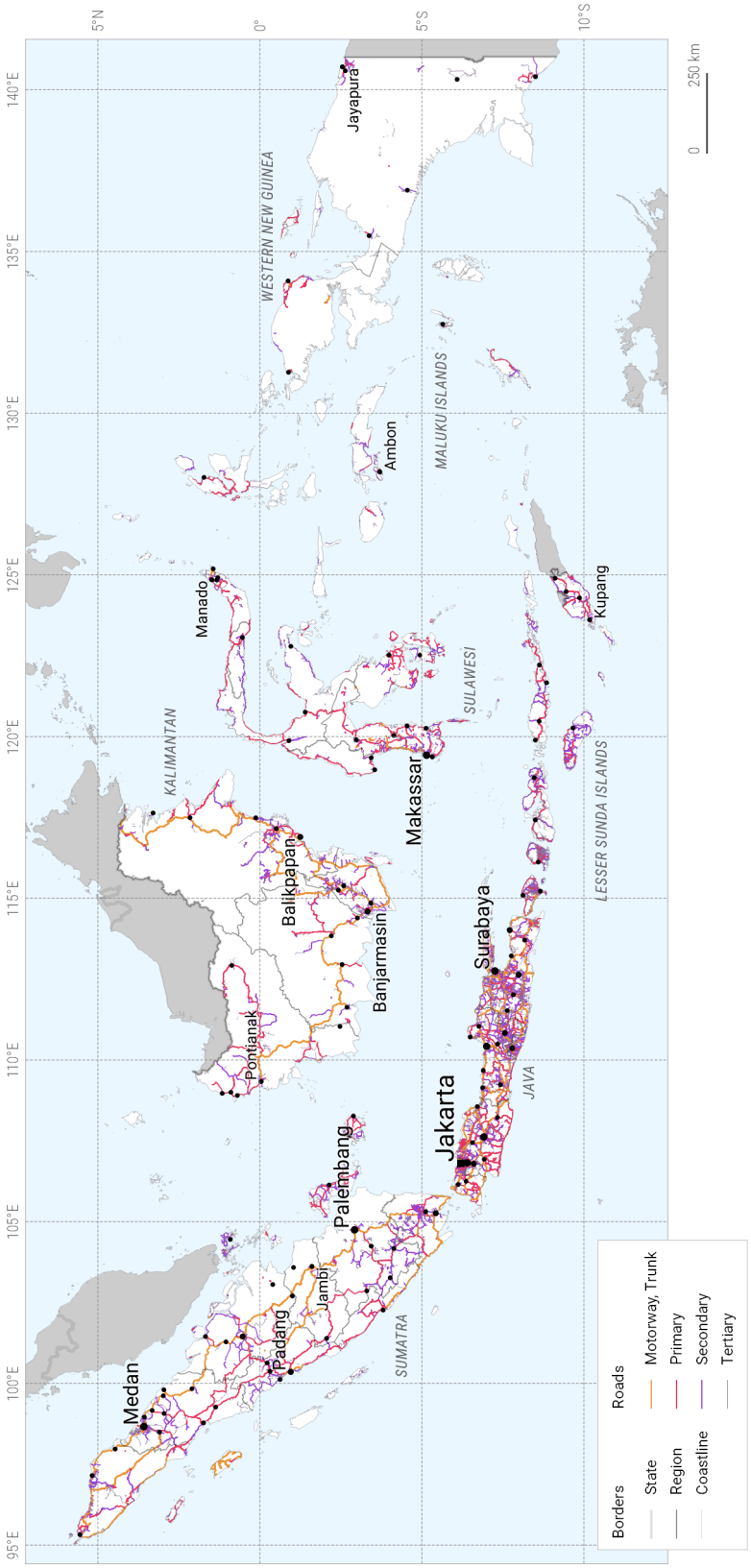
Map 3.2: Terrain elevation above sea level.
Source: SRTM-3 and Solargis



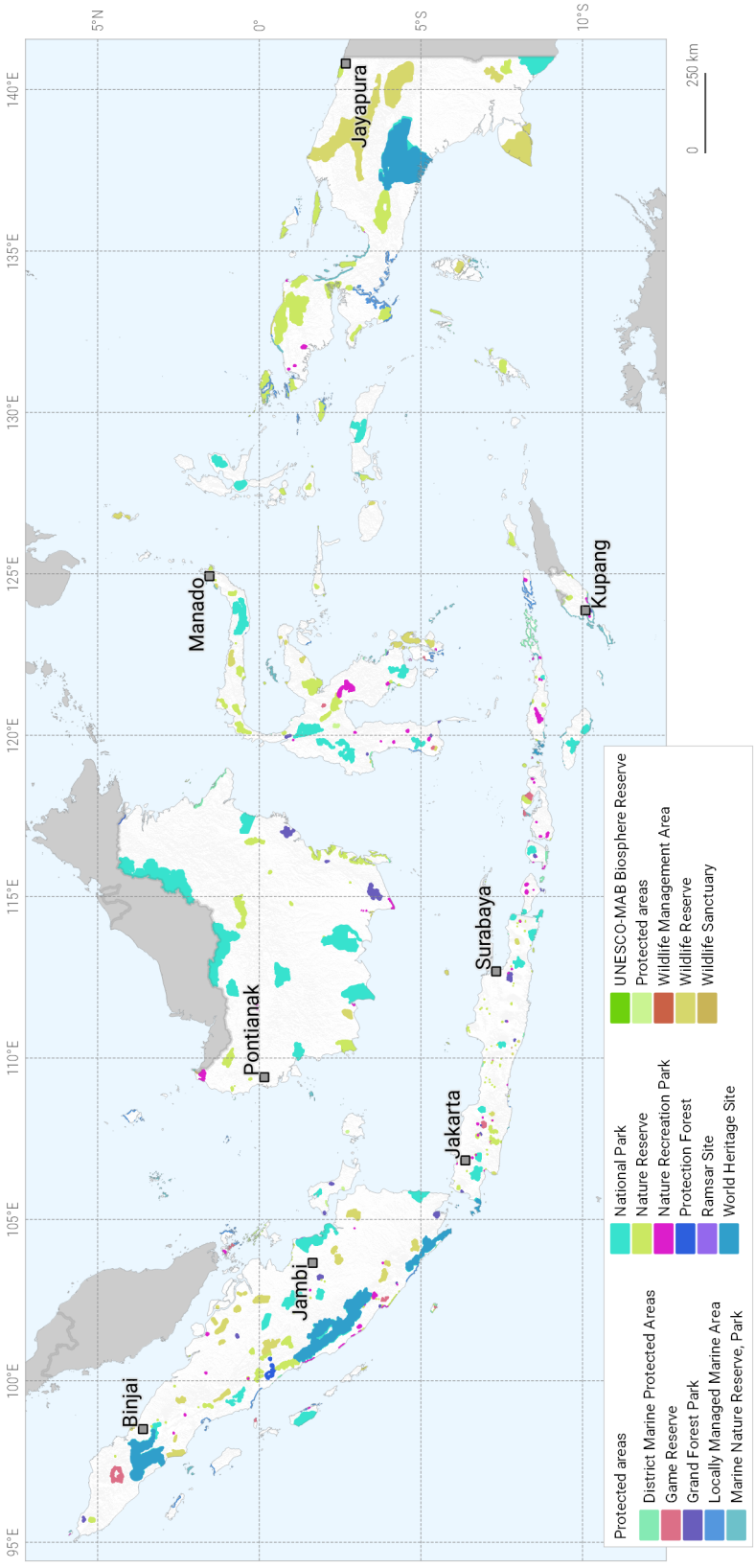
Map 3.3: Terrain slope.
Source: SRTM-3 and Solargis



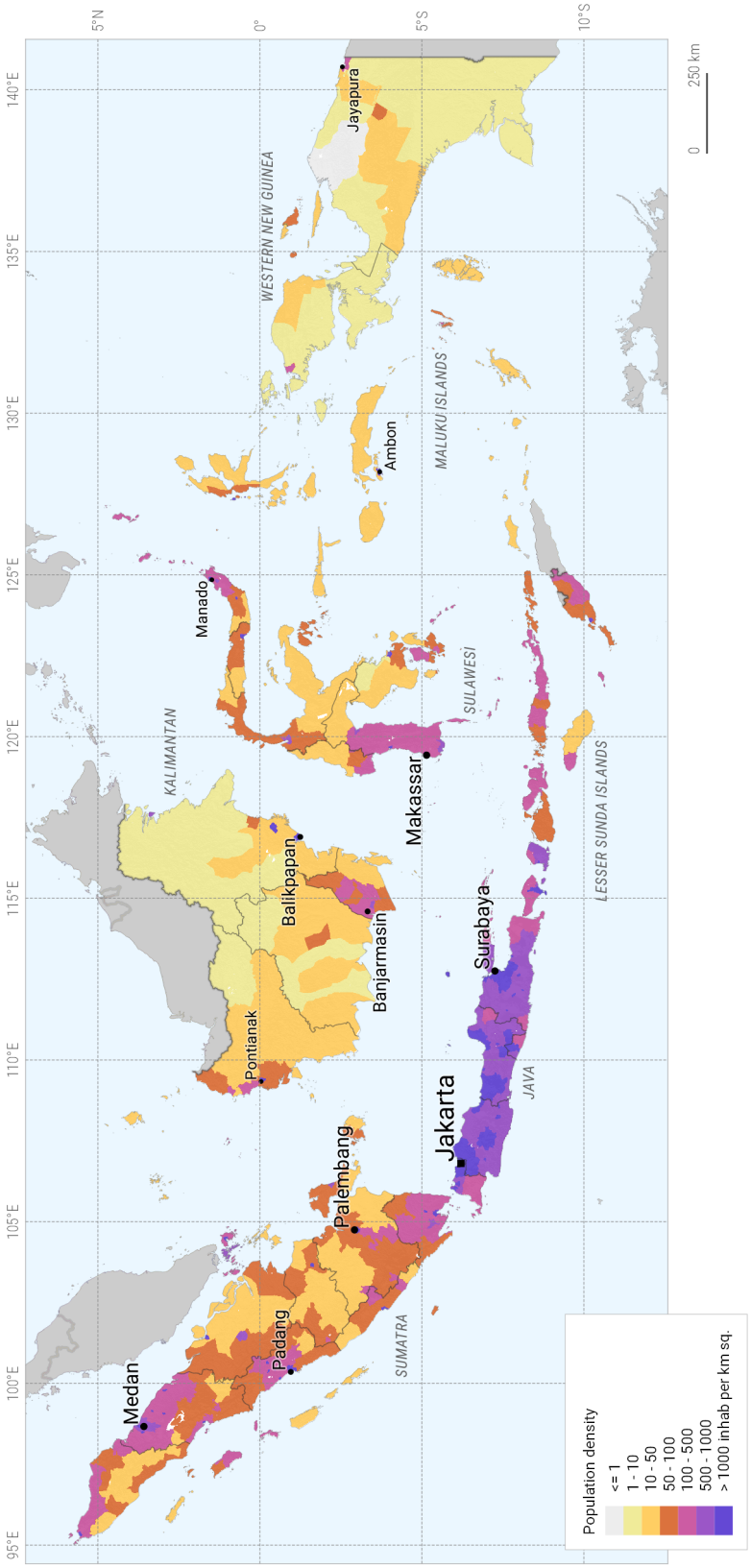
Map 3.4: Land cover.
Source: GlobCover 2009 (© ESA 2010 and UCLouvain)



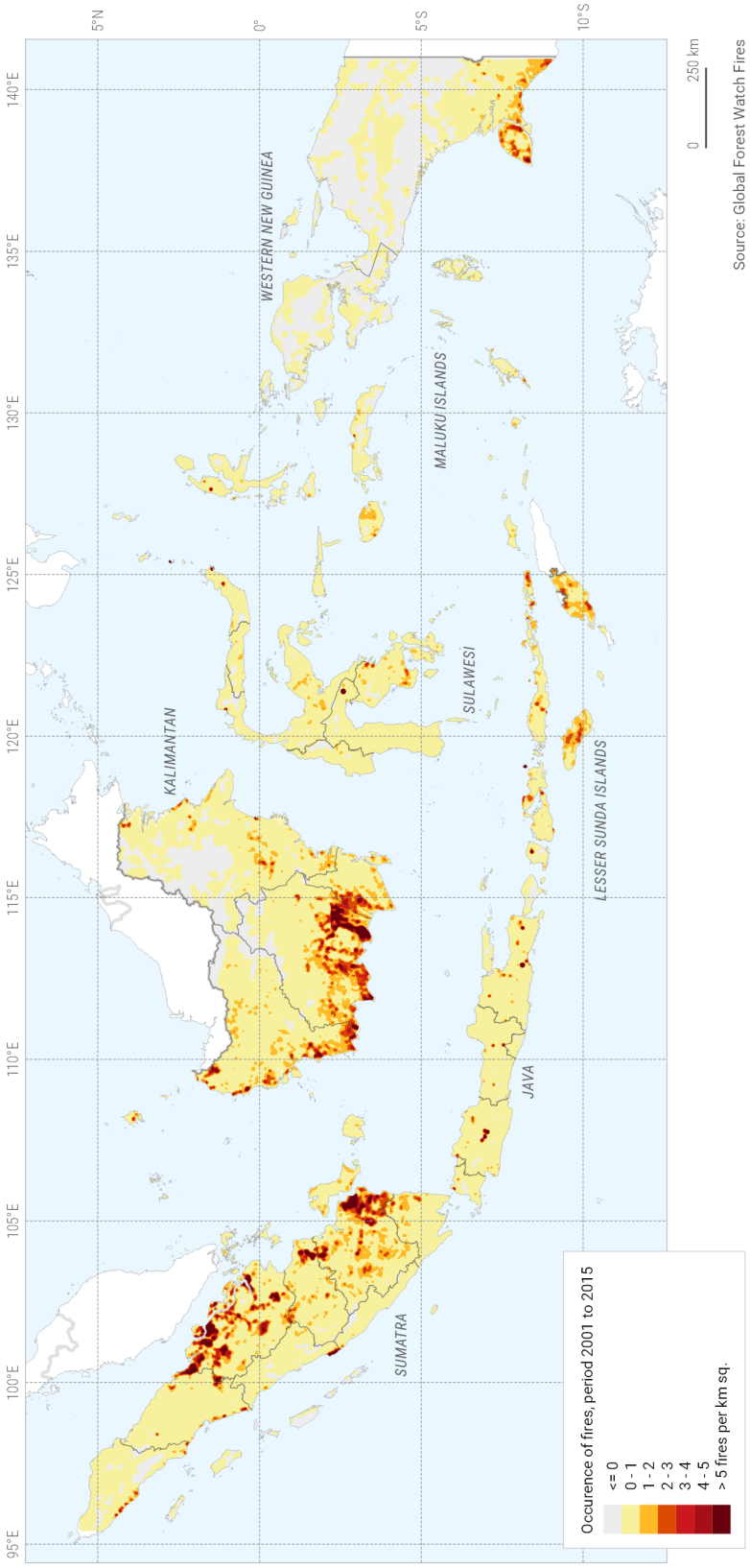
Map 3.5: Main roads and urban centres.
Source: OpenStreetMap.org contributors; administrative boundaries by Cartography Unit, GSDPM (World Bank Group)



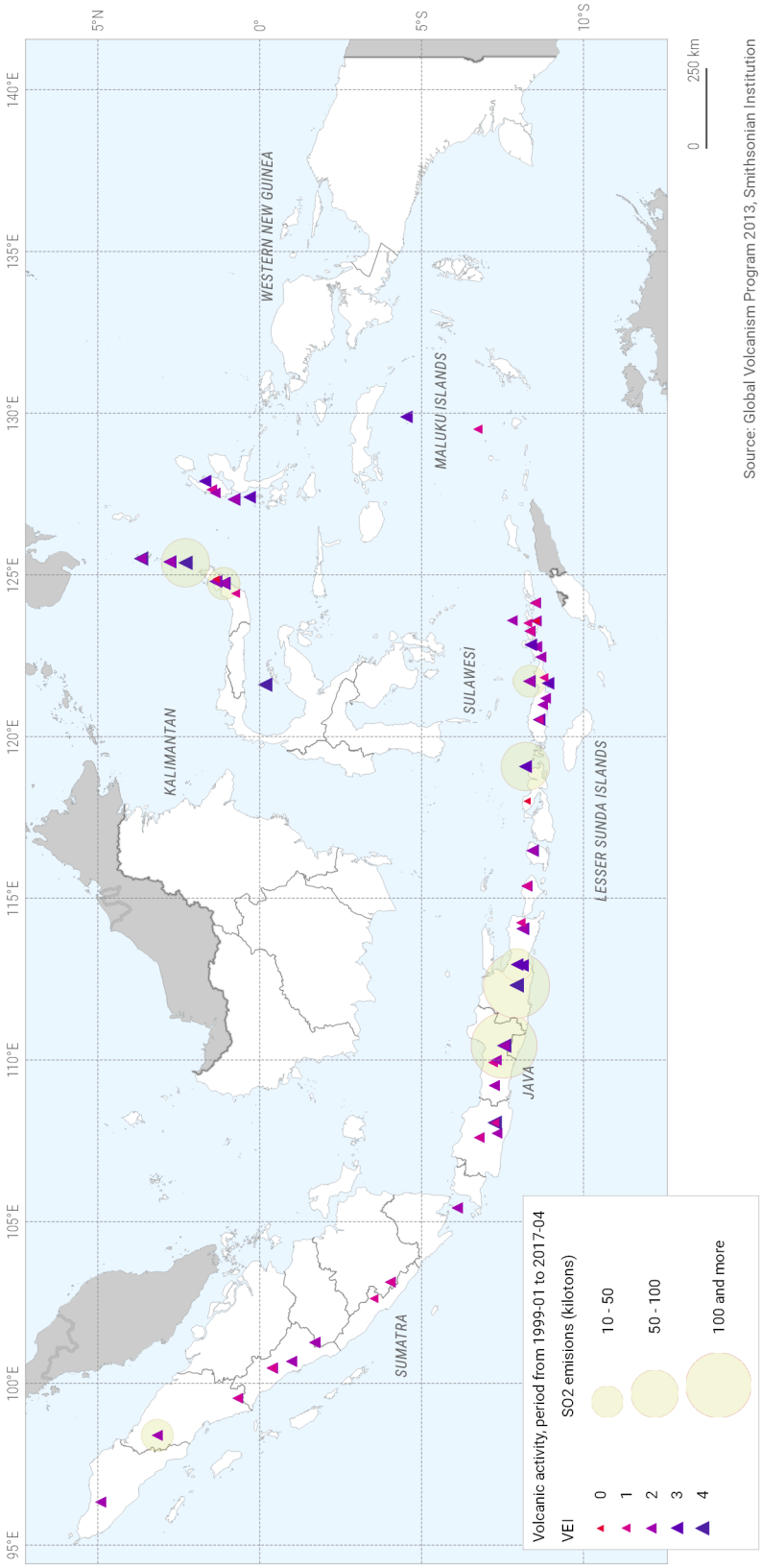
Map 3.6: Nature protection areas
Source: OpenStreetMap.org contributors; adapted by Solargis



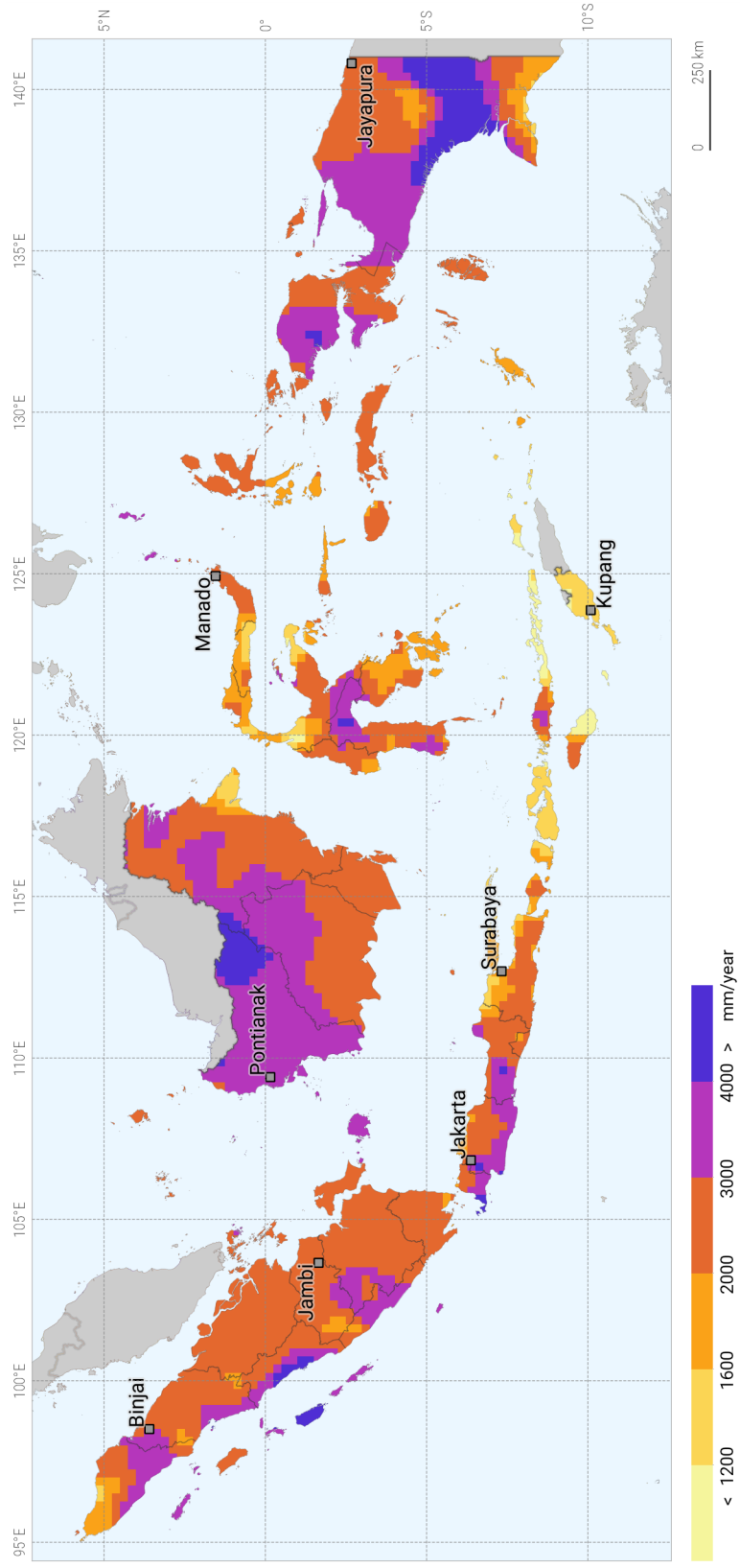
Map 3.7: Population density.
Source: Gridded Population of the World (GPW) v.4



Map 3.8: Occurrence of forest fires
Source: Global Forest Watch, World Resources Institute, Washington D.C.

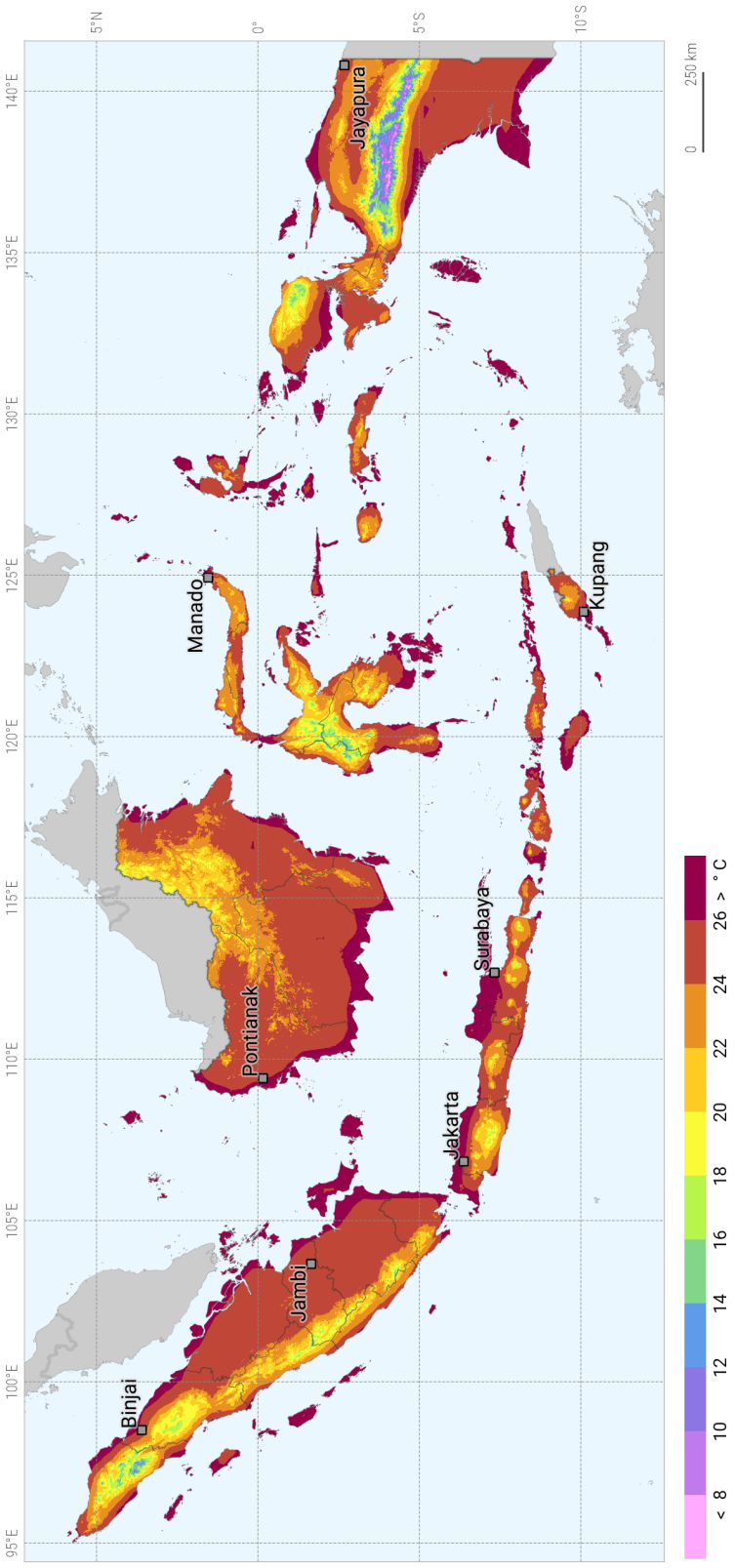


Map 3.9: Volcanic eruptions in Indonesia between 1999 and 2016
Source: Smithsonian Institution, Washington D.C.



Map 3.10: Long-term yearly average sum of rainfall (precipitation).
Source: Global Precipitation Climatology Centre (DWD)

3.2 Air temperature at 2 metres



Map 3.11: Long-term yearly average of air temperature at 2 metres.
Source: Models CFSR and CFSv2, NOAA, post-processed by Solargis

Air temperature determines the operating environment and performance efficiency of the solar power systems. Air temperature at 2 metres is used as one of inputs in the solar energy simulation models. In this report, data and maps showing the yearly and monthly average air temperature are discussed. Map 3.11 shows yearly average values.

The long-term averages of air temperature are aggregated from the hourly data derived from the CFSR and CFSv2 meteorological models (see Chapter 2.2) and post-processed by Solargis. The aggregated data show good match with the validation sites at number of meteorological stations in Indonesia (Chapter 2.2.2). As regards the hourly model values, the extreme day and night values of air temperature especially in the mountains may be partially smoothed, and the models may not represent sufficiently extreme values of the local microclimate.

In case of PV power plants, air temperature has a primary influence on the power conversion efficiency in the PV modules, and it also influences other components (inverters, transformers, etc.). Higher air temperature reduces power conversion efficiency of a PV power plant.

Table 3.2 shows monthly characteristics of air temperature at eight selected sites; they represent statistics calculated over 24-hour diurnal cycle. Minimum and maximum air temperatures are calculated as the average of minimum and maximum values of temperature during each day (assuming full diurnal cycle - 24 hours), individually for each month. Monthly averages of minimum and maximum daily values show typical daily amplitude in each month (Figure 3.1).

Table 3.2: Monthly averages and average minima and maxima of air-temperature at 2 m at 8 sites

Month	Temperature [°C]															
	Binjai		Jambi		Jakarta		Pontianak		Surabaya		Kupang		Manado		Jayapura	
	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max
January	**26.5**	22.8 32.0	**25.4**	22.9 29.5	**26.6**	23.2 31.2	**26.3**	23.5 31.0	**27.5**	24.2 33.0	**27.8**	24.8 32.7	**26.7**	25.0 29.1	**27.1**	24.8 30.5
February	**27.0**	22.9 33.1	**25.6**	22.7 30.2	**26.3**	23.2 30.4	**26.6**	23.4 32.2	**27.2**	24.2 32.2	**27.6**	24.3 32.4	**26.7**	24.8 29.2	**27.1**	24.6 30.8
March	**27.6**	23.4 34.1	**26.0**	23.0 31.0	**26.8**	23.4 31.5	**26.8**	23.5 32.5	**27.6**	24.3 33.1	**27.5**	23.5 33.2	**26.9**	25.0 29.4	**27.2**	24.8 30.8
April	**27.7**	23.6 34.3	**26.1**	23.0 31.4	**27.4**	23.8 32.5	**27.0**	23.8 32.5	**27.9**	24.4 33.2	**28.0**	23.7 34.1	**27.1**	25.1 30.0	**27.3**	25.0 31.2
May	**27.6**	23.3 34.7	**26.3**	22.9 32.0	**27.5**	23.7 32.6	**27.1**	23.7 32.8	**28.1**	24.5 33.4	**27.8**	23.9 33.4	**27.4**	25.3 30.7	**27.4**	24.8 31.3
June	**27.5**	22.9 35.0	**26.1**	22.5 32.3	**27.2**	23.2 32.5	**27.0**	23.2 32.9	**27.9**	23.9 33.5	**26.8**	22.9 32.1	**27.2**	25.1 30.7	**27.1**	24.5 31.0
July	**27.1**	22.4 34.7	**25.8**	22.2 31.9	**26.8**	22.3 32.7	**26.8**	23.1 32.6	**27.8**	23.1 33.9	**26.5**	22.3 32.2	**27.1**	25.1 30.5	**26.8**	24.1 30.8
August	**27.1**	22.6 34.5	**26.0**	22.3 32.2	**27.1**	22.2 33.6	**26.8**	23.3 32.8	**28.3**	23.1 34.8	**26.7**	21.9 33.7	**27.2**	25.1 31.0	**27.0**	24.2 31.1
September	**26.7**	22.6 33.5	**26.2**	22.3 32.6	**27.6**	22.7 34.5	**26.7**	23.2 32.3	**29.1**	23.5 36.1	**28.0**	22.3 36.0	**27.5**	25.0 32.0	**27.2**	24.4 31.5
October	**26.5**	22.8 32.7	**26.0**	22.6 31.8	**27.9**	23.5 34.2	**26.5**	23.3 31.7	**29.8**	24.5 36.4	**29.4**	23.7 37.2	**27.5**	25.0 31.6	**27.5**	24.5 32.0
November	**26.4**	23.2 31.9	**25.8**	22.9 30.7	**27.6**	23.8 33.3	**26.4**	23.8 30.7	**29.5**	25.0 36.2	**30.0**	24.5 37.6	**27.2**	25.1 30.5	**27.5**	24.8 31.7
December	**26.3**	23.1 31.4	**25.6**	23.0 30.0	**27.0**	23.7 31.9	**26.3**	23.7 30.6	**27.9**	24.3 33.8	**28.3**	24.6 34.2	**27.0**	25.4 29.5	**27.4**	25.0 31.3
YEAR	**27.0**		**25.9**		**27.1**		**26.7**		**28.2**		**27.9**		**27.1**		**27.2**	

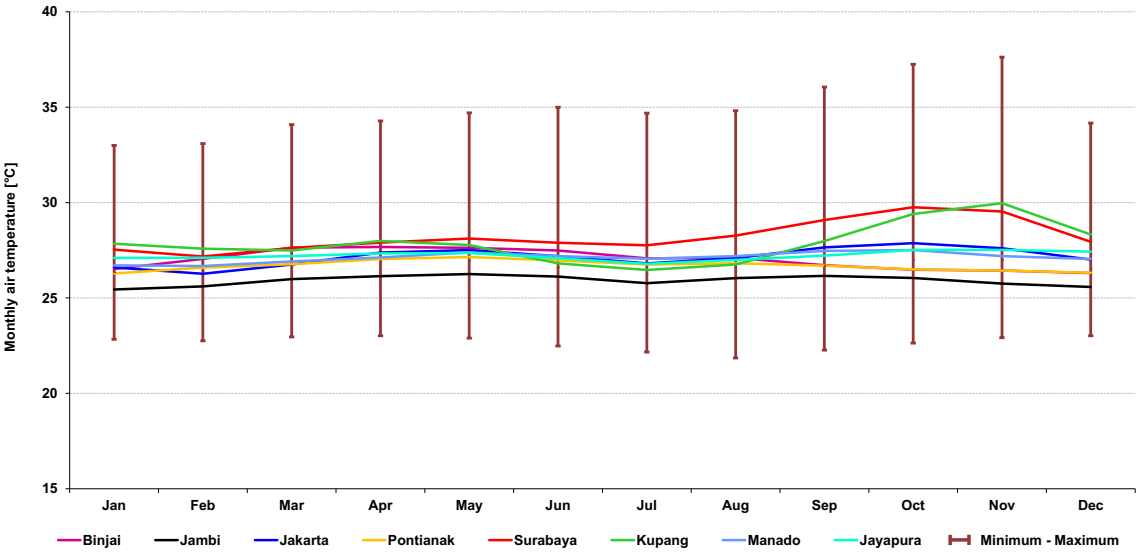
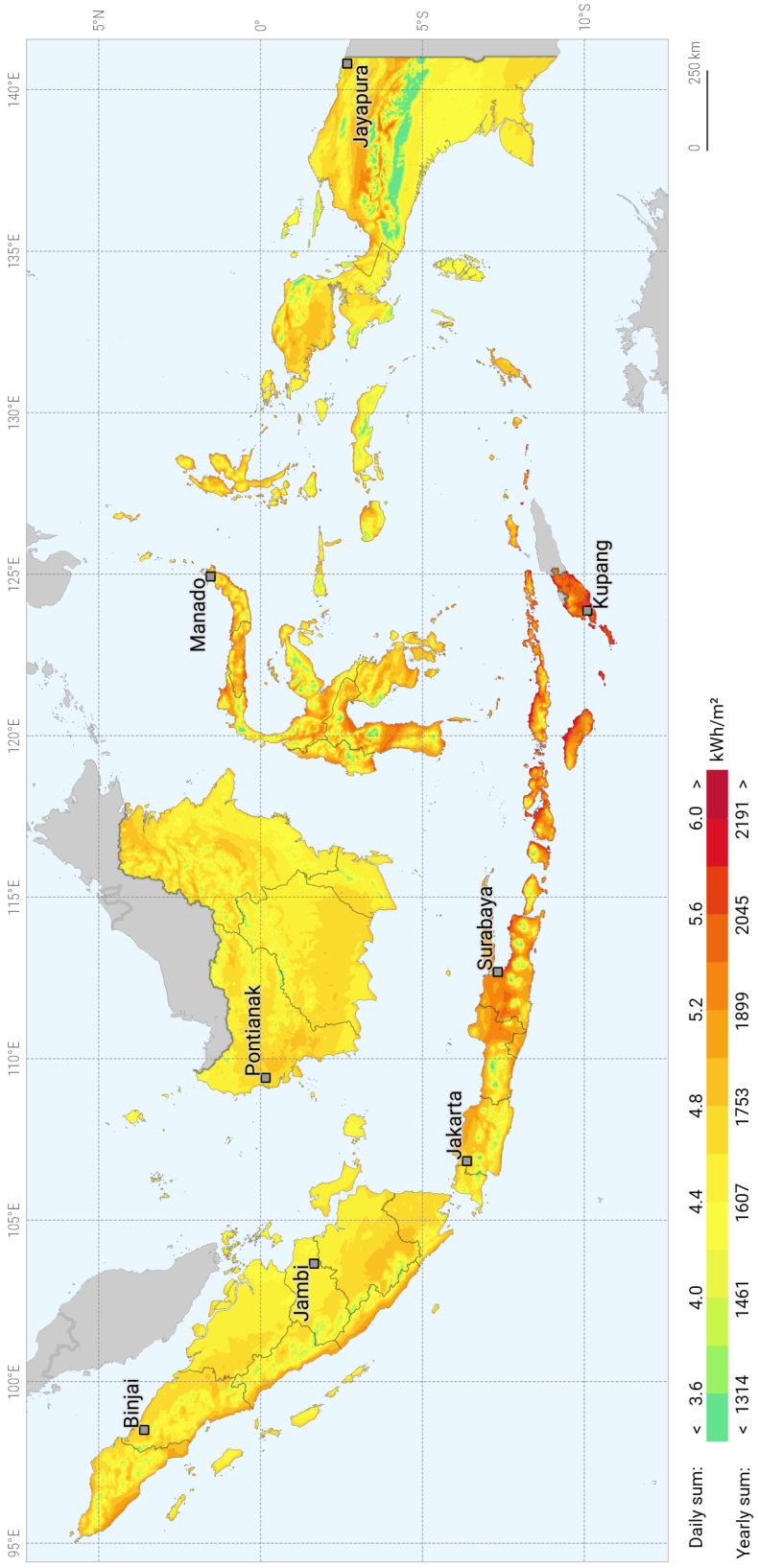
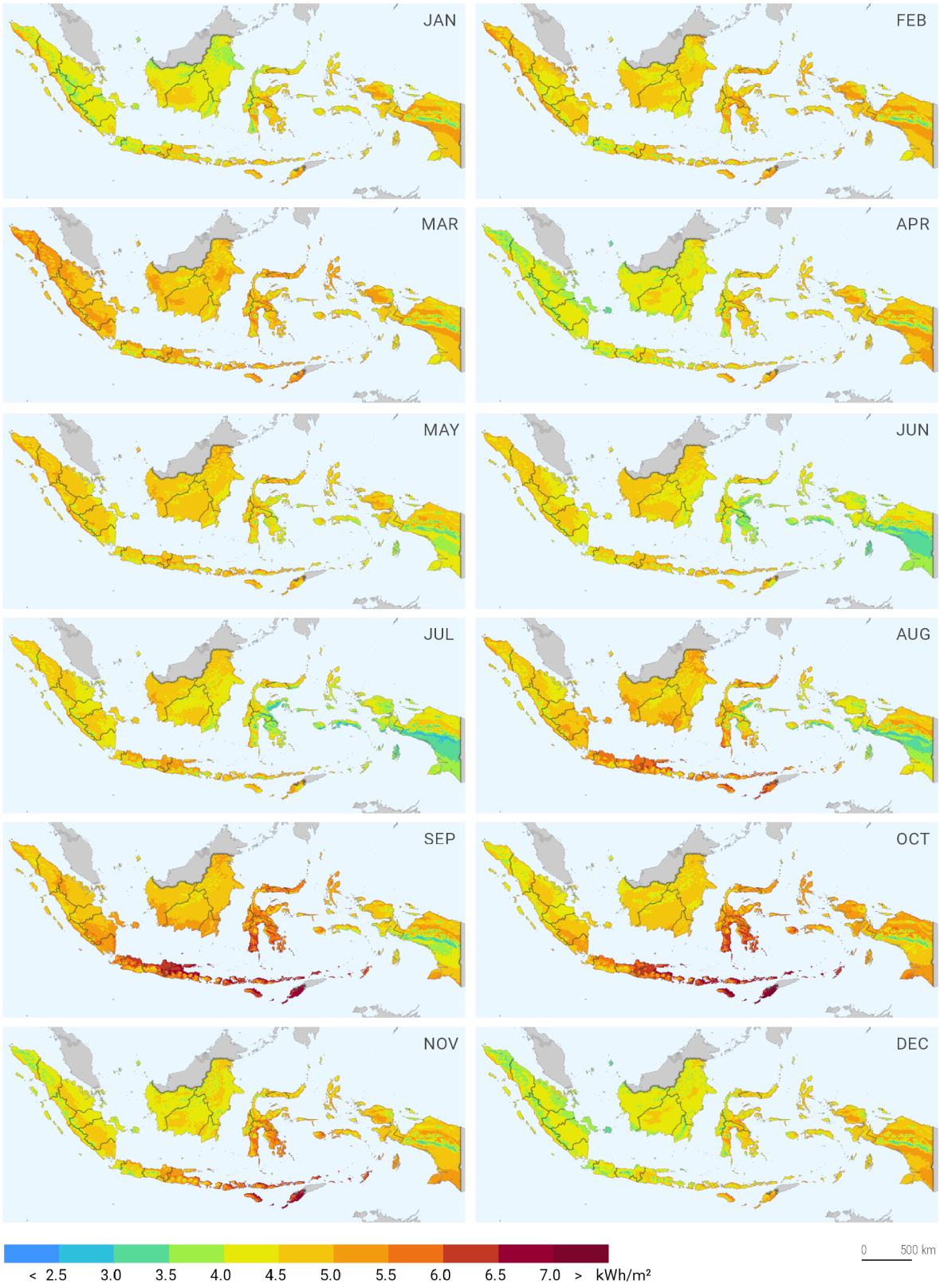


Figure 3.1: Monthly averages, minima and maxima of air-temperature at 2 m for selected sites.

3.3 Global Horizontal Irradiation



Map 3.12: Global Horizontal Irradiation – long term average of daily and yearly totals.
Source: Solargis



Map 3.13: Global Horizontal Irradiation – long-term monthly averages of daily totals.
Source: Solargis

Global Horizontal Irradiation (GHI) is used as a reference value for comparing solar potential related to PV electricity systems, as it eliminates the possible variations, given by the choice of technical components and the PV system design.

The highest GHI is identified in the southern islands of the archipelago, where the average daily totals reach 5.6 kWh/m^2 (average annual 2045 kWh/m^2) and higher (Map 3.12). Further north, average daily totals of GHI values occurs between 3.8 kWh/m^2 and 4.8 kWh/m^2 (annual sums are between 1400 and 1750 kWh/m^2). Minimum daily GHI values in the country are lower than 3.6 kWh/m^2 (average annual value lower than 1300 kWh/m^2), but the solar resource in these areas is still sufficiently high for small-scale PV.

Table 3.3: Daily averages and average minima and maxima of Global Horizontal Irradiation at 8 sites

Month	Global Horizontal Irradiation [kWh/m^2]																Variability between sites [%]
	Binjai		Jambi		Jakarta		Pontianak		Surabaya		Kupang		Manado		Jayapura		
	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	
January	**4.24**	3.82 4.60	**4.03**	3.61 4.57	**3.94**	3.32 5.02	**4.51**	3.95 5.40	**4.78**	4.10 5.55	**5.07**	3.97 6.46	**4.29**	3.90 4.83	**4.71**	3.96 5.60	**8.7**
February	**4.70**	4.13 5.32	**4.46**	4.07 4.79	**3.90**	2.97 4.68	**4.83**	3.94 5.37	**4.73**	4.02 5.41	**5.43**	4.24 6.36	**4.84**	4.41 5.71	**5.01**	4.23 5.49	**9.3**
March	**5.29**	4.46 5.73	**4.79**	4.53 5.32	**4.69**	4.34 5.71	**4.99**	4.26 5.52	**4.94**	4.16 5.63	**5.58**	4.39 6.41	**5.31**	4.11 6.11	**4.66**	3.87 5.85	**6.6**
April	**4.98**	4.52 5.30	**4.60**	3.98 4.95	**4.71**	4.37 5.24	**4.98**	4.72 5.25	**4.82**	4.32 5.27	**5.92**	5.01 6.47	**5.15**	4.20 6.13	**5.04**	4.58 5.50	**8.0**
May	**4.86**	4.16 5.31	**4.53**	4.16 4.78	**4.63**	4.07 5.24	**4.92**	4.74 5.31	**4.89**	3.96 5.66	**5.32**	4.60 5.85	**4.85**	4.39 5.51	**4.69**	4.33 4.95	**5.0**
June	**4.81**	4.30 5.23	**4.44**	4.04 5.02	**4.47**	3.84 4.98	**4.85**	4.60 5.10	**4.92**	3.77 5.48	**5.16**	4.52 5.62	**4.60**	3.88 4.99	**4.42**	4.01 5.10	**5.7**
July	**4.74**	4.15 5.18	**4.42**	3.94 4.90	**4.74**	3.63 5.42	**4.93**	4.47 5.37	**5.38**	4.64 5.86	**5.45**	4.82 5.79	**4.88**	4.25 6.02	**4.36**	3.84 5.13	**8.1**
August	**4.75**	4.17 5.28	**4.60**	4.04 4.93	**5.28**	4.55 5.64	**4.92**	4.44 5.22	**6.16**	5.45 6.50	**6.23**	5.79 6.56	**5.43**	4.84 6.53	**4.90**	4.31 5.69	**11.8**
September	**4.82**	4.39 5.56	**4.73**	3.73 5.30	**5.60**	4.39 6.29	**4.97**	4.38 5.42	**6.66**	4.89 7.18	**6.83**	5.86 7.40	**5.69**	4.99 6.86	**4.92**	4.43 5.43	**15.0**
October	**4.52**	4.05 5.01	**4.35**	2.58 4.76	**5.21**	4.15 6.15	**4.54**	4.19 4.86	**6.47**	4.91 7.36	**7.07**	6.14 7.77	**5.44**	4.80 6.57	**5.25**	4.51 5.85	**18.1**
November	**4.22**	3.72 4.54	**4.29**	3.93 4.55	**4.63**	4.19 5.16	**4.28**	3.46 4.63	**5.32**	4.50 6.47	**6.52**	5.64 7.13	**4.66**	4.25 4.98	**4.99**	4.40 5.69	**15.8**
December	**3.88**	3.39 4.36	**4.00**	3.63 4.33	**4.17**	3.41 4.56	**4.21**	3.76 4.94	**4.40**	3.86 5.27	**5.08**	4.21 5.60	**4.53**	4.17 5.06	**4.88**	4.46 5.51	**9.5**
YEAR	**4.65**	**4.54** **4.74**	**4.44**	**4.27** **4.55**	**4.67**	**4.39** **5.02**	**4.74**	**4.61** **4.86**	**5.29**	**4.81** **5.73**	**5.80**	**5.44** **6.13**	**4.97**	**4.65** **5.60**	**4.82**	**4.56** **5.12**	**8.9**

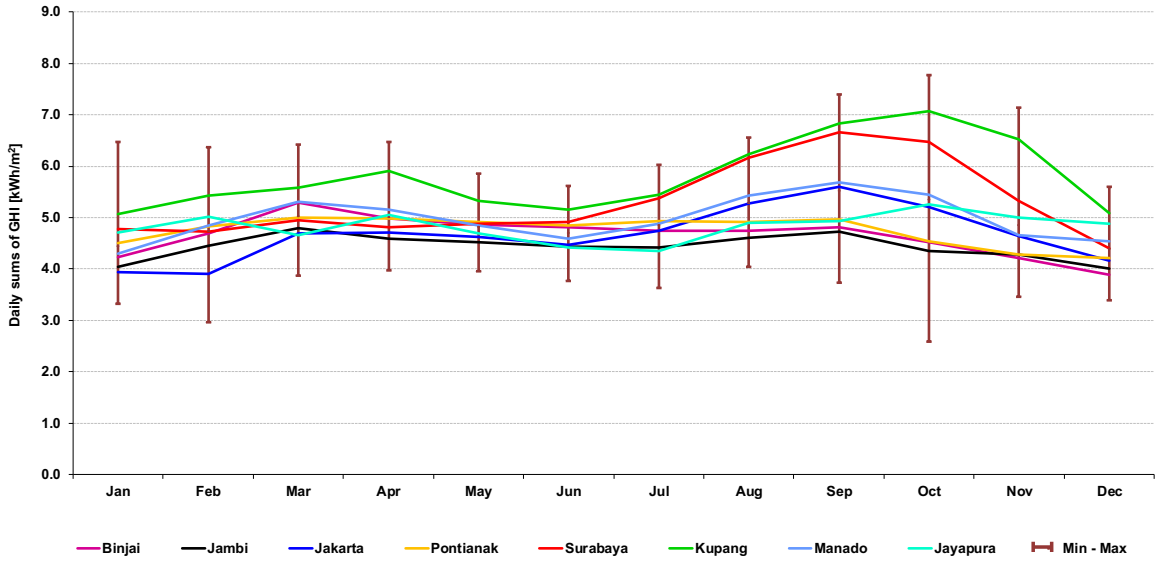


Figure 3.2: Long-term monthly averages, minima and maxima of Global Horizontal Irradiation.

Table 3.3 shows long-term average, and average minima and maxima of daily totals of Global Horizontal Irradiation (GHI) for a period 1999 to 2016 at Binjai and Jambi sites, while the remaining 6 sites encompasses the data for a period 2007 to 2016.

Figure 3.2 compares monthly averages of daily values of Global horizontal irradiation (GHI). Most stable weather, but with lower GHI values is from May to July. Highest GHI daily sums and also higher variability is seen during the period from August to November. Due to the equatorial position of Indonesia, the solar irradiance is very evenly distributed over the year, with some higher differences at Kupang and Surabaya sites. These are influenced by dry winds from Australia; thus lower occurrence of clouds or aerosols is the main driver for higher GHI.

Weather changes in cycles and has also stochastic nature. Therefore, annual solar radiation in each year can deviate from the long-term average in the range of few percent. Figure 3.3 shows interannual variability, i.e. the magnitude of the year-by-year GHI change. Locally, this variability might be exaggerated by the volcanic activity or forest fires.

The interannual variability is calculated from the unbiased standard deviation of GHI over 18 years (for Binjai and Jambi sites) and 10 years (for all other sites), considering a simplified assumption of normal distribution of the annual sums.

Sites Surabaya and Kupang show similar varying patterns of GHI over the recorded period, probably because their similar climatic conditions, influenced by winds from Australia. Other sites have different characteristics and relatively small extremes (minimum and maximum GHI) are found: for example, in years 2009, 2010, 2013 or 2015. The most stable GHI (the smallest interannual variability) is observed in Binjai, Jambi and Pontianak. The sites with the highest interannual variability are Manado and Surabaya.

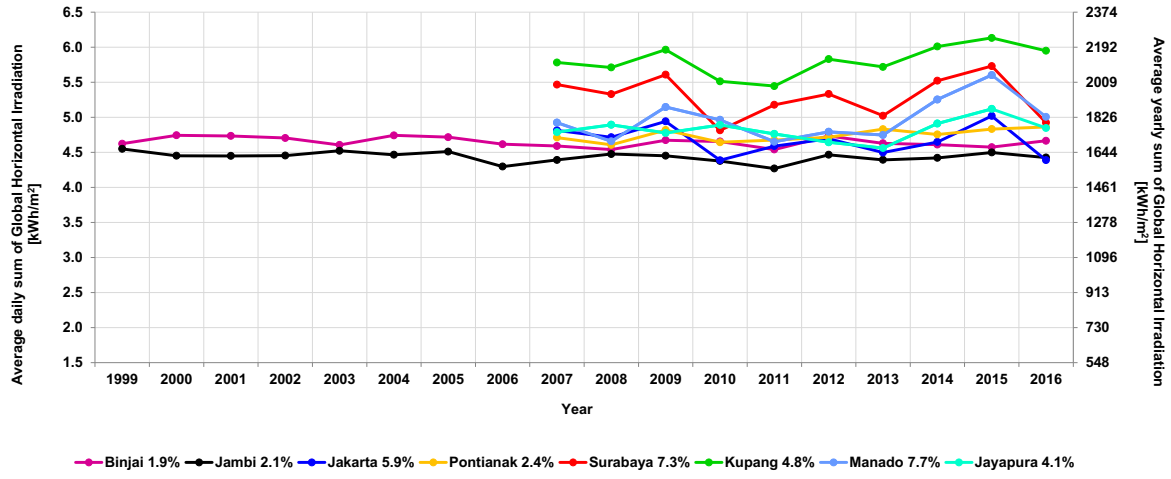
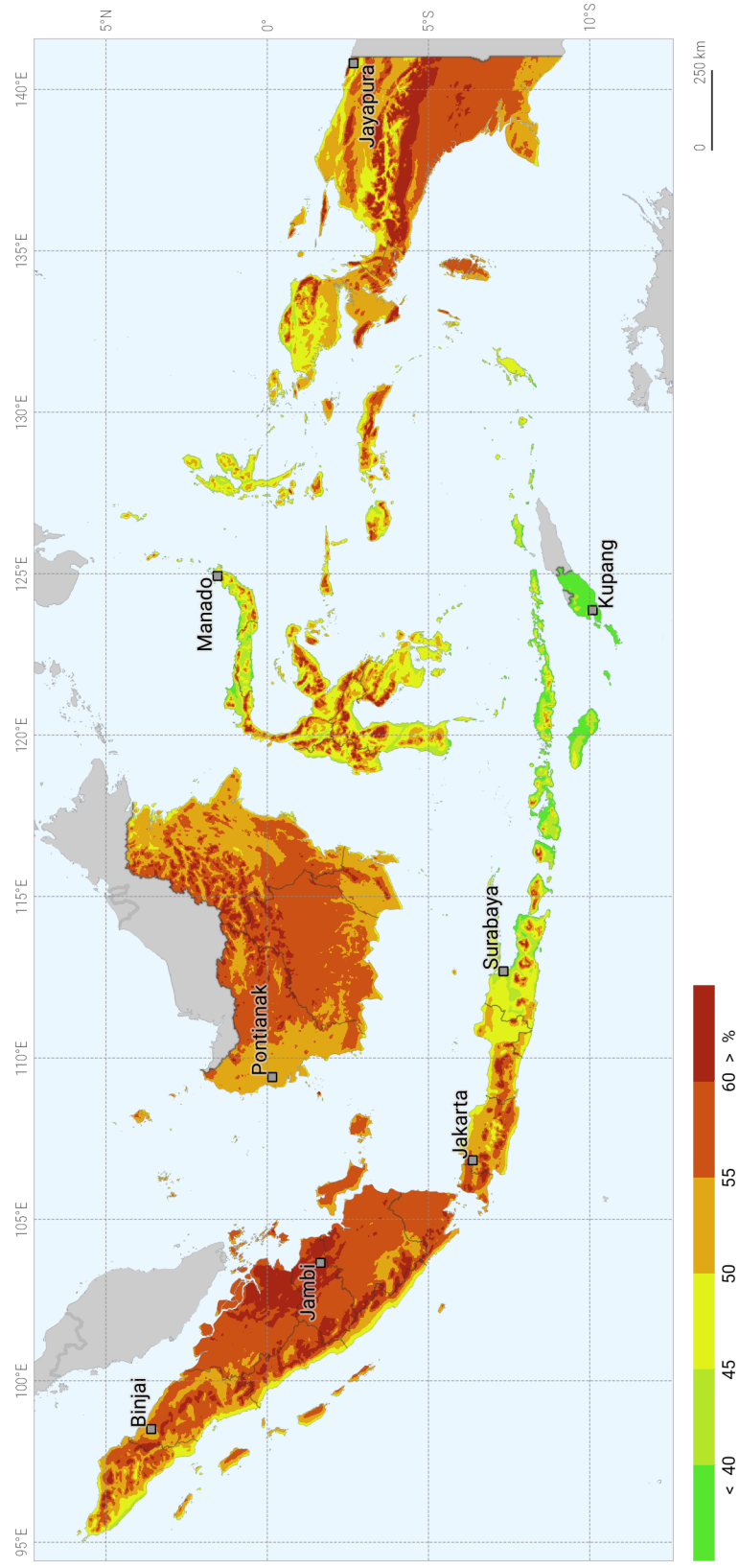


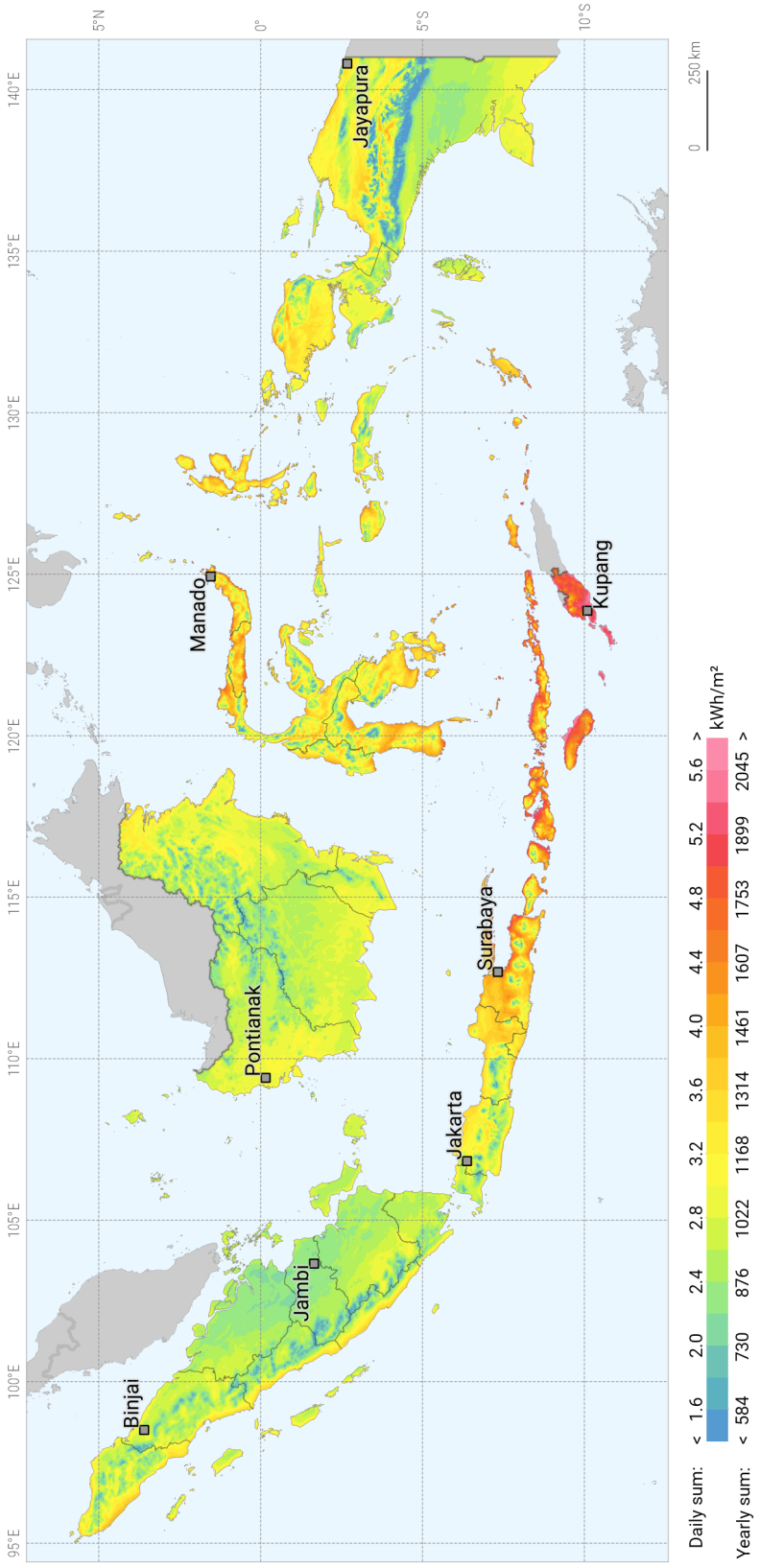
Figure 3.3: Interannual variability of Global Horizontal Irradiation for selected sites.

Map 3.14 delineates ratio of diffuse to global horizontal irradiation. This ratio is important for understanding the performance of PV systems.



Map 3.14: Long-term average for ratio of diffuse to global irradiation (DIF/GHI).
Source: Solargis

3.4 Direct Normal Irradiation



Map 3.15: Direct Normal Irradiation – long-term average of daily and yearly totals.
Source: Solargis

Direct Normal Irradiation (DNI) is one of the primary solar resource parameters, needed for computation of Global Tilted Irradiation (GTI, Chapter 3.5).

Table 3.4 and Figure 3.4 show long-term average daily totals and average daily minimum and maximum of DNI for eight selected sites, assuming a period 1999 (2007) to 2016. The highest DNI is found in Kupang, while the lowest at the Jambi airport.

Table 3.4: Daily averages and average minima and maxima of Direct Normal Irradiation at 8 sites

Month	Direct Normal Irradiation [kWh/m²]																Variability between sites [%]
	Binjai		Jambi		Jakarta		Pontianak		Surabaya		Kupang		Manado		Jayapura		
	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	
January	**2.27**	1.66 2.79	**1.70**	1.22 2.03	**1.92**	1.03 3.30	**2.61**	1.74 3.72	**2.70**	1.70 3.62	**3.35**	2.00 6.09	**2.84**	2.14 3.88	**3.15**	2.14 4.71	**22.4**
February	**2.54**	1.89 3.24	**1.96**	1.59 2.36	**1.68**	0.53 2.47	**2.78**	1.18 3.59	**2.61**	1.37 3.72	**4.14**	2.21 5.81	**3.32**	2.48 4.75	**3.30**	2.21 4.15	**28.3**
March	**3.22**	2.47 3.81	**2.43**	2.06 3.20	**2.64**	2.13 4.24	**2.93**	2.09 3.65	**3.05**	2.19 4.21	**4.93**	2.69 6.31	**4.03**	2.52 5.29	**2.87**	2.05 4.15	**25.3**
April	**2.91**	2.45 3.49	**2.52**	1.73 3.11	**2.90**	2.35 3.78	**3.30**	3.08 3.78	**3.32**	2.65 3.99	**6.16**	4.49 7.41	**4.15**	2.88 5.66	**3.66**	3.01 4.18	**31.7**
May	**3.00**	2.03 3.82	**2.67**	2.04 3.06	**3.19**	2.35 4.00	**3.61**	3.16 4.21	**4.14**	2.77 5.53	**5.76**	4.17 6.88	**4.14**	3.35 5.31	**3.70**	3.01 4.21	**25.3**
June	**3.04**	2.25 3.67	**2.73**	2.26 3.54	**3.18**	2.32 3.84	**3.73**	3.23 4.04	**4.68**	2.58 5.82	**5.88**	4.46 7.11	**3.80**	2.74 4.27	**3.51**	2.80 4.63	**26.8**
July	**2.94**	2.27 3.59	**2.56**	2.12 3.21	**3.39**	1.95 4.41	**3.63**	3.05 4.40	**5.37**	4.14 6.49	**6.25**	4.81 7.08	**4.13**	3.12 6.44	**3.31**	2.18 4.78	**32.0**
August	**2.68**	2.09 3.43	**2.31**	1.78 2.89	**3.55**	2.55 4.18	**3.05**	2.32 3.61	**6.01**	4.73 6.77	**7.07**	6.08 8.03	**4.64**	3.93 6.75	**3.76**	2.89 5.05	**40.3**
September	**2.64**	2.16 3.56	**2.21**	0.83 3.11	**3.48**	2.30 4.41	**2.67**	1.46 3.40	**6.21**	3.52 7.13	**6.96**	5.09 8.27	**4.55**	3.40 6.39	**3.46**	2.81 4.14	**43.4**
October	**2.37**	1.32 3.14	**1.88**	0.47 2.34	**2.70**	1.70 3.65	**2.35**	1.83 2.98	**5.18**	3.32 6.57	**6.83**	5.13 8.32	**4.29**	3.49 5.79	**3.69**	2.83 4.66	**46.5**
November	**2.32**	1.60 2.65	**1.98**	1.62 2.39	**2.19**	1.77 2.76	**2.42**	1.42 2.86	**3.33**	2.17 5.18	**5.91**	4.73 7.06	**3.57**	3.07 4.09	**3.41**	2.40 4.30	**40.6**
December	**1.97**	1.37 2.56	**1.73**	1.34 2.18	**1.87**	0.95 2.46	**2.43**	1.93 3.53	**2.15**	1.48 2.96	**3.53**	2.19 4.36	**3.41**	2.69 4.34	**3.46**	2.78 4.34	**30.0**
YEAR	**2.66**	**2.49** **2.92**	**2.22**	**1.93** **2.52**	**2.73**	**2.37** **3.16**	**2.96**	**2.76** **3.22**	**4.07**	**3.25** **4.77**	**5.57**	**4.83** **6.17**	**3.91**	**3.39** **4.97**	**3.44**	**3.11** **3.87**	**31.0**

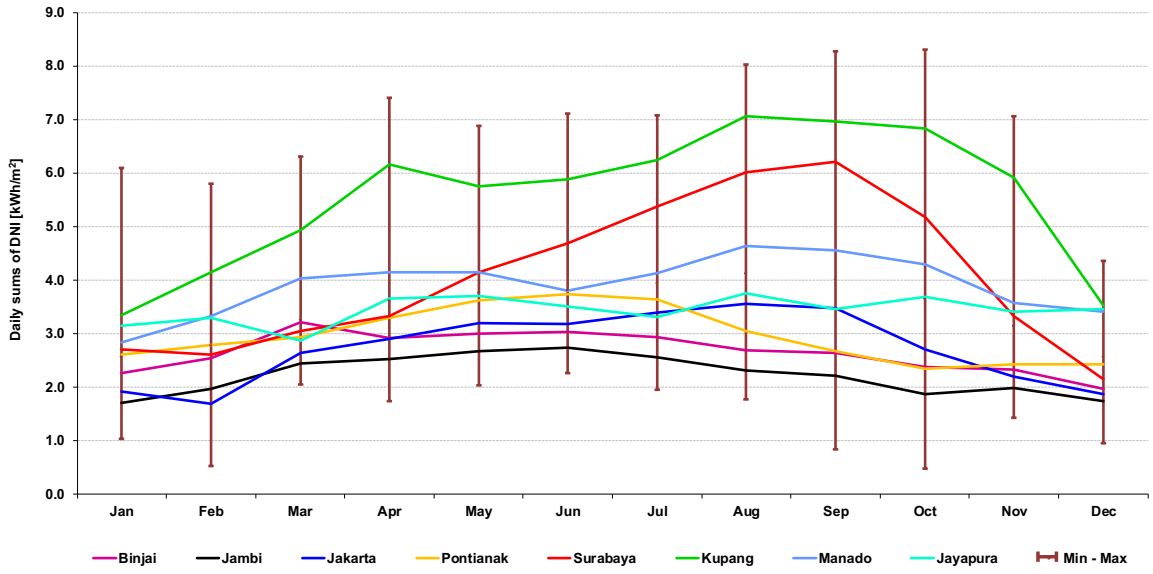


Figure 3.4: Daily averages of Direct Normal Irradiation at selected sites.

At all sites, minimum DNI values are observed during the period of November to February, which corresponds with the monsoon season in Indonesia. During this season, also the lowest DNI variability (given by minimum and maximum range of monthly values) occurs, probably due to constant and high occurrence of clouds and aerosols (fog, smoke). For the rest of the year, DNI patterns depend on the position of the site. For example,

Kupang or Manado sites have two maxima during year, while Jambi or Pontianak only one. All sites show highest DNI variability in September and October.

Generally, Eastern Java and the Lesser Sunda Islands have highest DNI potential; lower values are found in Sumatra and Kalimantan, and these are influenced by higher occurrence of clouds, and by higher concentrations of aerosols in the atmosphere.

Interannual variability of DNI for selected sites (Figure 3.5) is calculated from the unbiased standard deviation of yearly DNI over 10 years (18 years on Sumatra), and it is based on a simplified assumption of normal distribution of the yearly sums. Every site has its own variability pattern; few events were so strong that they influenced most of the sites - see for example high values in years 2009 or 2015. The most stable DNI (the smallest interannual variability) is observed in Jambi, Pontianak and Binjai, the most unstable DNI is recorded at Manado site. The lowest DNI is at Jambi airport.

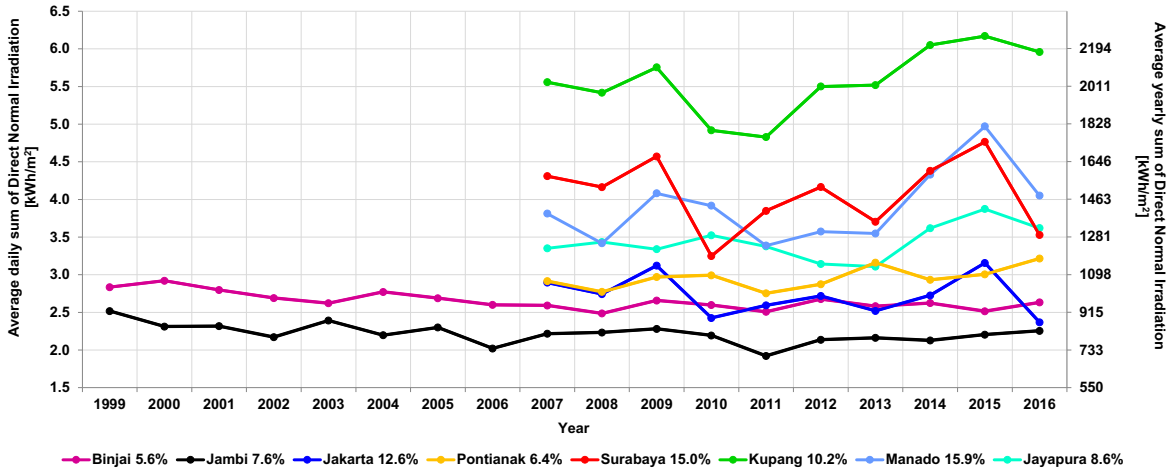


Figure 3.5: Interannual variability of Direct Normal Irradiation at representative sites

Daily totals in any single year can be displayed for a better visual presentation of DNI in relation to GHI. Figure 3.6 shows daily totals for year 2016 in Jakarta. GHI daily totals (blue pattern), are shown in the background to highlight the lower DNI values (yellow pattern).

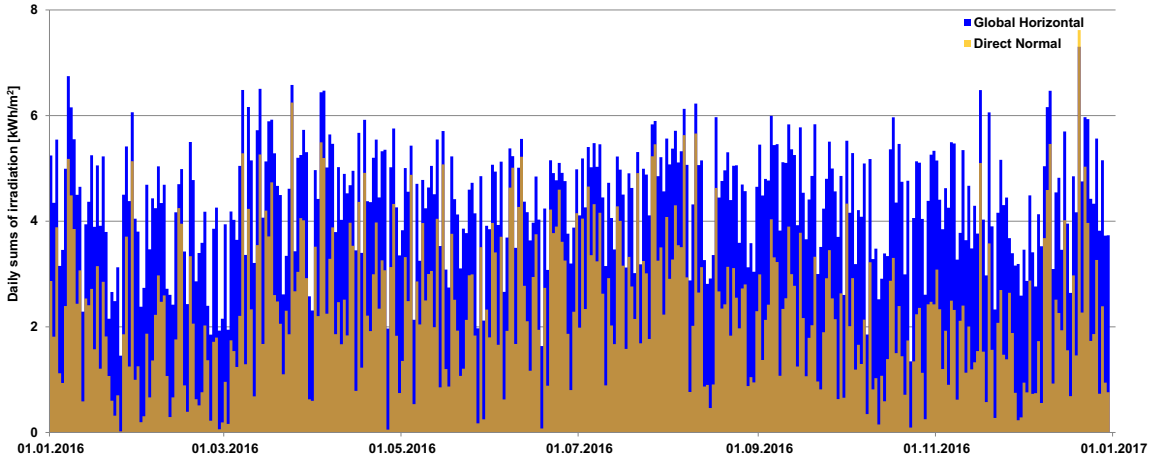
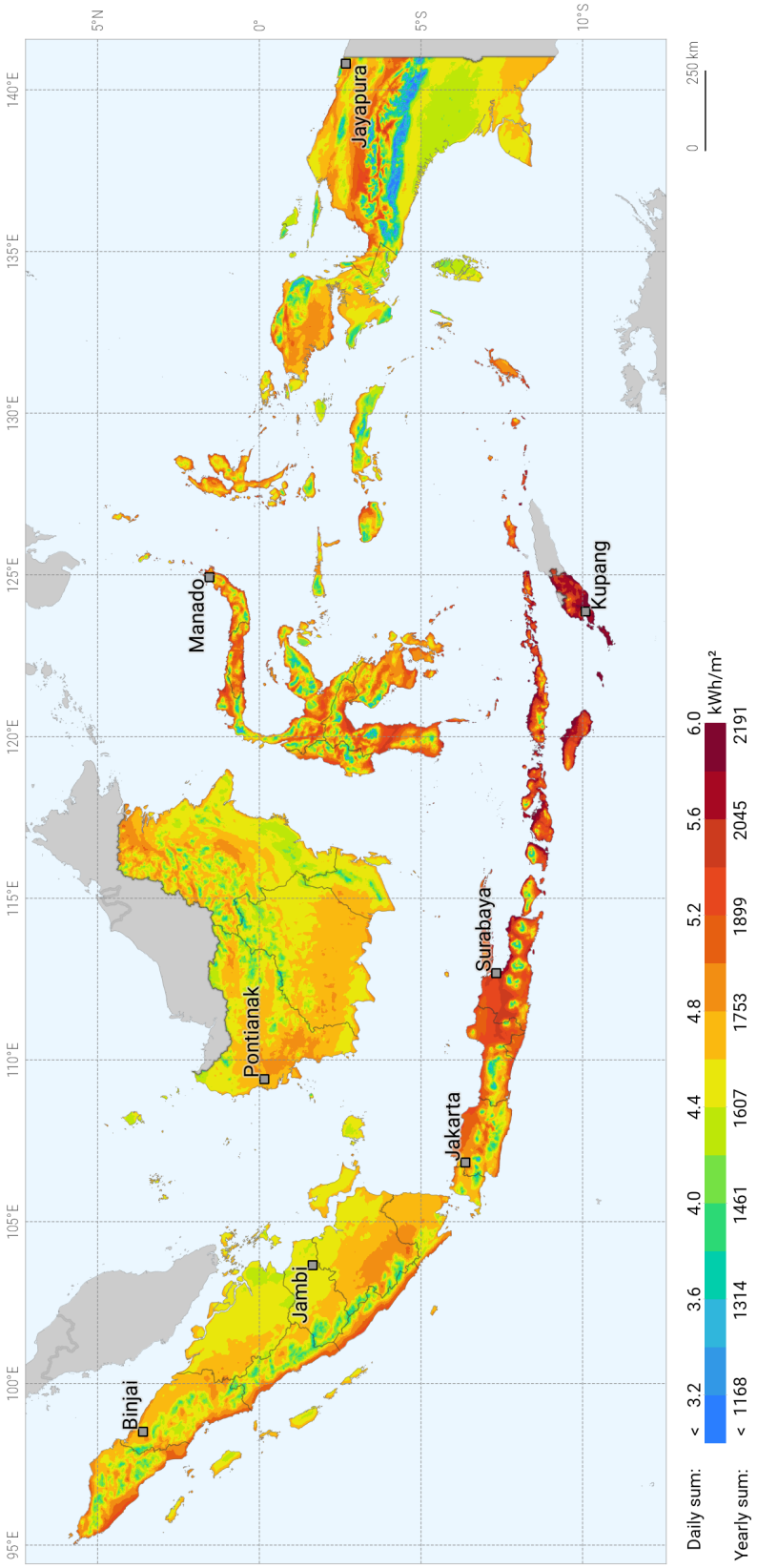
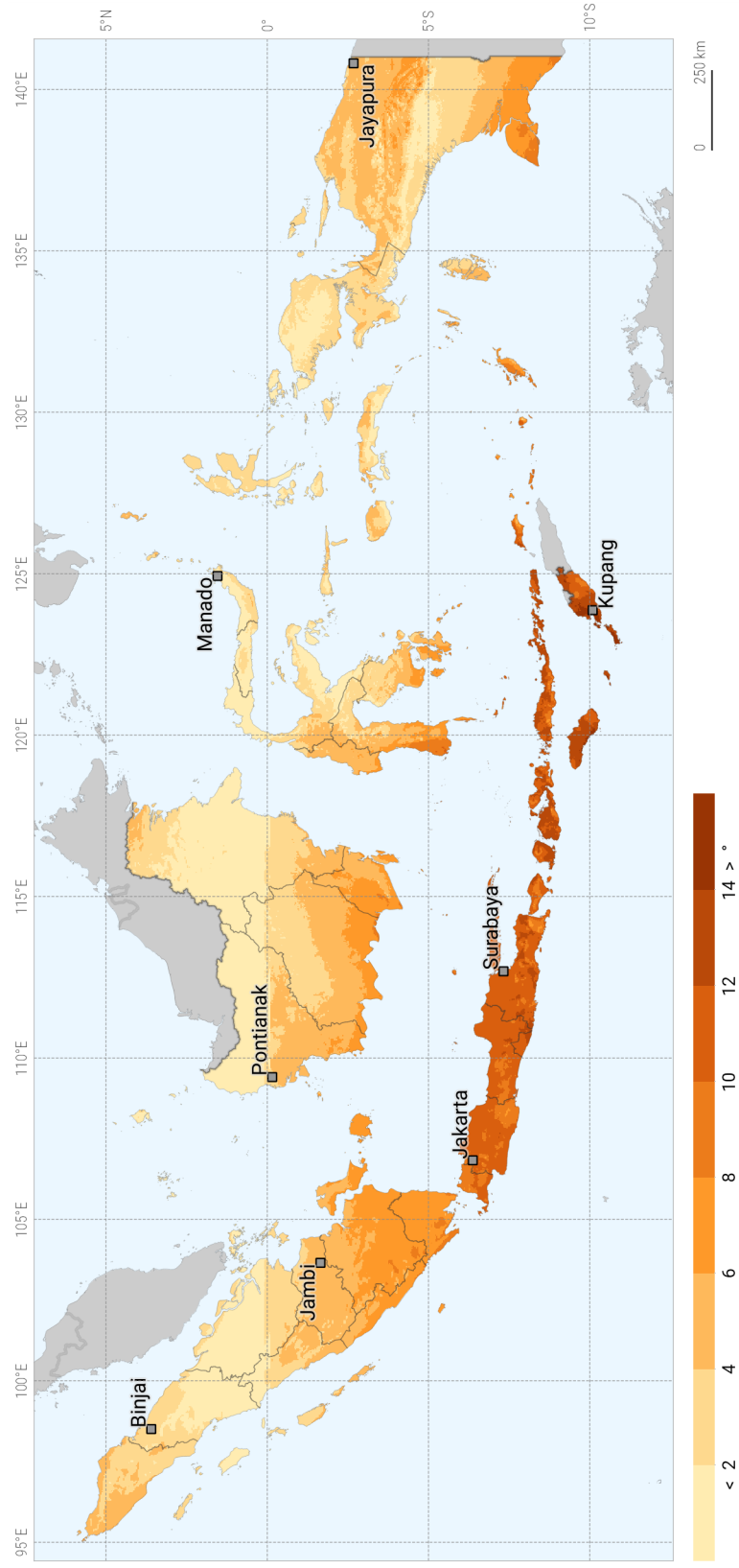


Figure 3.6: Daily totals of GHI and DNI in Jakarta, year 2016
Source: Solargis

3.5 Global Tilted Irradiation



Map 3.16: Global Tilted Irradiation at optimum angle – long-term average of daily and yearly totals.
Source: Solargis



Map 3.17: Theoretical optimum tilt of PV modules to maximize yearly PV power production. Source: Solargis, in practical applications tilt higher than 10° is applied.

Global Tilted Irradiation (GTI) is the key source of energy for flat-plate photovoltaic (PV) technologies (Chapter 3.6). The regional trend of GTI received by PV modules tilted at optimum angle (GTI) is similar to DNI (Map 3.15). PV modules tilted at optimum inclination show daily totals of GTI at about 5.6 kWh/m^2 (annual totals about 2045 kWh/m^2) and higher, especially in the Eastern Java and the Lesser Sunda Islands.

In Indonesia, latitude spans between 6° North and 11° South (Map 3.17). For this region, theoretical optimum tilt is 0° to 4° on a northern hemisphere and 0° to 15° on a southern hemisphere (increasing with distance from the Equator). Table 3.5 shows long-term averages of daily total of Global Tilted Irradiation (GTI) for selected sites. It is assumed that solar radiation is received by PV modules surface inclined at the optimum tilt.

Sites close to equator do not benefit much from optimal tilt as is visible on Figure 3.8. Jambi, Pontianak and Jayapura will gain in period from April to September up to 3.2%, but in season from October to March will lose up to 2.5%, thus annual GTI gain is close to 0%. Only Kupang and Surabaya can slightly benefit from installations at optimum tilt and are able to reach annual gains in GTI up to 2.8% and 1.9% respectively.

Generally, the main parameter influencing optimum tilt is latitude. With increasing latitude, surface inclined at optimum tilt gains more yearly global irradiation compared to the horizontal surface. As presented in Chapter 2.3, it is recommended to install PV modules at a tilt (inclination angle) close to optimum. However, for sites near equator, optimum angle is very low (or equal to 0°) and azimuth of installation is not important. In this case, it is not recommended to keep the tilt of PV modules close to the horizontal position as this prevents natural self-cleaning of PV modules by rain.

The PV modules installed at very low tilt will collect dirt and dust, which will result in reduction of the PV power output. In this report, optimum angles for selected sites are calculated, and GTI and PVOUT for optimum angles are delivered. However, for real projects, **it is a good practice to install modules at tilt of 10° or higher** for improved self-cleaning by rain. The difference between GTI for tilt 10° and lower is negligible.

Table 3.5: Daily averages and average minima and maxima of Global Tilted Irradiation at 8 sites

Month	Global Tilted Irradiation [kWh/m^2]																Variability between sites [%]
	Binjai		Jambi		Jakarta		Pontianak		Surabaya		Kupang		Manado		Jayapura		
	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	
January	**4.29**	3.86 4.65	**3.94**	3.53 4.46	**3.77**	3.18 4.76	**4.41**	3.87 5.28	**4.50**	3.90 5.20	**4.73**	3.74 5.93	**4.32**	3.90 4.83	**4.61**	3.89 5.47	**8.4**
February	**4.73**	4.16 5.36	**4.40**	4.01 4.72	**3.80**	2.91 4.55	**4.77**	3.90 5.30	**4.57**	3.90 5.22	**5.22**	4.09 6.08	**4.86**	4.41 5.71	**4.95**	4.18 5.42	**10.2**
March	**5.31**	4.46 5.75	**4.78**	4.52 5.32	**4.70**	4.34 5.72	**4.98**	4.25 5.51	**4.95**	4.17 5.65	**5.64**	4.40 6.48	**5.32**	4.11 6.11	**4.66**	3.87 5.84	**7.0**
April	**4.96**	4.50 5.28	**4.66**	4.03 5.02	**4.86**	4.51 5.43	**5.04**	4.77 5.32	**5.02**	4.49 5.50	**6.34**	5.34 6.96	**5.14**	4.20 6.13	**5.11**	4.64 5.58	**11.7**
May	**4.82**	4.13 5.26	**4.64**	4.26 4.91	**4.91**	4.29 5.59	**5.03**	4.84 5.44	**5.29**	4.22 6.20	**5.97**	5.09 6.62	**4.82**	4.39 5.51	**4.81**	4.44 5.08	**9.3**
June	**4.76**	4.25 5.17	**4.58**	4.16 5.20	**4.80**	4.09 5.37	**4.98**	4.72 5.24	**5.45**	4.08 6.12	**5.93**	5.11 6.53	**4.57**	3.88 4.99	**4.56**	4.13 5.28	**10.0**
July	**4.69**	4.12 5.13	**4.55**	4.04 5.05	**5.07**	3.82 5.83	**5.05**	4.58 5.52	**5.94**	5.07 6.52	**6.20**	5.42 6.63	**4.86**	4.25 6.02	**4.48**	3.93 5.30	**12.8**
August	**4.73**	4.15 5.25	**4.68**	4.10 5.03	**5.52**	4.73 5.91	**4.99**	4.49 5.30	**6.59**	5.80 6.98	**6.83**	6.32 7.23	**5.41**	4.84 6.53	**5.00**	4.38 5.82	**17.0**
September	**4.82**	4.39 5.56	**4.75**	3.73 5.33	**5.68**	4.44 6.39	**4.98**	4.39 5.43	**6.82**	4.97 7.35	**7.08**	6.03 7.68	**5.69**	4.99 6.86	**4.95**	4.46 5.47	**18.2**
October	**4.54**	4.07 5.04	**4.31**	2.56 4.71	**5.12**	4.08 6.05	**4.51**	4.15 4.82	**6.33**	4.80 7.19	**6.90**	6.00 7.58	**5.46**	4.80 6.57	**5.21**	4.48 5.80	**20.4**
November	**4.27**	3.75 4.59	**4.20**	3.85 4.46	**4.45**	4.04 4.95	**4.20**	3.41 4.54	**5.04**	4.29 6.09	**6.08**	5.28 6.63	**4.69**	4.25 4.98	**4.90**	4.33 5.57	**15.8**
December	**3.93**	3.42 4.42	**3.90**	3.55 4.22	**3.97**	3.28 4.33	**4.11**	3.68 4.81	**4.13**	3.65 4.93	**4.69**	3.93 5.14	**4.56**	4.17 5.06	**4.76**	4.35 5.37	**7.1**
YEAR	**4.65**	**4.54** **4.75**	**4.45**	**4.28** **4.56**	**4.73**	**4.43** **5.09**	**4.75**	**4.62** **4.87**	**5.39**	**4.88** **5.84**	**5.97**	**5.62** **6.29**	**4.97**	**4.65** **5.60**	**4.83**	**4.57** **5.14**	**11.5**

Figure 3.7 compares long-term daily averages in selected sites. Similar to GHI, high and variable values are observed in period from August to November, while lower and more stable values occur in season from May to July and December to January. Detailed comparison of daily GTI and GHI values for Jakarta is shown in Table 3.6 and Figure 3.9.

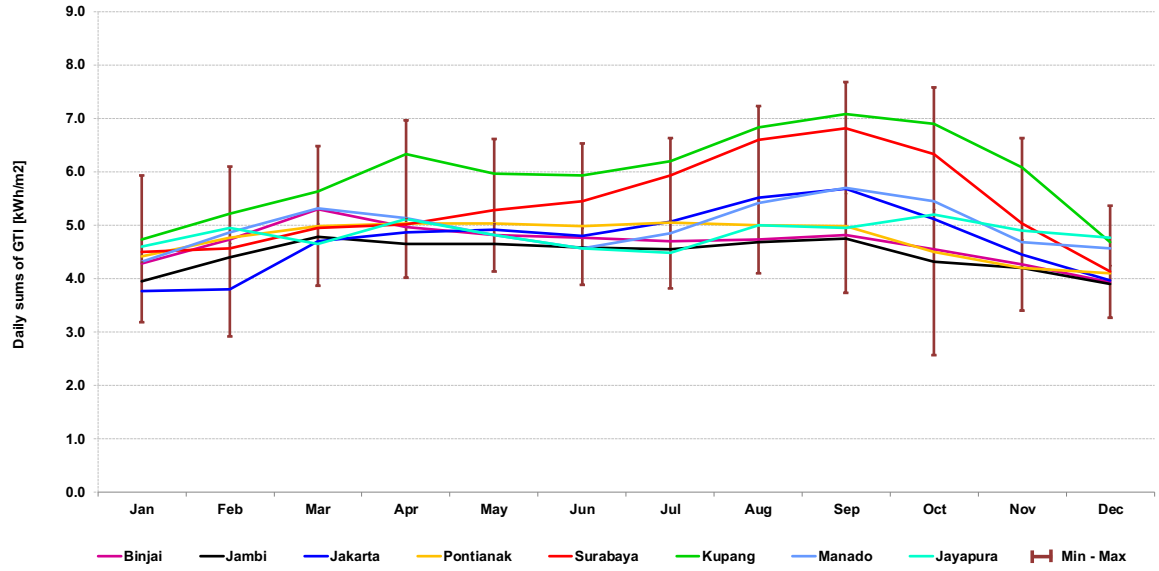


Figure 3.7: Global Tilted Irradiation – long term daily averages, minima and maxima.

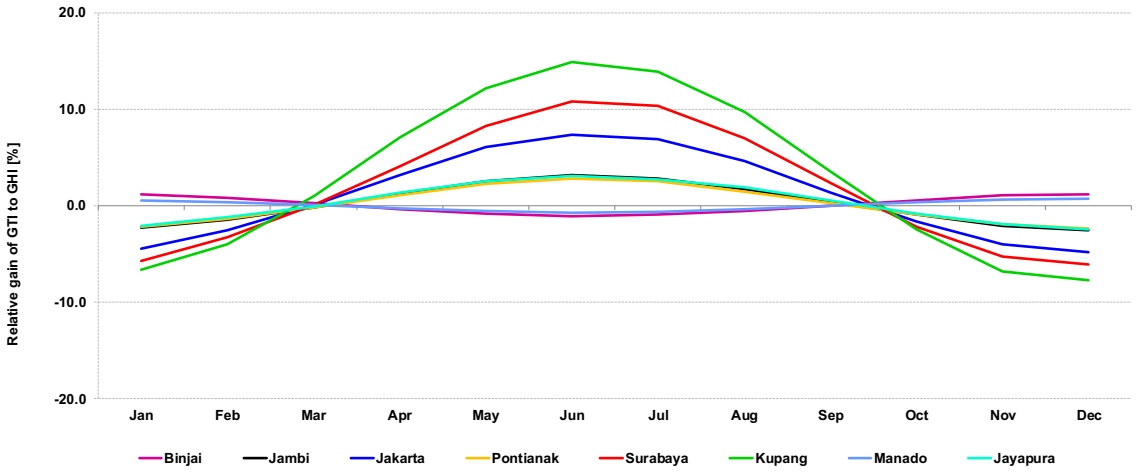


Figure 3.8: Monthly relative gain of GTI relative to GHI at selected sites.

Table 3.6: Relative gain of daily GTI (optimum tilt of PV modules 10°) to GHI in Jakarta

Jakarta	Average daily sum of irradiation [kWh/m^2]												Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Global Horizontal	3.94	3.90	4.69	4.71	4.63	4.47	4.74	5.28	5.60	5.21	4.63	4.17	4.67
Global Tilted	3.77	3.80	4.70	4.86	4.91	4.80	5.07	5.52	5.68	5.12	4.45	3.97	4.73
Global Tilted vs. Horizontal [%]	**-4**	**-3**	**0**	**3**	**6**	**7**	**7**	**5**	**1**	**-2**	**-4**	**-5**	**1**

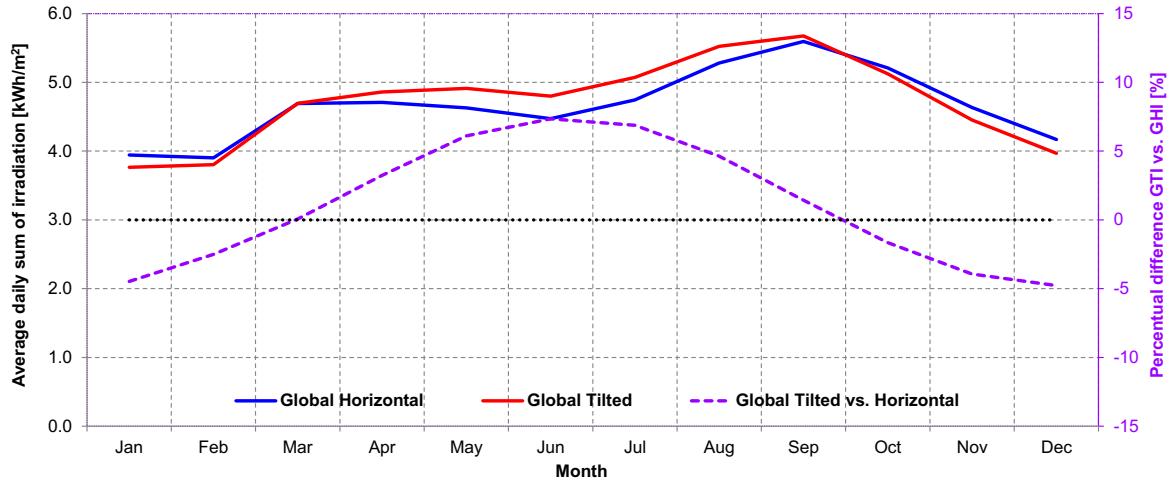


Figure 3.9: GHI and GTI monthly averages and relative gain of GTI to GHI in Jakarta
Optimum tilt of PV modules 10°

Daily totals, in one single year, are shown for better visual presentation of potential gain of solar electricity for tilted PV modules in comparison to horizontally-mounted. Figure 3.10 shows daily sums for year 2016 in Jakarta Blue pattern, representing GHI totals, is transparent to make visible lower values of red, GTI pattern, during the monsoon season. The GTI gains are visible in dry season, while in monsoon season the horizontally-mounted PV modules gain more energy (blue GHI pattern over red GTI).

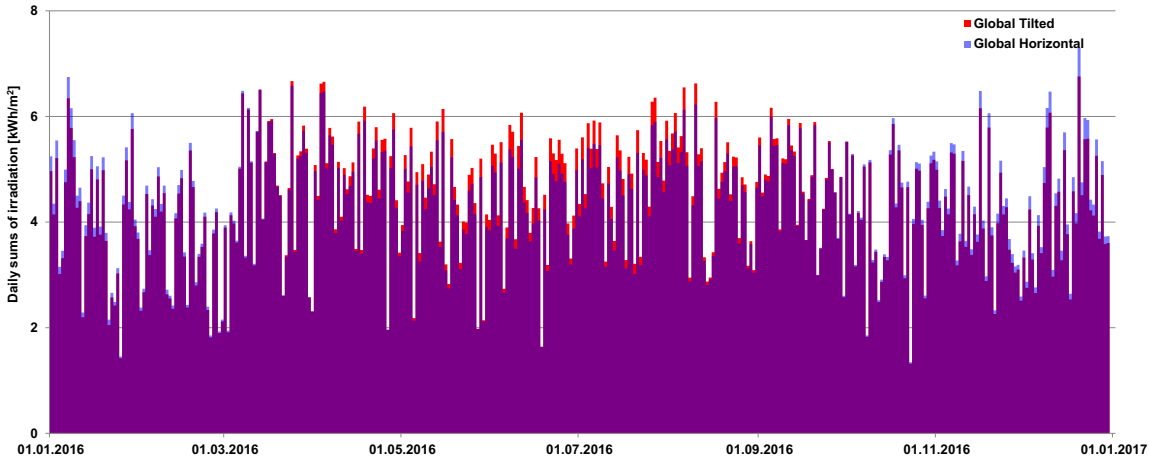
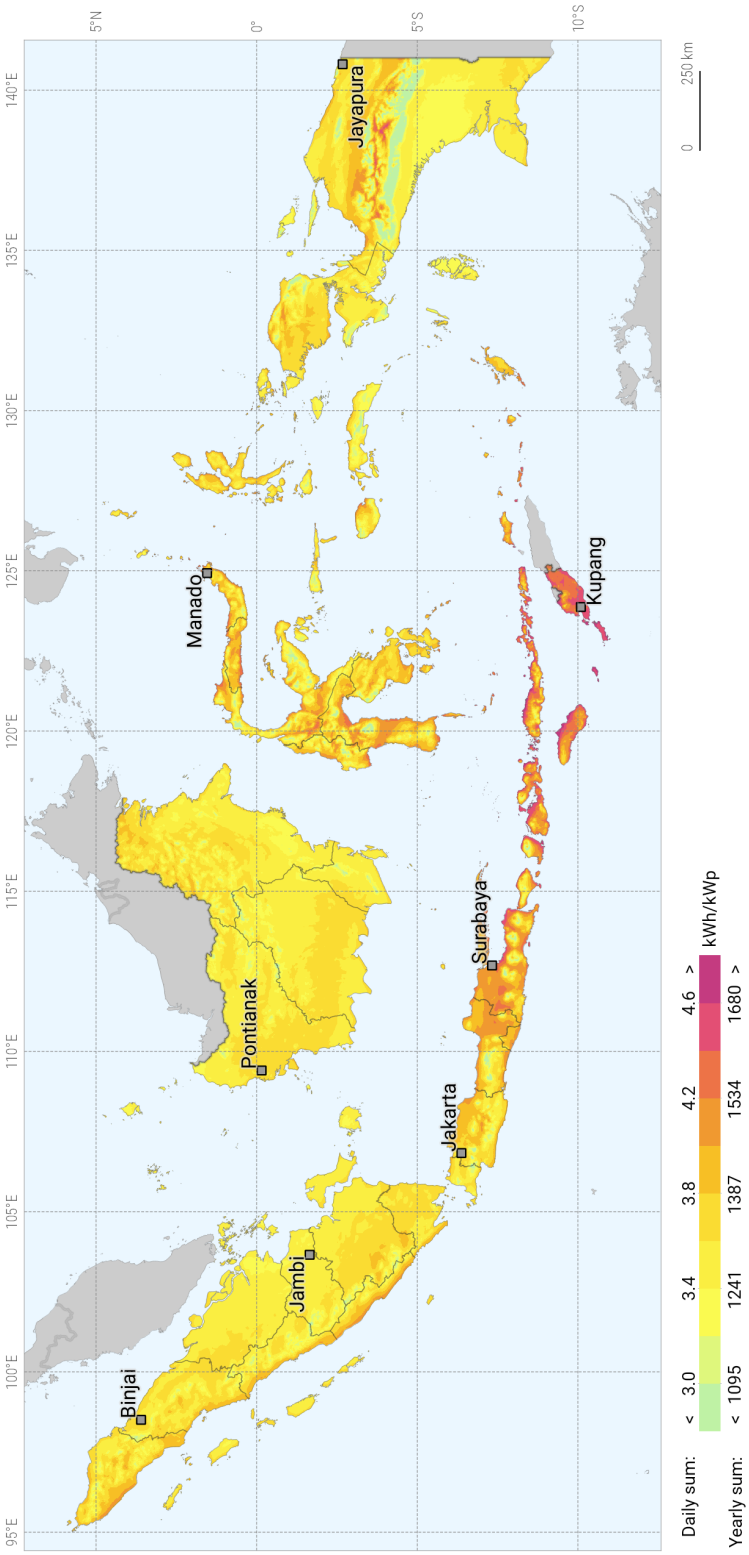
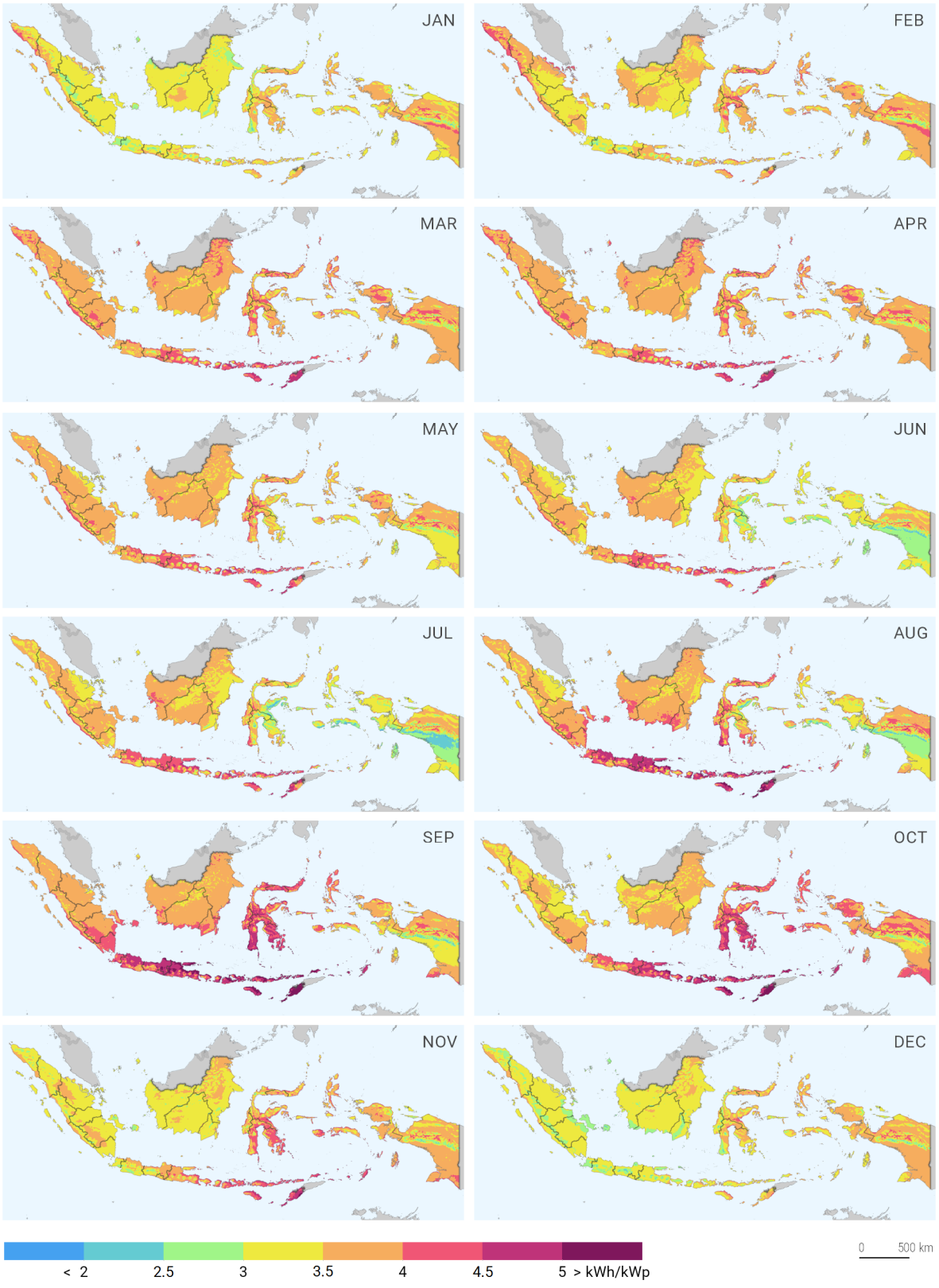


Figure 3.10: Daily values of GHI and GTI for Jakarta, year 2016
Optimum tilt of PV modules 10°

3.6 Photovoltaic power potential



Map 3.18: PV electricity output from an open space fixed-mounted PV system with PV modules mounted at an optimum tilt and a nominal peak power of 1 kWp. Long-term averages of daily and yearly totals.



Map 3.19: PV power generation potential for an open-space fixed-mounted PV system.
Long-term monthly averages of daily totals. PV modules mounted at optimum tilt. Source: Solargis

Map 3.18 shows the average daily totals of specific PV electricity output from a typical open-space PV system with a nominal peak power of 1 kW; the unit is kWh/kWp. Calculating PV output for 1 kWp of installed power makes it simple to scale the PV power production depending on the size of a power plant. Besides the technology choice, the electricity production depends on a geographical position of the power plant.

In Indonesia, the average daily total of specific PV power production from a reference system (Table 2.16) varies between 3.0 kWh/kWp (equals to average annual total of about 1100 kWh/kWp) in high and cloudy mountains, and 4.6 kWh/kWp (about 1680 kWh/kWp yearly) with the highest values see in southern islands of the archipelago. In the mountains, the power production can be reduced by up to 20% (or even more) due to terrain shading. Areas with high PV electricity production potential were previously identified also as areas with high GTI and DNI and lower DIF values.

Electricity production in a potential PV power plant depends on the site position and follows a combined pattern of global tilted irradiation and air temperature. High PV power production is identified at Kupang and Surabaya sites; lower potential is in Jambi and Binjai. Considering 8 selected sites (Tab. 3.7), the lowest specific PV production is seen in Jambi, which may be result of microclimatic conditions with highest annual DIF/GHI ratio (there are more clouds and aerosols in this site). The difference in PV power production between the selected sites with highest (Kupang, 4.47 kWh/kWp) and lowest (Jambi, 3.41 kWh/kWp) PV power production is about 24%.

Map 3.19 shows monthly production from a PV power system, and Figure 3.11 breaks down the values for eight sites. The season of relatively high PV yield is long enough for an effective operation of a PV system. As shown in Chapter 3.5, for sites Kupang and Surabaya it was recommended to install modules at an optimum tilt rather than at horizontal orientation. Besides higher yield, a benefit of tilted modules is improved self-cleaning of the surface pollution by rain. For other sites, it may be feasible to install modules in tilt at least at 10° for improved self-cleaning, because losses in soiled modules can be higher than losses due to suboptimal position to the sun.

Table 3.7: Annual performance parameters of a PV system with modules fixed at optimum angle

	Binjai	Jambi	Jakarta	Pontianak	Surabaya	Kupang	Manado	Jayapura
PVOUT Average daily total [kWh/kWp]	3.52	3.41	3.58	3.62	4.05	4.47	3.80	3.69
PVOUT Yearly total [kWh/kWp]	1287	1246	1309	1323	1480	1633	1389	1348
Optimum angle	2°	5°	10°	4°	12°	14°	1°	4°
PV system azimuth	180°	0°	0°	0°	0°	0°	180°	0°
Annual ratio of DIF/GHI	56.7%	61.8%	57.2%	53.8%	45.0%	33.9%	46.1%	50.3%
System PR	75.7%	76.7%	75.9%	76.2%	75.1%	74.9%	76.4%	76.4%

PVOUT - PV electricity yield for fixed-mounted modules at optimum angle; DIF/GHI – Ratio of diffuse/global horizontal irradiation; PR - Performance ratio for fixed-mounted PV

This shows potential in Indonesia for PV electricity generation. Southern parts of the archipelago (with highest PV electricity production potential), with existing medium voltage distribution lines, are best-suitable for development of medium- to large-scale grid connected PV power projects. During the day time, the newly-developed systems will improve electricity balance in the distribution grid and will help to reduce oil in the primary energy mix [47]. On the opposite side, remote areas without grid availability can benefit from developing the local micro-grids or small solar systems, as a good option for local electrification [26]. Northern parts of archipelago see higher DIF/GHI ratio, but these parts of country still have very good potential for PV electricity generation projects (see Jambi or Binjai in Table 3.8).

Monthly power production profiles have similar shape for sites Kupang, Surabaya, Jakarta and Manado. High production can be reached in dry season (from August to November), while rainy season from December to February reduces electricity gains. Different climatic conditions in sites Binjai, Jambi, Pontianak and Jayapura determine more stable electricity production during the whole year, without typical seasonal patterns.

Table 3.8: Average daily sums of PV electricity output from an open-space fixed PV system with a nominal peak power of 1 kW [kWh/kWp]

Site	Average daily sum of electricity production [kWh/kWp]												Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Binjai	3.26	3.58	4.00	3.75	3.64	3.60	3.54	3.57	3.65	3.45	3.26	3.00	3.52
Jambi	3.04	3.38	3.67	3.57	3.56	3.51	3.50	3.58	3.62	3.30	3.23	3.00	3.41
Jakarta	2.85	2.89	3.57	3.69	3.74	3.66	3.87	4.19	4.27	3.86	3.37	3.02	3.58
Pontianak	3.38	3.63	3.79	3.83	3.82	3.80	3.85	3.80	3.79	3.43	3.21	3.14	3.62
Surabaya	3.41	3.47	3.74	3.79	4.00	4.13	4.49	4.94	5.05	4.68	3.76	3.12	4.05
Kupang	3.56	3.92	4.23	4.75	4.51	4.52	4.72	5.14	5.24	5.06	4.46	3.51	4.47
Manado	3.31	3.73	4.07	3.93	3.69	3.49	3.72	4.13	4.32	4.14	3.58	3.50	3.80
Jayapura	3.52	3.78	3.55	3.91	3.69	3.50	3.43	3.83	3.77	3.96	3.73	3.63	3.69

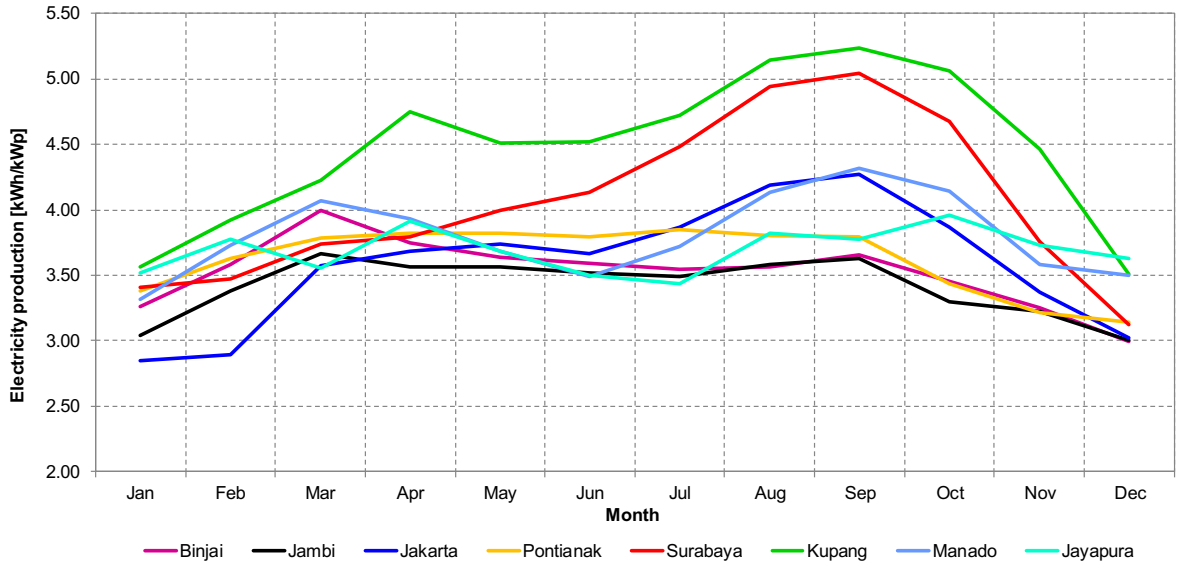


Figure 3.11: Monthly averages of daily totals of power production from the fixed tilted PV systems with a nominal peak power of 1 kW at eight sites [kWh/kWp]

Table 3.9 and Figure 3.12 show monthly and yearly performance ratios (PR) for a reference installation at the selected sites. The yearly PR is found in a range between 74.9% (Kupang) and 76.7% (Jambi). Jambi is the site with lowest solar radiation (GHI and DNI), yet a PV system would work there with best performance ratio, compared to the other selected sites; this is due to low air temperature. Monthly variations in PR fall in the range ±0.3% (Jayapura, Pontianak and Jambi) to ±1.4% (Kupang); depending on local climate conditions of a site, especially air temperature.

Table 3.9: Monthly and annual Performance Ratio of a free-standing PV system with fixed modules

Site	Monthly Performance Ratio [%]												Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Binjai	76.2	75.7	75.4	75.5	75.4	75.5	75.5	75.4	75.8	76.0	76.3	76.3	75.7
Jambi	77.0	76.8	76.7	76.6	76.7	76.7	76.9	76.6	76.4	76.4	76.8	76.9	76.7
Jakarta	75.7	76.0	76.0	75.9	76.1	76.3	76.3	75.8	75.2	75.4	75.8	76.1	75.9
Pontianak	76.5	76.2	76.0	75.9	76.1	76.1	76.2	76.1	76.0	76.2	76.5	76.5	76.2
Surabaya	75.7	75.9	75.6	75.6	75.6	75.9	75.5	74.9	74.0	73.9	74.5	75.5	75.1
Kupang	75.3	75.2	74.9	74.9	75.6	76.3	76.1	75.2	74.0	73.4	73.4	74.9	74.9
Manado	76.8	76.7	76.5	76.5	76.4	76.5	76.6	76.3	75.9	75.9	76.4	76.7	76.4
Jayapura	76.4	76.3	76.3	76.5	76.6	76.7	76.7	76.5	76.2	76.1	76.2	76.3	76.4

Impact of air temperature on the performance of PV power plants is seen when comparing monthly temperature profiles in Figure 3.1 with monthly PR profiles in Figure 3.12. Almost all sites, except Surabaya and Kupang, have similar and stable pattern of performance ratio, not influenced by significant changes in air temperature. Sites Surabaya and Kupang with visible temperature peak in September, October and November, see visible PR drop in the same months.

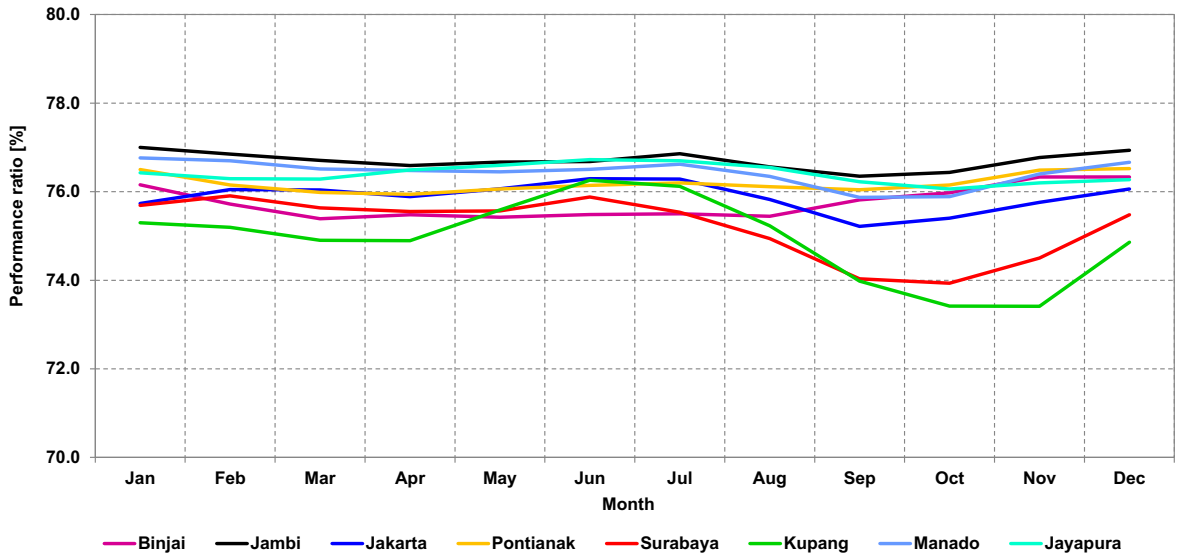


Figure 3.12: Monthly performance ratio of a PV system at selected sites.
Fixed mounted modules at optimum tilt are considered

3.7 Solar climate

The power production and performance efficiency of photovoltaic systems is primarily driven by **global horizontal irradiance**, GHI (Map 3.12). GHI determines absolute values of energy production of a PV system, and variability patterns of PV power production (interannual, seasonal, daily and very short-term variability). In general, the higher GHI, the higher PV energy is expected. Patterns of power generation are also determined by the ratio of diffuse to global radiation (Map 3.14). The simplified assumption about solar radiation is modulated by **air temperature**, TEMP (Map 3.11), as it affects operation efficiency of a PV system. In general, while high temperature reduces performance efficiency of a PV system, lower air temperature makes power conversion in the PV modules more efficient. In addition, high temperature areas represent regions where PV operates under higher stress.

For development of solar power systems, it is also important to consider **other geographical and meteorological factors**, e.g. terrain elevation, terrain shading, wind speed, rainfall, and land cover. These factors are also important for development and operation of solar power systems:

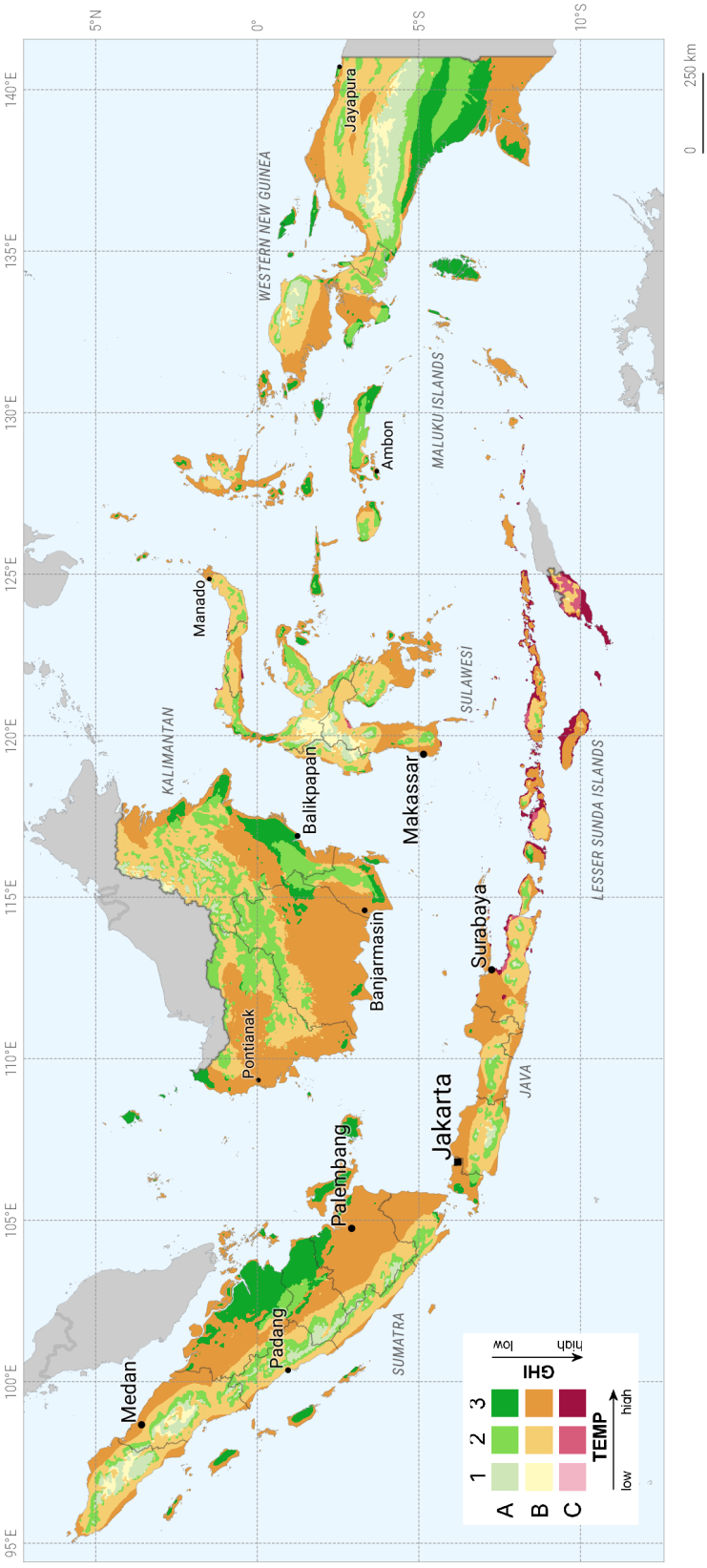
- **Terrain**: maps of elevation and slope inclination show limitations of installation and operating for the meteorological stations, but also for the PV power systems.

  Higher elevation above sea level (Map 3.2) in Indonesia relates to volcanos and high mountains with low population. Shading from high terrain blocks direct sunlight and it reduces power generation. Therefore, if possible a solar meteorological station and a PV system should be located in a place with no or limited shading.

  High slope inclination (Map 3.3) is challenging for logistics and operation, and indicates various geo-hazards in Indonesia, such as possible earthquakes, volcano eruptions, landslides, avalanches and floods.
- **Wind speed**: Low and medium speed wind, close to the ground, has a cooling effect on PV modules, which in turn increases their conversion efficiency and increases power production. However, occurrence of stronger winds poses a risk of damaging the modules and construction components. Wind speed map is not supplied in this report.
- **Rainfall** (Map 3.10): amount and periodicity of rainfall determine cleaning occurrence and intensity of surface of the PV modules. Lack of rainfall is not an issue in Indonesia.
- **Water bodies** (Map 3.6): in areas close to water bodies and the sea the PV power plants may be affected by microclimate features such as increased humidity, salinity or morning fog.
- **Industrial and highly urbanised areas** (Map 3.5 and 3.7): these areas typically correlate with higher air pollution that triggers higher intensity of soiling of PV modules. PV modules that are covered by dust or atmospheric pollution may show substantial reduction of power production and require more frequent cleaning of surface of the PV modules. The proximity of PV power plant to heavy industry or transport lines should be avoided.

Note: map of rainfall provides only indicative information at a regional level. It does not respect detailed and complex orography, and thus it does not represent the local climate.

Below, the geographical diversity of Indonesia is described by several climate zones relevant to PV power production. These climate zones are identified by combining maps of yearly GHI and TEMP (Tables 3.10 and 3.11).



Map 3.20: Solar climate zones of Indonesia – indicative classification based on a combination of GHI and TEMP. Source: Solargis

Table 3.10: Categories of long-term yearly average of global horizontal irradiation and their relative area

Category	Yearly average of daily global horizontal irradiation (GHI)		
A	Low	< 4.5 kWh/m^2	30.6%
B	Middle range	From 4.5 to 5.5 kWh/m^2	67.6%
C	High	> 5.5 kWh/m^2	1.7%

Table 3.11: Categories of long-term yearly average of air temperature and their relative area

Category	Yearly average of air temperature (TEMP)		
1	Low	< 20°C	7.6%
2	Middle range	From 20°C to < 25°C	42.2%
3	High	> 25°C	50.2%

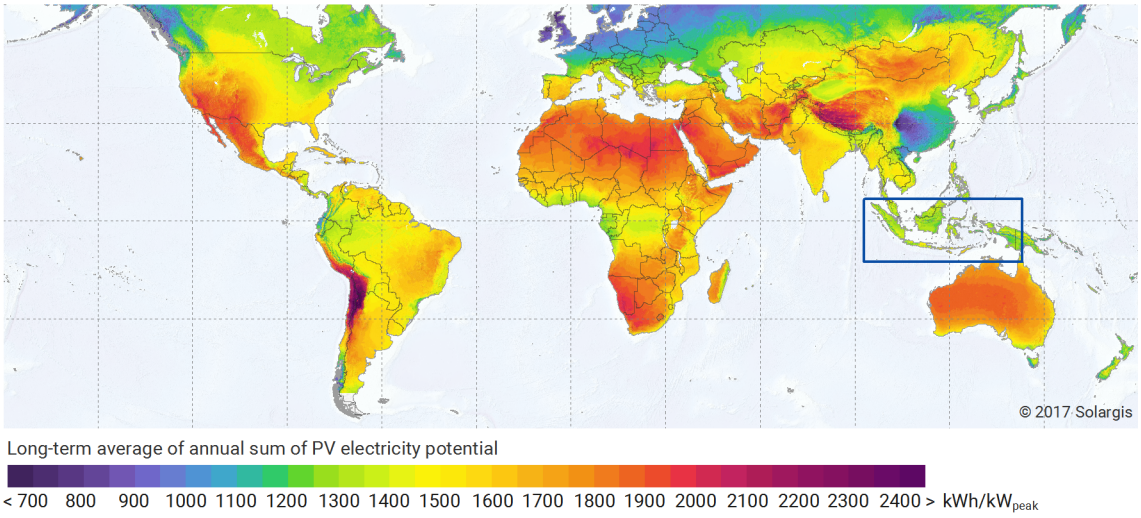
In this Chapter, we identified climate regions of Indonesia that may be relevant for taking decision from the perspective of solar power generation and performance efficiency of PV systems (Map 3.20, Tables 3.10 and 3.11, see also Maps 3.11 and 3.12). The zones are quite fragmented, which is given by geography of Indonesia:

- **Solar climate zone A** shows lower solar radiation areas (GHI long-term yearly average below 4.5 kWh/m^2 per day). This zone is spread in mostly unpopulated or very sparsely populated areas on the Sumatra, Sulawesi and Papua islands. It is mostly represented by *ridges and slopes of high mountains* with high occurrence of clouds and air temperature in the middle and lower range (A1 and A2). Occasionally, solar resource is reduced by terrain shading. This climate zone is dominating by forests. The challenge here is also accessibility.
- **Solar climate zone B** with GHI yearly average between 4.5 and 5.5 kWh/m^2 per day is prevailing in Indonesia. This region offers opportunities for installing large-scale PV power systems, where limitation factors are availability of land (in populated areas), terrain (high slope and volcanoes), accessibility (proximity to roads or airports) and the nature protected areas.
- **Solar climate zone C** is also widely spread in Indonesia and indicates areas with higher solar radiation (average above 5.5 kWh/m^2 per day). In Java and Southern islands the deployment of solar energy systems is favourable, as it coincides with the high population and high energy demand. Similar limitation factors apply as in zone B. Higher temperature slightly reduces performance of PV modules. The factor reducing efficiency of PV power systems in urban areas could be air pollution.

3.8 Evaluation

The Chapters above describe various aspects of PV power generation potential in Indonesia, and its relevance for development and operation of photovoltaic systems. Large parts of the country show daily specific PV electricity output in the range between 3.2 kWh/kWp and 4.2 kWh/kWp (equals to average yearly totals between approximately 1170 kWh/kWp and 1530 kWh/kWp). **Compared to other countries of the world, Indonesia has very favourable potential for PV power generation** (Map 3.21).

In addition, the seasonal variability in the country is very low, compared to other regions, further from the equator. The ratio between months with maximum and minimum GHI is about 1.43, compared to other examples, such as Upington, South Africa, it is 2.29 and in Sevilla, Spain, 3.54 (Figure 3.13).



Map 3.21: PV power potential of Indonesia in the global context.
Fixed mounted modules at optimum tilt are considered

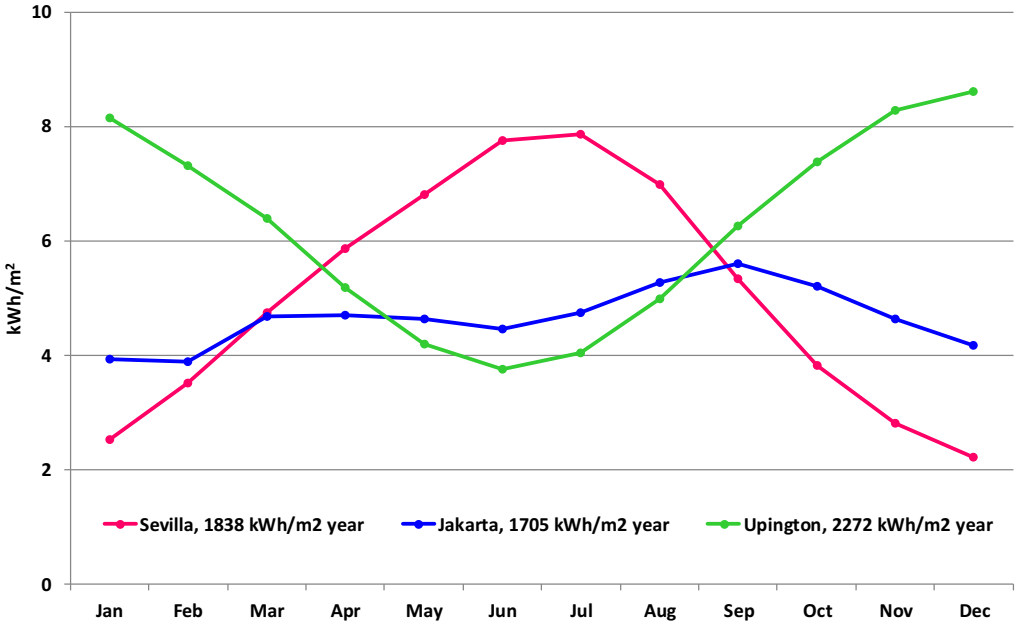


Figure 3.13: Comparing seasonal variability in three locations

Figure 3.14 demonstrates how PV power production depends on solar resource and air temperature in non-linear way. Even that the PV power production is feasible everywhere, for the case of large-scale PV power plants there might be some geographical preferences.

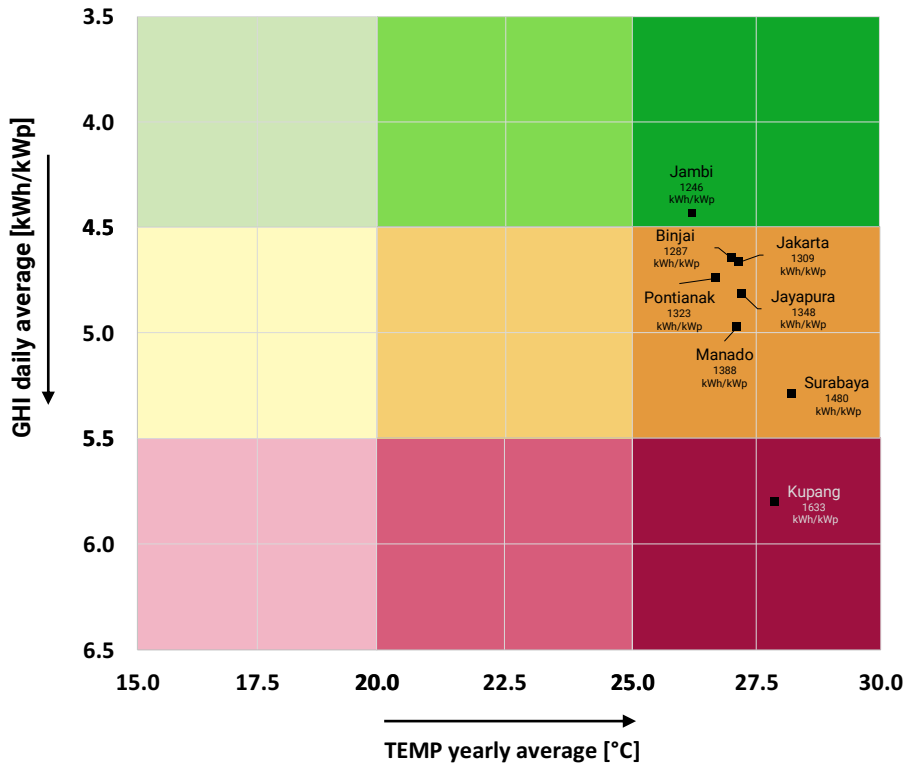


Figure 3.14: Comparing yearly GHI and TEMP with potential PV power output at selected sites

Indonesia has good potential for development of solar power generation, predominantly in southern part of the country. A lot of population in the country still lacks access to electricity. Medium or small installations are feasible in small and remote communities (off-grids, mini-grids) across the country.

Monsoon season has largest impact on decreasing the amount of solar radiation in Southern and coastal region from June to September. The microclimate factors should be considered as well for choosing a best site (see Chapter 3.7).

Based on the outcomes of this study, Table 3.12 provides indicative SWOT analysis relative to the exploitation of solar resources in Indonesia.

Table 3.12: SWOT analysis relative to the solar resource and photovoltaic potential in Indonesia

Strengths • Good solar resource and PV power potential • Existing and mature technology for off-grid and mini-grids systems for remote communities • Existing programs for PV installations [43]	**Weaknesses** • Islands or areas with small and isolated communities • Terrain constrains: terrain with high elevation, steep slope, shading, and limited accessibility • High costs of grid connection, long time of connection into HV lines for remote areas [44] • Air pollution in large urban areas
Opportunities • Growing demand for electricity • International support programs • Positive attitude to renewable energy • Reduced cost of PV • Combination with other renewable energy sources (mainly hydro) helps dealing with variability of solar resource • Potential synergy with gas-fired power plants	**Threats** • Geographical risks and extreme events: volcanic eruptions earthquakes, landslides, tsunamis, etc.) • Very short term variability of solar resource should be analyzed for effective PV integration (reduction of minute-scale ramps) • Volcanic eruptions

4 Priority areas for meteorological stations

4.1 Localisation criteria

Based on the analysis of maps presented in this report, and set of criteria, we identify areas proposed for prospective deployment of solar meteorological stations. Here we have in mind the need for the validation of the solar and meteorological models, and reduction of the solar resource data uncertainty for the need of effective development of large-scale photovoltaic power systems. The methodology includes two steps:

- Identification of solar climate regions in Indonesia, which may show some difference regarding the performance of large-scale photovoltaic power plants (Chapter 3.7),
- Identification of areas preferred for deployment of solar meteorological stations (Chapter 4.2).

4.2 Areas suitable for solar meteorological stations

Based on the analysis in Chapter 3.7, we propose location of solar measuring stations by excluding areas that are not suitable. One of requirements of the solar measurement campaign is to receive high quality, continuous data sets that can be used for *satellite data validation* and *regional adaptation of the solar model*.

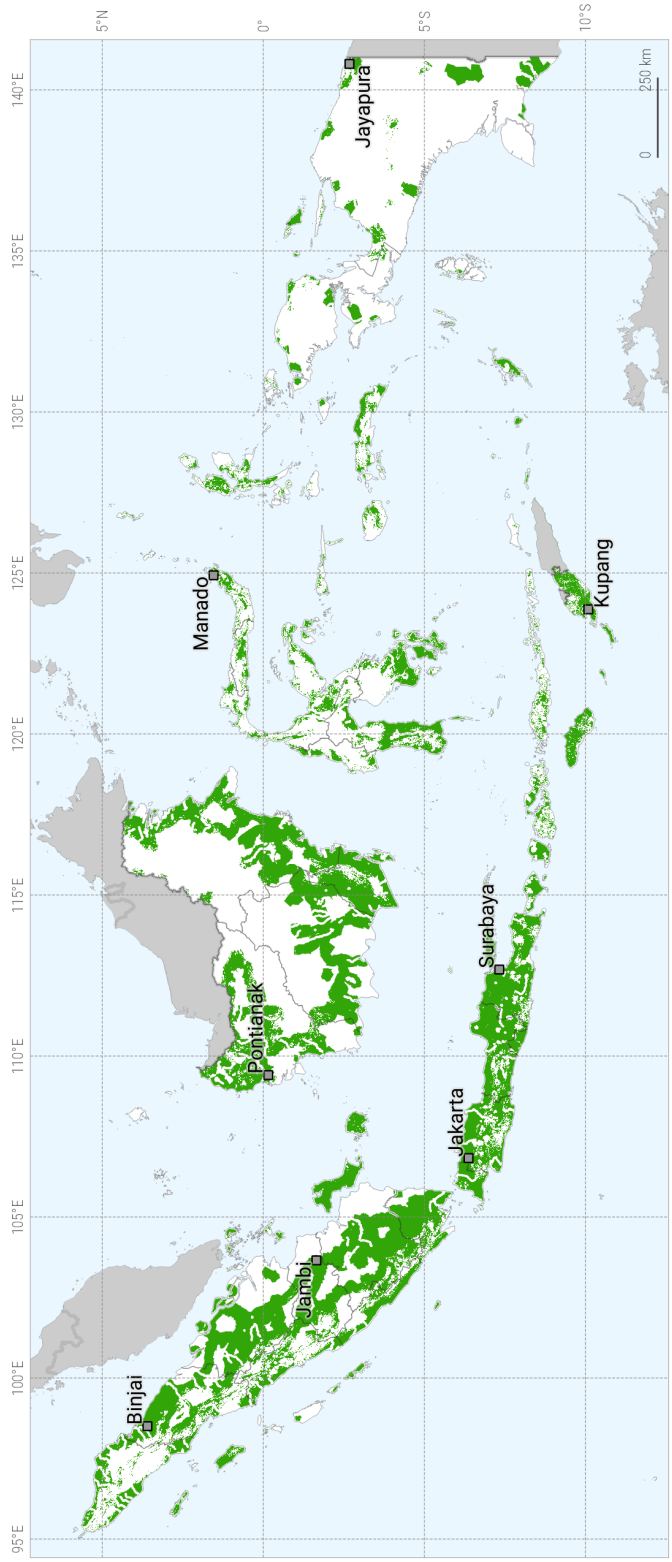
From the **regional perspective**, *suitable areas* for deployment of solar meteorological stations should be geographically representative, i.e. they should represent a wider territory, certain type of climate where solar resource, terrain, air temperature and land use are similar, and where they do not change abruptly. We also identify *exclusion areas*, where installation of stations is not recommended, for reasons such as fast changing terrain and landscape, in industrial zones, but also in remote and difficult-to-access areas.

From the **local perspective**, there are several additional localisation criteria for deployment of solar meteorological stations, such as accessibility, availability of personnel for maintenance and cleaning, security, sustainability of running the measurement campaign in a long term, acceptance/interest of the land owner, and other economical and logistical criteria.

This report focuses on the *regional selection criteria*. The local criteria are not considered in this report. Map 4.1 is based on the overlay of the following factors:

- Areas close to the transport means and populated areas are preferred, due to requirements for logistics, regular maintenance and likelihood that the meteo station will serve the data needs for local solar power plant. In the low populated zones, areas at a distance more than 5 km from the nearest main road are excluded.
- Areas in the distance closer than 3 km from the coast and water are excluded, due to higher uncertainty of solar model data and possible effect from nearby sea or lake.
- Areas with slope inclination higher than 10 degrees are excluded; these are areas with rapidly changing terrain and landscape and they are not suitable for localisation of solar meteorological stations (from the perspective of the model validation).
- Excluded are also areas with elevation higher than 3000 m.

Map 4.1 presents areas *excluded* (white colour on the map) and *prioritized* (green colour on the map) from the point of view of localisation of the solar measuring stations. Consulting also Map 3.20 and Figure 3.14, we propose that the meteorological stations are deployed in all three GHI zones: A, B and C (see Chapter 3.7).



Map 4.1: Preferred areas for deployment of solar meteorological stations (green colour)
Note: areas with high air pollution are not shown in this map

Quality and reliability of the measuring campaign is also of the highest importance. Besides choosing the high-accuracy sensors, implementation of the best measurement practices is necessary precondition for achieving reliable data sets required for calibration and validation of solar models. The meteorological instruments must

be regularly maintained, cleaned and calibrated. Measurement sites should be in the areas, which are not affected by excessive dust and pollution. Locally shaded areas, caused by surrounding buildings, structures and vegetation, should be also avoided. If shading takes place, the affected solar radiation values should be identified and flagged.

5 Solargis data delivery for Indonesia

The key features of the delivered data and maps for Indonesia are:

- Harmonized solar, meteorological and geographical data based on the best available methods and input data sources.
- Historical long-term averages representing 18/10 years at high spatial and temporal resolution, available for any location.
- The Solargis database and energy simulation software is extensively validated by company Solargis, and by independent organizations. They are also verified within monitoring of commercial PV power plants and solar measuring stations worldwide.
- Additional data can be accessed online at http://solargis.com.

The delivered data and maps offer a good basis for knowledge-based decision-making and project development. The Solargis data are updated in real time, and it can be further used in solar monitoring, performance assessment and forecasting.

5.1 Spatial data products

High-resolution Solargis data have been delivered in the format suitable for common GIS software. The *Primary data* represent solar radiation, meteorological data and PV power potential. The *Supporting data* include various vector data, such administrative divisions, etc.

Tables 5.1 and 5.2 show information about the data layers and the technical specification is summarized in Tables 5.3 and 5.4. File name convention, used for the individual data sets, is described in Table 5.5.

Table 5.1: General information about GIS data layers

Geographical extent	Federal Democratic Republic of Indonesia with buffer 20 km along the borders and the coast (approx. 3 180 000 km^2)
Map projection	Geographic (Latitude/Longitude), datum WGS84 (also known as *GCS_WGS84*; *EPSG: 4326*)
Data formats	ESRI ASCII raster (AAIGRID) data format (***asc***) GeoTIFF raster data format (***tif***)
Metadata	Each data layer is accompanied by metadata, provided in separate files according to ISO19139 standards in two formats: *PDF* - human readable; *XML* - for machine-to-machine communication

Notes:

- Data layers of both formats (*asc* and *tif*) contain the same information, the user is free to choose the preferential data format. Data layers can be also converted to other standard raster formats.
- More information about ESRI ASCII grid format can be found at http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/ESRI_ASCII_raster_format/009t0000000z000000/
- More information about GeoTIFF format can be found at https://trac.osgeo.org/geotiff/

Table 5.2: Description of primary GIS data layers

Acronym	Full name	Unit	Type of use	Type of data layers
GHI	Global Horizontal Irradiation	kWh/m^2	Reference information for the assessment of flat-plate PV (photovoltaic) and solar heating technologies (e.g. hot water)	Long-term yearly and monthly average of daily totals
DNI	Direct Normal Irradiation	kWh/m^2	Assessment of Concentrated PV (CPV) and Concentrated Solar Power (CSP) technologies, but also calculation of GTI for fixed mounting and sun-tracking flat plate PV	Long-term yearly and monthly average of daily totals
DIF	Diffuse Horizontal Irradiation	kWh/m^2	Complementary parameter to GHI and DNI	Long-term yearly and monthly average of daily totals
GTI	Global Irradiation at optimum tilt	kWh/m^2	Assessment of solar resource for PV technologies	Long-term yearly and monthly average of daily totals
OPTA	Optimum angle	°	Optimum tilt to maximize yearly PV production	-
PVOUT	Photovoltaic power potential	kWh/kWp	Assessment of power production potential for a PV power plant with free-standing fixed-mounted c-Si modules, mounted at optimum tilt to maximize yearly PV production	Long-term yearly and monthly average of daily totals
TEMP	Air Temperature at 2 m above ground level	°C	Defines operating environment of the solar power plants	Long-term (diurnal) annual and monthly averages

Table 5.3: Technical specification of primary GIS data layers

Acronym	Full name	Data format	Spatial resolution	Time representation	No. of data layers
GHI	Global horizontal irradiation	Raster	9 arc-sec. (approx. 275x275 m)	1999 (2007) to 2016	12+1
DNI	Direct normal irradiation	Raster	9 arc-sec. (approx. 275x275 m)	1999 (2007) to 2016	12+1
DIF	Diffuse horizontal irradiation	Raster	9 arc-sec. (approx. 275x275 m)	1999 (2007) to 2016	12+1
GTI	Global irradiation at optimum tilt	Raster	9 arc-sec. (approx. 275x275 m)	1999 (2007) to 2016	12+1
OPTA	Optimum angle (tilt) of PV modules	Raster	2 arc-min (approx. 3700x3700 m)	-	1
PVOUT	Photovoltaic power potential	Raster	9 arc-sec. (approx. 275x275 m)	1999 (2007) to 2016	12+1
TEMP	Air temperature at 2 m above ground level	Raster	30 arc-sec. (approx. 925x925 m)	1999 (2007) to 2016	12+1

Table 5.4: Characteristics of the raster output data files

Characteristics	Range of values
West – East	94:00:00E – 142:00:00E
North – South	7:00:00N – 12:00:00S
Resolution (GHI, DNI, GTI, DIF, PVOUT)	00:00:09 (19200 columns x 7600 rows)
Resolution (TEMP)	00:00:30 (5760 columns x 2280 rows)
Resolution (OPTA)	00:02 (1440 columns x 570 rows)
Data type	Float (OPTA as Integer)
No data value	-9999, NaN

Data layers are provided as separate files in a tree structure, organized according to

- File format: ESRI ASCII grid (AAIGRID) and GEOTIFF
- Time summarization: *yearly* and *monthly*

Complementary files:

- Project files (*.prj) complement ESRI ASCII grid files (*.asc)

The support GIS data are provided in a vector format (ESRI shapefile, Table 5.5).

Filename convention of data layers

The filename consits of:

- Parameter acronym (*GHI, DNI, etc*)
- Filenames with no number represent yearly data.
- Filenames with numbers represent monthly data, where January = 01, …, December = 12
- File extension (*asc, prj, tif, xml, pdf*)

Examples of filenames:

- GHI.asc: ESRI ASCII grid of long-term average of annual sum of GHI
- GHI.prj: projection metadata file for GHI.asc data layer
- GHI.asc.xml: metadata for ASC file in XML format
- GHI.asc.pdf: metadata for ASC file in PDF format (human readable and printable)
- GHI_01.asc: ESRI ASCII grid of long-term average of monthly sum (January) GHI
- GHI_01.prj: projection metadata file for GHI_01.asc data layer
- GHI_01.asc.xml: metadata in XML format
- GHI_01.asc.pdf: metadata in PDF format (human readable and printable)
- GHI.tif: GEOTIF file containing data of long-term average of annual sum of GHI
- GHI.tif.xml: metadata for GEOTIFF file in XML format
- GHI.tif.pdf: metadata for GEOTIFF file in PDF format (human readable and printable)

Approximate size of provided data

- AAIGRID files uncompressed: **52 GB**
- GeoTIFF files (LZW compression): **5.8 GB**
- Complete compressed archive (ZIP): **6.9 GB**

Table 5.5: Support GIS data

Data type	Source	Data format
Cities	OpenStreetMap.org contributors, GeoNames.org, adapted by Solargis	Point shapefile
Administrative boundaries	Cartography Unit, GSDPM, World Bank Group	Polyline shapefile
Roads	OpenStreetMap.org contributors	Polyline shapefile
Water bodies	OpenStreetMap.org contributors	Polygon shapefile

5.2 Project in QGIS format

For easy manipulation with the GIS data files, selected vector and raster data files are integrated into ready-to-open QGIS project file with colour schemes and annotation (see Figure 5.1). QGIS is state-of-art open-source GIS software allowing visualization, query and analysis on the provided data. QGIS includes a rich toolbox to manipulate with data. More information about the software and download packages can be found at http://qgis.org.

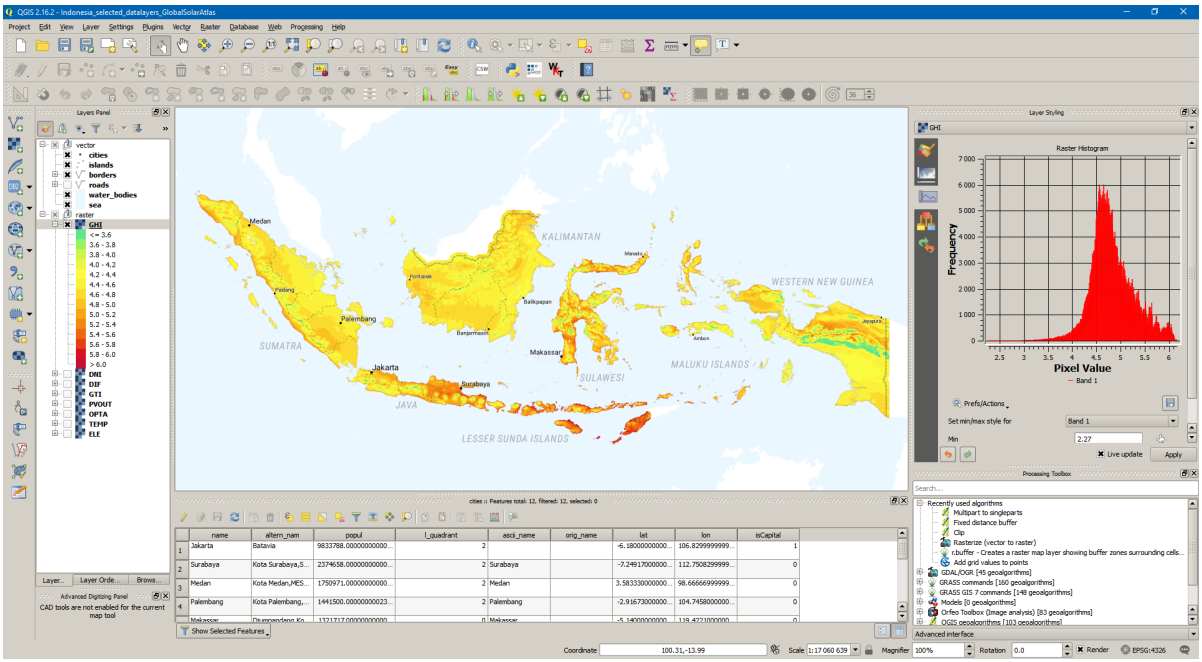


Figure 5.1: Screenshot of the map and data in the QGIS software

5.3 Digital maps

Besides the GIS data layers, digital maps are also delivered for selected data layers for presentation purposes. Digital maps are prepared in three types; each suitable for different purpose:

- High-resolution poster maps
- Medium-resolution maps for presentations

Digital images for high-resolution poster printing (size 120 x 80 cm). The colour-coded maps are prepared in a TIFF format at 300 dpi density and lossless compression.

Following three map files are delivered for high-resolution poster printing:

- Global Horizontal Irradiation – Yearly average of the daily totals
- Direct Normal Irradiation − Yearly average of the daily totals
- Photovoltaic electricity production from a free-standing power plant with optimally tilted c-Si modules − Yearly average of the daily totals

Digital images prepared in a resolution suitable for A4 printing or on-screen presentation. The colour-coded maps are prepared in PNG format at 300 dpi density and lossless compression.

Following map files are delivered:

- Long-term yearly average of Global Horizontal Irradiation
- Annual and monthly long-term averages of ratio Diffuse/Global Horizontal Irradiation
- Long-term yearly average of Global Tilted Irradiation (for optimum tilt)
- Long-term yearly average of Direct Normal Irradiation
- Long-term yearly average of Air Temperature
- Long-term yearly average of Photovoltaic (PV) Electricity Potential
- High resolution Terrain Elevation
- Indonesia in the world context of Global Horizontal Irradiation map

The maps also include visualization of the following layers:

- Main cities, location and names
- Administrative borders
- Water bodies

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PRESIDEN
REPUBLIK INDONESIA

PERATURAN PRESIDEN REPUBLIK INDONESIA
NOMOR 22 TAHUN 2017
TENTANG
RENCANA UMUM ENERGI NASIONAL

DENGAN RAHMAT TUHAN YANG MAHA ESA

PRESIDEN REPUBLIK INDONESIA,

Menimbang : a. bahwa dalam rangka pelaksanaan lebih lanjut Pasal 12 ayat (2) dan Pasal 17 ayat (1) Undang-Undang Nomor 30 Tahun 2007 tentang Energi, perlu ditetapkan Rencana Umum Energi Nasional;

b. bahwa berdasarkan Sidang Paripurna Dewan Energi Nasional ke 3 (tiga) tanggal 22 Juni 2016, telah disepakati Rancangan Rencana Umum Energi Nasional menjadi Rencana Umum Energi Nasional;

c. bahwa berdasarkan pertimbangan sebagaimana dimaksud dalam huruf a dan huruf b, perlu menetapkan Peraturan Presiden tentang Rencana Umum Energi Nasional;

Mengingat : 1. Pasal 4 ayat (1) Undang-Undang Dasar Negara Republik Indonesia Tahun 1945;

2. Undang-Undang Nomor 30 Tahun 2007 tentang Energi (Lembaran Negara Republik Indonesia Tahun 2007 Nomor 96, Tambahan Lembaran Negara Republik Indonesia Nomor 4746);

3. Peraturan Pemerintah Nomor 79 Tahun 2014 tentang Kebijakan Energi Nasional (Lembaran Negara Republik Indonesia Tahun 2014 Nomor 300, Tambahan Lembaran Negara Republik Indonesia Nomor 5609);

4. Peraturan ...

4. Peraturan Presiden Nomor 1 Tahun 2014 tentang Pedoman Penyusunan Rencana Umum Energi Nasional (Lembaran Negara Republik Indonesia Tahun 2014 Nomor 11);

MEMUTUSKAN:

Menetapkan : PERATURAN PRESIDEN TENTANG RENCANA UMUM ENERGI NASIONAL.

Pasal 1

Dalam Peraturan Presiden ini yang dimaksud dengan:

1. Rencana Umum Energi Nasional, yang selanjutnya disingkat RUEN adalah kebijakan Pemerintah Pusat mengenai rencana pengelolaan energi tingkat nasional yang merupakan penjabaran dan rencana pelaksanaan Kebijakan Energi Nasional yang bersifat lintas sektor untuk mencapai sasaran Kebijakan Energi Nasional.
2. Rencana Umum Energi Daerah Provinsi yang selanjutnya disingkat RUED-P adalah kebijakan pemerintah provinsi mengenai rencana pengelolaan energi tingkat provinsi yang merupakan penjabaran dan rencana pelaksanaan RUEN yang bersifat lintas sektor untuk mencapai sasaran RUEN.
3. Kebijakan Energi Nasional, yang selanjutnya disingkat KEN adalah kebijakan pengelolaan energi yang berdasarkan prinsip berkeadilan, berkelanjutan, dan berwawasan lingkungan guna terciptanya kemandirian energi dan ketahanan energi nasional.

4. Pemerintah Pusat adalah Presiden Republik Indonesia yang memegang kekuasaan pemerintahan negara Republik Indonesia yang dibantu oleh Wakil Presiden dan Menteri sebagaimana dimaksud dalam Undang-Undang Dasar Negara Republik Indonesia Tahun 1945.
5. Kementerian adalah kementerian negara yang menyelenggarakan urusan pemerintahan di bidang energi dan sumber daya mineral.
6. Pemerintah Daerah adalah kepala daerah sebagai unsur penyelenggara pemerintahan daerah yang memimpin pelaksanaan urusan pemerintahan yang menjadi kewenangan daerah otonom.
7. Dewan Energi Nasional adalah suatu lembaga bersifat nasional, mandiri, dan tetap, yang bertanggung jawab atas kebijakan energi nasional.

Pasal 2

(1) RUEN disusun oleh Pemerintah Pusat dan ditetapkan oleh Dewan Energi Nasional untuk jangka waktu sampai dengan tahun 2050 yang memuat:
   a. Pendahuluan;
   b. Kondisi Energi Nasional Saat Ini dan Ekspektasi Masa Mendatang;
   c. Visi, Misi, Tujuan dan Sasaran Energi Nasional;
   d. Kebijakan dan Strategi Pengelolaan Energi Nasional; dan
   e. Penutup.

(2) RUEN sebagaimana dimaksud pada ayat (1) tercantum dalam Lampiran I yang merupakan bagian tidak terpisahkan dari Peraturan Presiden ini.

(3) Penjabaran Kebijakan dan Strategi Pengelolaan Energi Nasional sebagaimana dimaksud pada ayat (1) huruf d diuraikan lebih lanjut dalam matrik program RUEN sebagaimana tercantum dalam Lampiran II yang merupakan bagian tidak terpisahkan dari Peraturan Presiden ini.

Pasal 3...

Pasal 3

(1) RUEN sebagaimana dimaksud dalam Pasal 2 berfungsi sebagai rujukan:
   a. penyusunan dokumen perencanaan pembangunan pusat dan perencanaan pembangunan daerah;
   b. penyusunan Rencana Umum Ketenagalistrikan Nasional (RUKN) dan Rencana Usaha Penyediaan Tenaga Listrik (RUPTL); dan
   c. penyusunan Anggaran Pendapatan dan Belanja Negara (APBN)/Anggaran Pendapatan dan Belanja Daerah (APBD) oleh kementerian negara/lembaga pemerintah non kementerian dan Pemerintah Daerah serta pelaksanaannya.

(2) RUEN sebagaimana dimaksud dalam Pasal 2 berfungsi sebagai pedoman bagi:
   a. kementerian negara/lembaga pemerintah non kementerian untuk menyusun dokumen rencana strategis;
   b. pemerintah provinsi untuk menyusun RUED-P;
   c. Kementerian dan Pemerintah Daerah untuk melaksanakan koordinasi perencanaan energi lintas sektor; dan
   d. masyarakat untuk berpartisipasi dalam pelaksanaan pembangunan nasional bidang energi.

Pasal 4

Dewan Energi Nasional bersama Kementerian melakukan :

a. sosialisasi RUEN kepada instansi terkait baik pusat maupun daerah dan pihak lain terkait; dan
b. pembinaan penyusunan rancangan RUED-P.

Pasal 5 ...

Pasal 5

(1) Dewan Energi Nasional melakukan pengawasan terhadap pelaksanaan RUEN dan kebijakan di bidang energi yang bersifat lintas sektoral.

(2) Pelaksanaan pengawasan sebagaimana dimaksud pada ayat (1) dilakukan secara terkoordinasi dengan instansi terkait baik pusat maupun daerah dan pihak lain terkait dengan tetap memperhatikan ketentuan peraturan perundang-undangan.

(3) Hasil pengawasan dibahas dalam Sidang Anggota Dewan Energi Nasional dan dilaporkan kepada Ketua Dewan Energi Nasional atau dapat dibahas dalam Sidang Paripurna Dewan Energi Nasional.

(4) Dewan Energi Nasional memantau tindak lanjut rekomendasi hasil pengawasan pelaksanaan KEN, RUEN dan kebijakan energi lintas sektoral.

Pasal 6

(1) RUEN dapat ditinjau kembali dan dimutakhirkan secara berkala setiap 5 (lima) tahun sekali atau sewaktu-waktu, dalam hal:
    a. KEN mengalami perubahan mendasar; dan/atau
    b. perubahan lingkungan strategis antara lain perubahan indikator perencanaan energi baik di tingkat nasional, regional maupun internasional.

(2) Rencana perubahan RUEN sebagaimana dimaksud pada ayat (1) diputuskan dalam Sidang Paripurna Dewan Energi Nasional.

Pasal 7

Peraturan Presiden ini mulai berlaku pada tanggal diundangkan.

Agar ...

Agar setiap orang mengetahuinya, memerintahkan pengundangan Peraturan Presiden ini dengan penempatannya dalam Lembaran Negara Republik Indonesia.

Ditetapkan di Jakarta
pada tanggal 2 Maret 2017

PRESIDEN REPUBLIK INDONESIA,

ttd.

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pada tanggal 13 Maret 2017
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Deputi Bidang Kemaritiman,

Satya Bhakti Parikesit

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LAMPIRAN I
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NOMOR 22 TAHUN 2017
TENTANG
RENCANA UMUM ENERGI NASIONAL

RENCANA UMUM ENERGI NASIONAL

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APBN	Anggaran Pendapatan dan Belanja Negara
BAU	Business as Usual Kondisi tanpa adanya perubahan signifikan dari perilaku, teknologi, ekonomi maupun kebijakan sehingga terjadi secara terus menerus tanpa adanya perubahan yang berarti
BBM	Bahan Bakar Minyak
BBN	Bahan Bakar Nabati
BOE	Barrel Oil Equivalent
BOPD	Barrel Oil Per Day
CBDR	Common but Differentiated Responsibilities Semua negara mempunyai tanggung jawab yang sama dalam melindungi lingkungan hidup serta mempromosikan pembangunan berkelanjutan, namun masing-masing negara harus membagi beban serta kewajiban yang berbeda-beda karena ada perbedaan sosial, ekonomi, kemajuan teknologi, dan kontribusi terkait kerusakan lingkungan hidup global
CBM	Coal Bed Methane Gas metana (gas alam) yang dihasilkan selama proses geokimia (pembatubaraan) dan terperangkap dalam batubara
CFL	Compact Fluorescent
CO_2	Karbon Dioksida
Coal Gasification	Konversi (gasifikasi) batubara menjadi gas hidrokarbon yang lebih bersih dan lebih mudah diangkut dan disalurkan

CPO	Crude Palm Oil Minyak kelapa sawit mentah yang berwarna kemerah-merahan yang diperoleh dari hasil ekstraksi atau dari proses pengempaan daging buah kelapa sawit
DME	Dimethyl Ether Senyawa eter yang dihasilkan dari berbagai sumber seperti gas alam, batubara, dan biomasa yang memiliki sifat dan jenis seperti layaknya LPG
EBT	Energi Baru dan Terbarukan
EOR	Enhanced Oil Recovery Metode untuk meningkatkan cadangan minyak pada suatu sumur dengan cara mengangkat volume minyak yang sebelumnya tidak dapat diproduksi
EPC	Engineering Procurement Construction
ESCO	Energy Service Company
ESDM	Energi dan Sumber Daya Mineral
FiT	Feed-in Tariff (FiT) patokan pembelian harga energi yang ditentukan berdasarkan komponen biaya produksi
GRK	Gas Rumah Kaca
GW	Gigawatt
GWh	Gigawatt-Hours
HOMC	High Octane Mogas Component Komponen bensin yang mempunyai angka oktana tinggi
IMB	Izin Mendirikan Bangunan
INDC	Intended Nationally Determined Contribution Kontribusi yang diniatkan dan ditetapkan secara nasional menargetkan pembangunan masa depan rendah karbon dengan fokus pada sektor pangan, energi, dan sumber daya air, serta memperhatikan karakter Indonesia sebagai negara kepulauan

KEN	Kebijakan Energi Nasional
KKKLL	Keselamatan, Kesehatan Kerja dan Lindungan Lingkungan
KKS	Kontrak Kerja Sama
kW	Kilowatt
kWh	Kilowatt hour
LED	Light-Emitting Diode
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LRT	Light Rail Transit Kereta api ringan
MBOPD	M Barrel Oil per Day (M merupakan huruf romawi yang berarti satuan ribu)
MEPS	Minimum Energy Peformance Standard
Migas	Minyak dan gas bumi
MOPS	Mean of Platts Singapore Acuan harga BBM di Indonesia berdasarkan Perpres 55/2005
MRT	Mass Rapid Transit Kereta api cepat terpadu
MTOE	Million Ton Oil Equivalen
MW	Megawatt
PDB	Produk Domestik Bruto
Petroleum Pra-Tersier	Salah satu riset dasar migas terhadap pembentukan cekungan dari jenis batuan tertentu dalam mendelineasi/ menggambarkan wilayah kerja baru migas
PLTA	Pembangkit Listrik Tenaga Air
PLTB	Pembangkit Listrik Tenaga Bayu
PLTD	Pembangkit Listrik Tenaga Diesel
PLTM	Pembangkit Listrik Tenaga Minihidro
PLTMH	Pembangkit Listrik Tenaga Mikrohidro

PLTP	Pembangkit Listrik Tenaga Panas Bumi
PLTS	Pembangkit Listrik Tenaga Surya
PLTU	Pembangkit Listrik Tenaga Uap
PLTU USP	Pembangkit Listrik Tenaga Uap Ultra Super Critical
PMK	Peraturan Menteri Keuangan
POD	Plan of Development
POME	Palm Oil Mill Effulent Limbah cair dari kelapa sawit yang berasal dari pemurnian minyak mentah yang dapat dimanfaatkan sebagai bahan bakar pembangkit listrik biogas
Possible Reserves	Cadangan tambahan yang telah dianalisa secara ilmu kebumian dan didukung dengan data teknik yang menunjukkan kecil kemungkinannya untuk dapat diperoleh dibandingkan Probable Reserves
Probable Reserves	Cadangan tambahan yang telah dianalisa secara ilmu kebumian dan didukung dengan data teknik yang menunjukkan kecenderungan untuk mendapatkan perolehan cadangan lebih kecil dari Proven Reserves tetapi lebih pasti dari Possible Reserves
Proven Reserves	Jumlah cadangan Migas yang terbukti, yang telah dianalisa baik secara ilmu kebumian dan didukung oleh data teknik, dapat diperkirakan dengan alasan yang pasti untuk diambil/diproduksi secara komersial, pada jangka waktu tertentu, dari reservoir yang diketahui dan di bawah definisi kondisi ekonomi, metode operasi, dan Peraturan Pemerintah
RDMP	Refinery Development Masterplan Program
RRR	Reserve Replacement Ratio Rasio penemuan cadangan terhadap jumlah produksi
RUED-K	Rencana Umum Energi Daerah-Kabupaten

RUED-P	Rencana Umum Energi Daerah-Provinsi
RUEN	Rencana Umum Energi Nasional
RUKN	Rencana Umum Ketenagalistrikan Nasional
SBM	Setara Barel Minyak
Synthetic Gas	Hasil gasifikasi batubara yang merupakan campuran gas karbon monoksida, hidrogen, metana, karbon dioksida, dan gas lainnya yang berfungsi sebagai bahan baku dari produk lainnya seperti bahan baku pembuatan methanol, pupuk urea, dan lain-lain
TCF	Trillion Cubic Feet
TSCF	Trillion Standard Cubic Feet
TOE	Ton Oil Equivalent
TWh	Terrawatt-Hours
WK	Wilayah Kerja
WP&B	Work Plan and Budget

I. PENDAHULUAN

Rencana Umum Energi Nasional (RUEN) merupakan amanat Undang-Undang (UU) Nomor 30 Tahun 2007 tentang Energi. Berdasarkan amanat Pasal 17 ayat (1) Undang-Undang tersebut, Pemerintah menyusun Rancangan RUEN berdasarkan Kebijakan Energi Nasional (KEN) dan Pasal 12 ayat (2) huruf b mengamanatkan Dewan Energi Nasional (DEN) bertugas menetapkan RUEN. Adapun KEN disusun oleh DEN dan telah ditetapkan melalui Peraturan Pemerintah (PP) Nomor 79 Tahun 2014 yang memuat antara lain:

1. Tujuan KEN yang merupakan pedoman untuk memberi arah pengelolaan energi nasional guna mewujudkan kemandirian energi dan ketahanan energi nasional untuk mendukung pembangunan nasional berkelanjutan.
2. Sasaran penyediaan dan pemanfaatan energi termasuk penyediaan pembangkit listrik dan pemanfaatan listrik per kapita.
3. Pencapaian sasaran KEN, antara lain terwujudnya paradigma baru bahwa sumber energi merupakan modal pembangunan nasional, dan tercapainya elastisitas energi, intensitas energi, rasio elektrifikasi, rasio penggunaan gas rumah tangga, dan bauran energi primer yang optimal.
4. Arah kebijakan energi nasional yang meliputi kebijakan utama dan kebijakan pendukung.

KEN menjadi dasar dalam penyusunan RUEN dan Rencana Umum Ketenagalistrikan Nasional (RUKN).

RUEN adalah kebijakan Pemerintah Pusat mengenai rencana pengelolaan energi tingkat nasional yang menjadi penjabaran dan rencana pelaksanaan KEN yang bersifat lintas sektor untuk mencapai sasaran KEN, yang berisi hasil pemodelan kebutuhan-pasokan (*demand-supply*) energi hingga tahun 2050, dan kebijakan serta strategi yang akan dilakukan untuk mencapai sasaran tersebut.

RUEN ...

RUEN merupakan pedoman untuk mengarahkan pengelolaan energi nasional guna mewujudkan kemandirian energi dan ketahanan energi nasional dalam mendukung pembangunan nasional berkelanjutan. RUEN juga menjadi acuan dalam penyusunan Rencana Umum Energi Daerah (RUED).

Arah kebijakan energi ke depan berpedoman pada paradigma bahwa sumber daya energi tidak lagi dijadikan sebagai komoditas ekspor semata, tetapi sebagai modal pembangunan nasional untuk tujuan mewujudkan kemandirian pengelolaan energi, menjamin ketersediaan energi dan terpenuhinya kebutuhan sumber energi dalam negeri, mengoptimalkan pengelolaan sumber daya energi secara terpadu dan berkelanjutan, meningkatkan efisiensi pemanfaatan energi, menjamin akses yang adil dan merata terhadap energi, pengembangan kemampuan teknologi, industri energi dan jasa energi dalam negeri, menciptakan lapangan kerja dan terkendalinya dampak perubahan iklim dan terjaganya fungsi lingkungan hidup.

Untuk mencapai tujuan tersebut, diperlukan berbagai terobosan sebagaimana tercantum dalam naskah ini dan Lampiran matriks antara lain percepatan pembangunan infrastruktur energi, peningkatan nilai tambah dalam negeri, pembangunan industri penunjang sektor energi, pengembangan EBT secara masif, peningkatan upaya konservasi energi serta peningkatan eksplorasi dan produksi minyak dan gas bumi.

RUEN terdiri dari 5 Bab dan Lampiran yang penyusunannya mengacu pada Peraturan Presiden Nomor 1 Tahun 2014 tentang Pedoman Penyusunan Rencana Umum Energi Nasional. Sistematika RUEN secara ringkas dapat dilihat pada Tabel 1.

Tabel 1 ...

Tabel 1. Sistematika RUEN

BAB	KETERANGAN	SUBSTANSI
Bab I	Pendahuluan	Latar Belakang
Bab II	Kondisi Energi Nasional Saat Ini dan Ekspektasi Masa Mendatang	• Isu dan permasalahan umum terkait energi Nasional • Kondisi ekonomi dan energi saat ini dan ke depan (indikator sosio-ekonomi, indikator energi, dan indikator lingkungan) • Hasil pemodelan kebutuhan dan pasokan energi, serta dampak emisi GRK tahun 2015-2050
Bab III	Visi, Misi, Tujuan dan Sasaran Energi Nasional	Menjabarkan Visi, Misi, Tujuan dan Sasaran yang terdapat dalam KEN
Bab IV	Kebijakan dan Strategi Pengelolaan Energi Nasional	• Kebijakan, strategi, program dan kegiatan unggulan untuk mencapai sasaran KEN (ringkasan dari Lampiran Matriks Program) • Rencana indikatif pengembangan energi per provinsi/wilayah
Bab V	Penutup	Kesimpulan
Lampiran	Matriks Program	• Rincian detail kebijakan, strategi, program dan kegiatan yang akan dilakukan berdasarkan PP No. 79/2014 tentang KEN • Mencantumkan Kementerian Negara/Lembaga yang bertanggung jawab dan instrumen kebijakan yang diperlukan.

II. KONDISI ...

II. KONDISI ENERGI NASIONAL SAAT INI DAN EKSPEKTASI MASA MENDATANG

Pada Bab II ini diuraikan tentang Isu dan Permasalahan Energi serta Kondisi Energi Nasional Saat Ini yang menjadi landasan untuk melakukan hasil pemodelan kebutuhan-pasokan energi sampai dengan 2050.

2.1. Isu dan Permasalahan Energi

Isu dan permasalahan energi saat ini dapat diuraikan sebagai berikut:

1. **Sumber Daya Energi Masih Diperlakukan Sebagai Komoditas yang Menjadi Sumber Devisa Negara, Belum Sebagai Modal Pembangunan**

   Sumber daya energi terutama gas dan batubara masih menjadi komoditas andalan untuk menopang devisa negara. Ekspor gas bumi masih dilakukan karena gas yang diproduksi telah didedikasikan untuk memenuhi kewajiban kontrak jangka panjang dan tidak mudah untuk dialihkan. Devisa dari ekspor gas, dengan harga jual sesuai harga pasar internasional, masih menjadi andalan bagi penerimaan negara. Di sisi lain, pemanfaatan gas bumi domestik belum optimal, karena terbatasnya infrastruktur gas dan penyerapan konsumsi gas dalam negeri yang rendah. Akibatnya penciptaan *multiplier effect* bagi ekonomi domestik, terutama pengembangan industri, penyerapan tenaga kerja, dan peningkatan nilai tambah belum maksimal.

   Demikian juga halnya dengan batubara, dari total produksi batubara nasional sebesar 461,6 juta ton pada tahun 2015, hanya 20,7% atau 95,8 juta ton yang dipasok ke pasar domestik, dimana sebagian besar dimanfaatkan oleh pembangkit listrik. Selebihnya, sekitar 79,3% produksi setara dengan 365,8 juta ton diekspor ke berbagai negara. Hal ini menjadikan Indonesia menjadi negara eksportir batubara terbesar di dunia, padahal cadangan batubara Indonesia hanya 3,1% dari cadangan

dunia ...

dunia (BP *Statistical Review of World Energy* 2014). Tingginya ekspor batubara mengindikasikan bahwa batubara masih menjadi sumber penghasil devisa. Untuk mencapai tujuan KEN, produksi batubara perlu dikendalikan, ekspornya dikurangi secara bertahap dan akan dihentikan serta pemanfaatan domestiknya ditingkatkan.

KEN menetapkan bahwa energi merupakan modal pembangunan nasional, bukan lagi sebagai penghasil devisa, namun peraturan perundang-undangan yang ada belum sepenuhnya mendukung kebijakan tersebut. Oleh karena itu, dalam RUEN ini dijabarkan berbagai program dan kegiatan untuk benar-benar mewujudkan energi sebagai modal pembangunan melalui prioritas alokasi energi sebagai bahan bakar pembangkit listrik dan sebagai bahan bakar/bahan baku industri yang mendukung peningkatan nilai tambah pembangunan nasional.

2. Penurunan Produksi dan Gejolak Harga Minyak dan Gas Bumi

Indonesia merupakan salah satu negara produsen minyak tertua di dunia dengan cadangan yang relatif kecil dibandingkan dengan kebutuhannya. Minyak bumi telah diproduksi lebih dari 100 tahun. Pada saat ini jumlah cadangan minyak terbukti sekitar 0,2% dari cadangan dunia, yaitu berada di kisaran 3,6 miliar barel. Sejak tahun 1995 produksi minyak bumi Indonesia terus mengalami penurunan dari 1,6 juta *barrel oil per day* (BOPD) menjadi hanya 786 ribu BOPD tahun 2015. Dalam 5 tahun terakhir, laju penemuan cadangan dibandingkan dengan tingkat produksi atau Rasio Pemulihan Cadangan (*Reserve Replacement Ratio* (RRR)) hanya berkisar 65%. RRR ini tergolong rendah dibandingkan dengan tingkat RRR ideal sebesar 100% yang berarti setiap melakukan produksi sebesar 1 barel minyak, idealnya harus mendapatkan penemuan cadangan sebesar 1 barel juga.

Rendahnya ...

Rendahnya RRR dan penurunan produksi minyak dan gas bumi (migas) disebabkan oleh sejumlah faktor, diantaranya rendahnya kegiatan eksplorasi migas dan rendahnya tingkat keberhasilan eksplorasi yang dilakukan oleh perusahaan minyak, minimnya keterlibatan pemerintah langsung dalam kegiatan eksplorasi, maupun iklim investasi migas yang kurang kondusif bagi pelaku usaha, seperti tumpang tindih lahan, perizinan yang rumit, permasalahan tata ruang, dan masalah sosial. Selain itu terdapat berbagai kendala teknis antara lain, penurunan cadangan secara alami lapangan-lapangan yang sudah tua dan belum optimalnya penerapan teknologi *Enhanced Oil Recovery* (EOR) pada sebagian besar lapangan-lapangan minyak tua di Indonesia.

Fenomena turunnya harga minyak dunia dalam 2 tahun terakhir tidak pernah diperkirakan sebelumnya. Kecenderungan harga energi yang selalu meningkat dalam sepuluh tahun terakhir berubah dengan turunnya harga minyak, dari sekitar US$ 100 per barel pada tahun 2014 menjadi di bawah US$ 35 per barel pada akhir tahun 2015.

Kecenderungan rendahnya harga minyak dan gas bumi dunia diperkirakan akan terus berlangsung hingga beberapa tahun mendatang. Hal ini disebabkan oleh berlimpahnya pasokan akibat lonjakan produksi migas non-konvensional yaitu minyak/gas serpih (*shale oil/gas*) di Amerika Serikat, disusul Tiongkok dan Argentina. Sementara itu, pasokan gas dunia diperkirakan akan melimpah dengan adanya penemuan-penemuan cadangan gas raksasa dunia (Rusia, Qatar, Iran, PNG, Australia, dll), yang dapat menekan harga jual gas di pasar internasional.

Kelebihan pasokan (*over supply*) energi tersebut akan membentuk keseimbangan pasar dan struktur harga energi dunia (*energy equilibrium*) yang dapat mempengaruhi kebijakan energi hampir semua negara di dunia.

Penurunan ...

Penurunan produksi migas domestik dan gejolak harga minyak dunia perlu disikapi dengan tepat dan hati-hati. Penurunan harga migas menyebabkan pemerintah dapat mengurangi biaya impor dan mengendalikan harga bahan bakar domestik. Walaupun demikian, menurunnya harga migas juga menyebabkan penerimaan negara berkurang secara signifikan, dan menjadi disinsentif bagi kegiatan eksplorasi dan eksploitasi migas. Dalam jangka menengah, dampak dari rendahnya kegiatan eksplorasi dan eksploitasi adalah semakin berkurangnya produksi migas nasional, yang dapat mengancam pencapaian tujuan kemandirian energi nasional.

3. Akses dan Infrastruktur Energi Terbatas

Kondisi geografis Indonesia sebagai negara kepulauan terbesar di dunia merupakan anugerah sekaligus tantangan dalam membangun infrastruktur energi dalam rangka memenuhi kebutuhan energi secara handal dan merata di seluruh wilayah Indonesia.

Kilang pengolahan minyak dan pipa transmisi merupakan sebagian dari infrastruktur energi yang vital untuk menyediakan dan mendistribusikan minyak dan gas. Keterbatasan kapasitas kilang menyebabkan Indonesia mengalami ketergantungan dalam hal impor minyak mentah dan BBM. Volume impor minyak mentah dan BBM cenderung meningkat setiap tahun.

Transportasi gas antar pulau yang menghubungkan Sumatera, Jawa, Kalimantan, Sulawesi, dan Papua belum terintegrasi sepenuhnya, sehingga gas yang diproduksi tidak dapat langsung didistribusikan ke pusat-pusat industri dan pembangkit listrik yang membutuhkan pasokan gas dengan harga yang rasional.

Kekurangan ...

Kekurangan infrastruktur energi ini menyebabkan terjadinya kelangkaan BBM dan LPG di sejumlah wilayah, terutama di wilayah Timur Indonesia. Di samping itu, adanya disparitas harga energi yang sangat tinggi antara Pulau Jawa dan pulau-pulau lainnya membuat biaya aktivitas ekonomi menjadi tinggi.

Dalam hal ketenagalistrikan, kondisi infrastruktur juga masih belum sempurna. Transmisi listrik di masing-masing wilayah Sumatera, Kalimantan, Sulawesi, dan Papua belum terintegrasi sepenuhnya. Sebagai dampak belum terintegrasinya infrastruktur, rasio elektrifikasi nasional baru mencapai 88,5%, yang artinya masih ada sekitar 29,4 juta rumah tangga Indonesia belum mendapatkan akses listrik. Kapasitas terpasang per kapita Indonesia baru mencapai sekitar 218 watt/kapita (konsumsi listrik sebesar 910 kWh/kapita), disebabkan kapasitas terpasang pembangkit nasional pada tahun 2015 baru mencapai sekitar 55 GW. Untuk mencapai konsumsi listrik sekitar 1.000 watt/kapita, diperlukan tambahan kapasitas sekitar 200 GW atau 4 kali total kapasitas pembangkit listrik di Indonesia saat ini. Kekurangan listrik ini menyebabkan terkendalanya pemanfaatan listrik untuk meningkatkan produktivitas dan terhambatnya pengembangan potensi-potensi ekonomi.

4. Ketergantungan Terhadap Impor BBM dan LPG

Sejak tahun 2004, Indonesia telah menjadi negara pengimpor minyak netto (*net oil importer*). Hal tersebut disebabkan karena kebutuhan minyak yang terus meningkat sementara produksinya terus menurun. Peningkatan konsumsi minyak dalam negeri merupakan dampak dari pertumbuhan ekonomi dan pertambahan penduduk.

Peningkatan ...

Peningkatan konsumsi BBM dalam negeri juga disebabkan pola konsumsi yang sangat boros atau tidak efisien, yang salah satunya karena pemakaian BBM yang sebagian masih disubsidi. Borosnya energi Indonesia tercermin dari tingginya indikator elastisitas energi, yang merupakan perbandingan antara pertumbuhan konsumsi energi dengan pertumbuhan ekonomi. Elastisitas energi dalam 5 tahun terakhir masih di atas 1, padahal idealnya di bawah 1.

Kondisi ini diperburuk dengan terbatasnya fasilitas kilang minyak yang tidak mengalami penambahan berarti sejak pembangunan kilang Balongan pada tahun 1994, sehingga impor BBM terus meningkat. Saat ini, terdapat tujuh kilang PT Pertamina (Persero) dan empat kilang non-PT Pertamina (Persero) dengan kemampuan produksi BBM sekitar 681 ribu BOPD.

Tabel 2. Konsumsi BBM dan Produksi Kilang Tahun 2010 – 2015

Satuan: Ribu bopd

Tahun	Konsumsi BBM	Produksi Kilang		Impor BBM
		BBM	Non BBM	
2010	1.094	646	235	448
2011	1.187	650	285	537
2012	1.206	657	306	549
2013	1.234	671	233	563
2014	1.339	673	266	666
2015	1.229	681	204	548

Keberhasilan program konversi minyak tanah ke LPG pada 2007-2010 menyebabkan konsumsi LPG dalam negeri naik cukup tajam. Namun, kapasitas kilang LPG untuk pasokan dalam negeri terbatas. Akibatnya, sekitar 60% konsumsi LPG domestik dipenuhi melalui impor.

Salah ...

Salah satu upaya untuk mengendalikan pertumbuhan konsumsi LPG adalah dengan meningkatkan pemanfaatan gas alam di daerah perkotaan melalui ekspansi jaringan gas kota, namun belum optimal.

5. **Harga EBT Belum Kompetitif dan Subsidi Energi Belum Tepat Sasaran**

Harga EBT belum kompetitif karena adanya subsidi untuk BBM dan listrik selain karena sebagian besar teknologi EBT masih mahal. Akibatnya EBT kalah bersaing dengan energi fosil seperti tercermin pada Tabel 3 di bawah ini.

Tabel 3. Biaya Pokok Penyediaan Tenaga Listrik Nasional Tahun 2015

No.	EBT	
	Pembangkit	Harga (Rp/kWh)
1	PLTS	8.786
2	PLTP	1.058
3	PLTA	388

No.	Fosil	
	Pembangkit	Harga (Rp/kWh)
1	PLTD	3.992
2	PLTGU	1.843
3	PLTG	806
4	PLTU	661

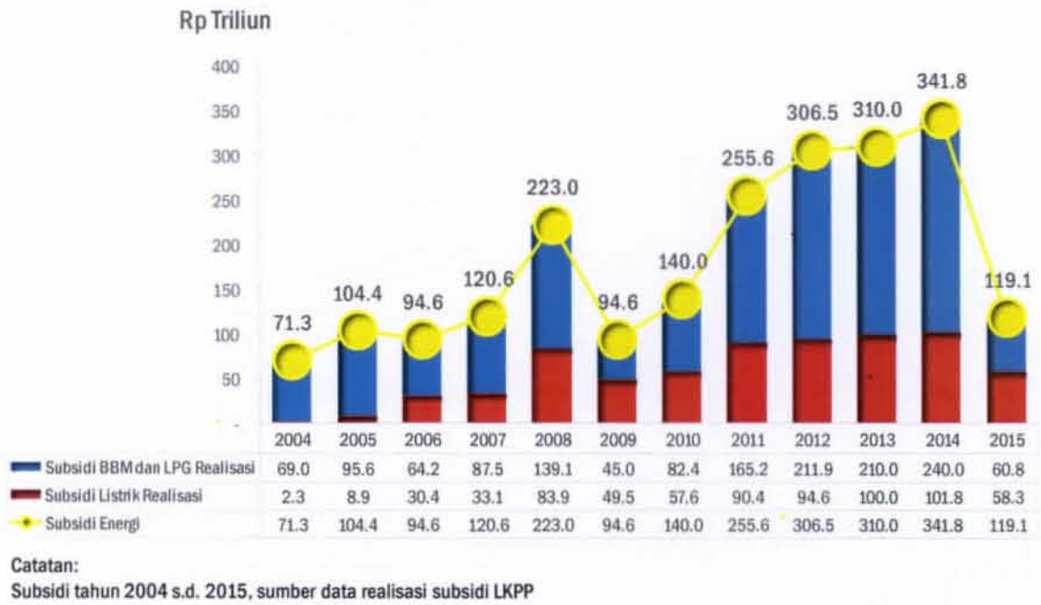
Hal ini menyebabkan pengembangan dan pemanfaatan EBT selalu terkendala dan tidak maksimal, dan pada gilirannya mengakibatkan ketergantungan yang besar pada energi fosil yang kotor dan sebagian diimpor.

Salah satu upaya untuk meningkatkan pemanfaatan EBT adalah dengan mengalihkan subsidi untuk energi fosil kepada subsidi untuk EBT yang pada saat ini belum optimal dilakukan.

Subsidi energi sangat membebani APBN. Dalam 12 tahun terakhir sejak tahun 2004 hingga tahun 2015, subsidi energi mencapai Rp. 2.182 triliun sebagaimana dapat terlihat pada Gambar 1. Namun demikian, dengan diterapkannya kebijakan penyesuaian harga BBM dan listrik yang

lebih ...

lebih berkeadilan, maka pada tahun 2015, subsidi energi mengalami penurunan menjadi Rp. 119,1 triliun dibandingkan tahun 2014 sebesar Rp. 341,8 triliun. Besarnya subsidi dipengaruhi oleh dinamika harga minyak dan LPG di pasar dunia.



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Subsidi BBM dan LPG Realisasi	69.0	95.6	64.2	87.5	139.1	45.0	82.4	165.2	211.9	210.0	240.0	60.8
Subsidi Listrik Realisasi	2.3	8.9	30.4	33.1	83.9	49.5	57.6	90.4	94.6	100.0	101.8	58.3
Subsidi Energi	71.3	104.4	94.6	120.6	223.0	94.6	140.0	255.6	306.5	310.0	341.8	119.1

Catatan:
Subsidi tahun 2004 s.d. 2015, sumber data realisasi subsidi LKPP

Gambar 1. Subsidi Energi Tahun 2004–2015

Selain jumlahnya, subsidi energi juga tidak tepat sasaran, karena sebagian besar dari subsidi tersebut justru dinikmati oleh kelompok masyarakat berpendapatan tinggi dan pemilik kendaraan bermotor. Kelompok masyarakat berpendapatan rendah justru hanya menikmati sebagian kecil dari subsidi tersebut. Tahun 2015, secara bertahap telah dilakukan perubahan kebijakan harga BBM dan listrik sehingga harga energi mencerminkan keekonomian dan lebih berkeadilan. Kepentingan masyarakat kurang mampu tetap terlindungi dengan adanya program bantuan sosial untuk kelompok masyarakat miskin.

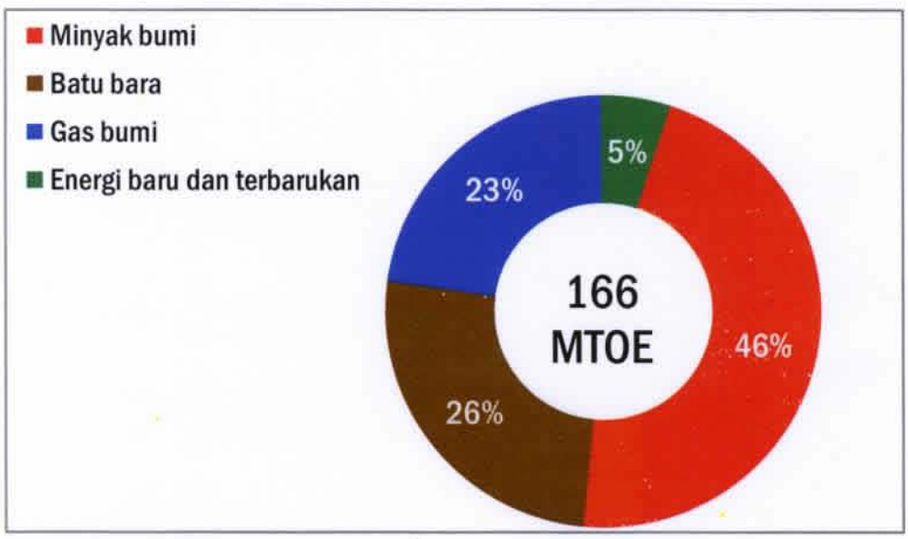
Kebijakan ...

Kebijakan subsidi belum sepenuhnya diarahkan untuk menurunkan harga listrik dari EBT. Berbagai upaya telah dilakukan tetapi masih belum optimal, diantaranya penerapan *feed-in tariff* pada harga listrik untuk EBT dan lemahnya implementasi regulasi.

6. Pemanfaatan EBT Masih Rendah

Potensi EBT seperti panas bumi, air, bioenergi, sinar matahari dan angin/bayu sangat melimpah di Indonesia. Kawasan hutan Indonesia seluas 120 juta hektar di samping berfungsi sebagai sumber daya alam dan penyangga kehidupan juga memiliki potensi sumber biomassa, energi air, dan panas bumi yang sangat besar.

Pada tahun 2015 porsi energi fosil dalam bauran energi nasional sebesar 95%, sedangkan EBT hanya sebesar 5% sebagaimana terlihat pada Gambar 2.

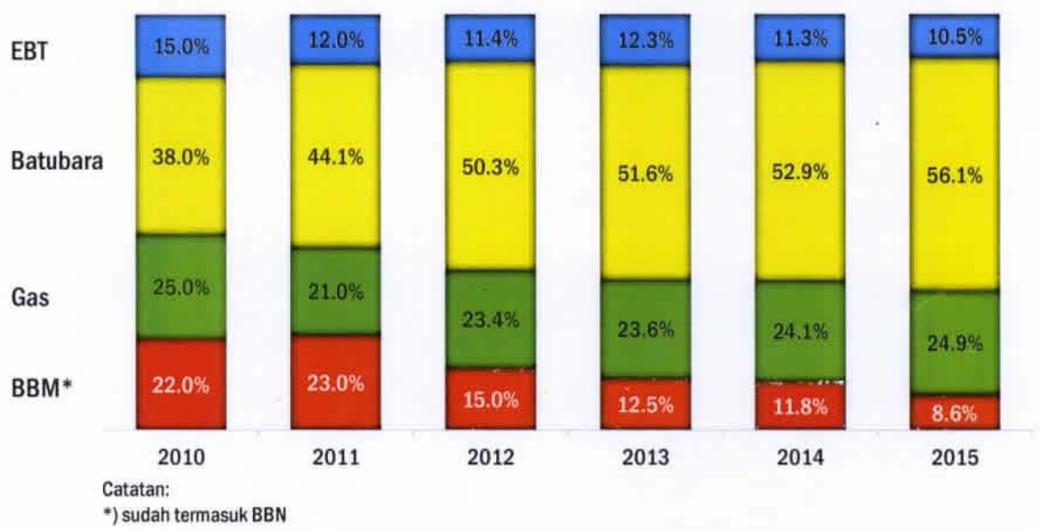


Sumber Data: *Unaudited*

Gambar 2. Bauran Energi Tahun 2015

Pada ...

Pada tahun 2015 porsi EBT dalam bauran energi nasional di sektor kelistrikan juga masih rendah, yaitu sebesar 10,5% dari total produksi. Sebagian besar energi yang digunakan pada pembangkit listrik adalah batubara sebesar 56,1% kemudian diikuti oleh gas bumi sebesar 24,9% dan BBM sebesar 8,6% sebagaimana dapat dilihat pada Gambar 3.



Gambar 3. Bauran Produksi Listrik Energi Tahun 2010-2015

Rendahnya pemanfaatan dan pengembangan EBT pada pembangkit listrik terjadi karena berbagai permasalahan, antara lain:

- Belum maksimalnya pelaksanaan kebijakan harga.
- Ketidakjelasan subsidi EBT pada sisi pembeli (*off-taker*).
- Regulasi yang belum dapat menarik investasi.
- Belum adanya insentif pemanfaatan EBT.
- Minimnya ketersediaan instrumen pembiayaan yang sesuai dengan kebutuhan investasi.
- Proses perizinan yang rumit dan memakan waktu yang lama.
- Permasalahan lahan dan tata ruang.

Salah ...

Salah satu contoh terkait dengan permasalahan pemanfaatan potensi EBT dapat dilihat pada pengembangan panas bumi, dimana potensi panas bumi Indonesia adalah yang terbesar di dunia dan telah dikembangkan sejak 1972. Potensi tersebut umumnya terletak di kawasan hutan lindung dan hutan konservasi. Pemanfaatannya terkendala dengan izin khusus dan isu kelestarian hutan. Kendala lainnya adalah risiko eksplorasi panas bumi yang masih tinggi, rasio keberhasilan pengeboran (*drilling success ratio*) masih rendah, dan tingginya komponen impor pabrikasi khususnya komponen pembangkit dan fasilitas produksi.

7. Pemanfaatan Energi Belum Efisien

Pemanfaatan energi yang belum efisien dapat dilihat dari indikator efisiensi penggunaan energi yaitu intensitas energi nasional, sebesar 543 TOE/US$ (berdasarkan harga konstan 2005), dan elastisitas energi rata-rata lebih dari 1 selama 5 tahun terakhir. Hal ini menunjukkan bahwa Indonesia masih belum efisien dalam penggunaan energi. Pemanfaatan energi yang belum efisien ini disebabkan antara lain oleh:

- Kewajiban konservasi energi yang diamanatkan dalam PP Nomor 70 Tahun 2009 belum dilaksanakan secara konsisten.
- Ketersediaan standar dan label belum mencakup seluruh peralatan dan perangkat yang diwajibkan untuk hemat energi, dan belum optimalnya pelaksanaan standar dan label untuk produk-produk yang beredar di pasar domestik.
- Program restrukturisasi mesin atau peralatan industri belum dilaksanakan secara luas ke industri-industri lain yang lahap energi (selain industri tekstil, alas kaki, dan gula).
- Sistem transportasi massal belum secara luas diterapkan.

• Insentif ...

- Insentif untuk pelaksanaan efisiensi energi dan konservasi energi masih terbatas.
- Subsidi terhadap harga energi menjadi disinsentif bagi penghematan.
- Belum konsistennya pelaksanaan disinsentif bagi pengguna energi yang tidak melaksanakan efisiensi dan konservasi energi.
- Harga peralatan yang efisien/hemat energi masih mahal.
- Belum berjalannya *Energy Service Company* (ESCO) di industri dan bangunan komersial. ESCO merupakan usaha efisiensi energi dengan kontrak kinerja yang menjamin penghematan biaya energi.
- Sistem monitoring dan evaluasi hasil pelaksanaan konservasi energi lintas sektor belum tersedia.
- Terbatasnya jumlah manajer dan auditor energi dan keterbatasan sumber daya pelatih serta fasilitas pelatihannya.
- Pengetahuan, pemahaman, dan kesadaran masyarakat maupun industri terhadap manfaat efisiensi dan konservasi energi masih terbatas.
- Penelitian dan pengembangan terkait efisiensi energi kurang berkembang.

8. Penelitian, Pengembangan, dan Penguasaan Ilmu Pengetahuan dan Teknologi Masih Terbatas

Hasil-hasil Penelitian, Pengembangan, dan Penguasaan Ilmu Pengetahuan dan Teknologi (P3IPTEK) nasional belum mampu memberikan kontribusi secara optimal untuk mendukung kemandirian industri energi nasional. Hal ini disebabkan oleh:

- Budaya inovasi dan keberpihakan penggunaan inovasi dalam negeri masih lemah.
- Ketersediaan material penelitian terbatas.
- Prasarana dan sarana penelitian terbatas.

- Kerjasama ...

- Kerjasama dan jaringan inovasi lemah.
- Sinergitas antara lembaga penelitian, industri, dan Pemerintah lemah.
- Anggaran penelitian dan sistem administrasi penganggarannya belum mendukung.
- Insentif bagi peneliti dan perekayasa rendah.

Permasalahan tersebut di atas dapat menghambat upaya-upaya penciptaan teknologi baru, kemampuan alih teknologi, kerja sama, dan partisipasi peneliti dan perekayasa ke dalam industri, serta perolehan paten.

Khusus di bidang energi, kelemahan itu dapat dilihat dari terbatasnya penemuan sumber energi yang baru terutama dalam meningkatkan eksplorasi dan eksploitasi untuk mempertahankan produksi migas, mengembangkan EBT, penguasaan teknologi konversi energi, dan pengembangan standarisasi komponen.

9. Kondisi Geopolitik Dunia dan Isu Lingkungan Global

Eksploitasi sumber daya energi dan pemanfaatannya menimbulkan dampak sosial, ekonomi, dan lingkungan yang telah menjadi perhatian masyarakat global. Dampak penggunaan bahan bakar fosil untuk energi listrik, transportasi dan pemanasan serta memasak telah mengakibatkan terjadinya peningkatan pemanasan global dan perubahan iklim dengan segala dampak ikutannya yang mengancam kehidupan dan kelestarian bumi.

Pertemuan Perserikatan Bangsa Bangsa (PBB) tentang Perubahan Iklim ke 21 di Paris pada Desember 2015, menyepakati *Paris Agreement* yang menyatakan bahwa kenaikan suhu Bumi harus dikendalikan menjadi kurang dari 2^0C. Kesepakatan tersebut berlaku untuk semua negara (*applicable to all*) dan mengikat secara hukum (*legally binding*), dengan prinsip *Common but Differentiated Responsibilities* (CBDR).

Pemerintah Indonesia telah menyampaikan *Intended Nationally Determine Contribution* (INDC) kepada *United Nations Framework Convention on Climate Change* (UNFCCC) dimana dalam naskah tersebut Indonesia memberikan janji untuk menurunkan emisi (mitigasi) GRK sebesar 29% dibandingkan *Business as Usual* (BAU) dan dengan tambahan 12% menjadi 41% dengan bantuan internasional pada tahun 2030.

Seiring dengan target pembatasan kenaikan temperatur global di *Paris Agreement* ada kemungkinan besarnya penurunan emisi GRK yang pernah disampaikan oleh Indonesia tahun 2015 lalu tidak cukup untuk mencapai target nasional. Dengan kata lain, ada kemungkinan target mitigasi GRK yang dijanjikan Indonesia perlu ditingkatkan. Dengan demikian penurunan emisi dari sektor energi yang menjadi kontributor kedua emisi GRK setelah tata-guna lahan dan kehutanan, diharapkan lebih besar dari yang telah direncanakan.

KEN dan penjabarannya dalam RUEN menjadi sangat strategis untuk merespon kecenderungan dan agenda-agenda global yang dimaksud. KEN mempunyai tujuan ganda yaitu percepatan pengembangan EBT sekaligus menekan laju pertambahan emisi GRK dari penggunaan energi fosil. Konsistensi implementasi pokok-pokok kebijakan dalam KEN yang dituangkan RUEN menjadi kunci keberhasilan Indonesia meningkatkan ketersediaan dan akses energi, sekaligus membangun sistem energi yang rendah karbon.

10. Cadangan Penyangga Energi Belum Tersedia

Cadangan Penyangga Energi (CPE) mempunyai peranan sangat penting bagi Indonesia untuk mengurangi dampak ekonomi, politik dan sosial yang timbul ketika terjadi kondisi krisis dan darurat energi. Namun, dikarenakan kebutuhan pembiayaan pembentukan CPE yang besar serta kendala penetapan prioritas anggaran belanja negara, maka CPE masih menjadi tantangan besar bagi pengelolaan energi di Indonesia.

Berdasarkan ...

Berdasarkan PP Nomor 79 Tahun 2014 tentang KEN, cadangan energi nasional terdiri dari cadangan operasional, CPE dan cadangan strategis. Menurut UU Nomor 22 Tahun 2001 tentang Minyak dan Gas Bumi, cadangan operasional yang mencakup cadangan BBM Nasional disediakan oleh badan usaha. Hingga saat ini ketersediaan cadangan operasional BBM masih bersifat sukarela (*voluntary*) oleh Pertamina yaitu hanya sekitar 21-23 hari konsumsi BBM dan belum pernah ditetapkan oleh Pemerintah menjadi keharusan kepada badan usaha sejak diamanatkan UU Nomor 22 Tahun 2001 tentang Minyak dan Gas Bumi.

Dalam rangka menjamin ketahanan energi nasional Pemerintah wajib menyediakan CPE. Belum adanya mandatori keharusan menyediakan cadangan operasional minyak dan BBM serta belum tersedianya CPE di Indonesia juga ikut menurunkan ketahanan energi Indonesia dan membuat posisi tawar politik, pertahanan keamanan dan bisnis energi Indonesia terhadap negara-negara tetangga menjadi lemah.

2.2. Kondisi Energi Nasional Saat Ini

Proyeksi pemodelan kebutuhan dan pasokan energi jangka panjang dimulai dari pemahaman atas kondisi saat ini (*existing condition*), yang mengacu pada tiga indikator yaitu indikator sosio-ekonomi, indikator energi, dan indikator lingkungan hidup.

a. Indikator Sosio-Ekonomi

Indikator sosio-ekonomi menjadi asumsi dasar (*key assumption*) dalam penyusunan proyeksi kebutuhan energi jangka panjang. Indikator sosio-ekonomi yang digunakan, antara lain Produk Domestik Bruto (PDB), pertumbuhan ekonomi, PDB per kapita, pertumbuhan PDB per kapita, populasi, pertumbuhan populasi, populasi urban, dan jumlah rumah tangga. Indikator-indikator tersebut disajikan pada Tabel 4 dan bersumber dari Badan Pusat Statistik (BPS).

Tabel 4 ...

Tabel 4. Indikator Sosio – Ekonomi Tahun 2013–2015

No.	Indikator	Satuan	2013	2014	2015
1	PDB*	Triliun Rupiah	9.524,7	10.542,7	11.540,8
2	Pertumbuhan ekonomi	%	5,6	5,0	4,8
3	PDB per kapita*	Juta Rupiah	38,3	41,8	45,2
4	Pertumbuhan PDB per kapita*	%	9,1	9,1	8,1
5	Populasi	Juta Penduduk	248,8	252,2	255,5
6	Pertumbuhan populasi	%	1,4	1,4	1,3
7	Populasi urban	%	51,9	52,6	53,3
8	Jumlah rumah tangga	Juta RT	64,3	64,8	66,5

Catatan:
1. Angka PDB* : berdasarkan harga berlaku
2. Sumber : Kementerian Keuangan dan BPS, diolah

b. Indikator Energi

Indikator energi Indonesia antara lain meliputi potensi energi, bauran energi, pasokan energi primer, konsumsi energi final, rasio elektrifikasi, konsumsi listrik, dan pertumbuhan konsumsi listrik.

Potensi energi Indonesia terdiri dari energi fosil dan EBT yang mencakup sumber daya, cadangan, produksi, dan umur energi fosil sebagaimana dapat dilihat pada Tabel 5.

Tabel 5. Potensi Energi Fosil Indonesia Tahun 2015

No.	Jenis Energi	Sumber Daya	Cadangan	Produksi	Umur*
1	Minyak Bumi	151 Miliar barel	3,6 Miliar barel	288 Juta barel	12 tahun
2	Gas Bumi	487 TCF	98,0 TCF	3,0 TSCF	33 tahun
3	Batubara	120,5 Miliar ton	32,4 Miliar ton	393 Juta ton	82 tahun
4	CBM	453 TSCF	-	-	-
5	Shale Gas	574 TSCF	-	-	-

Catatan:
*) asumsi apabila tidak ada temuan cadangan baru

Potensi ...

Potensi, kapasitas terpasang, dan pemanfaatan jenis-jenis EBT Indonesia saat ini dapat dilihat pada Tabel 6.

Tabel 6. Potensi Energi Terbarukan Indonesia Tahun 2015

No.	Jenis Energi	Potensi	Kapasitas Terpasang	Pemanfaatan
1	Panas Bumi	29.544 MW	1.438,5 MW	4,9 %
2	Air	75.091 MW	4.826,7 MW	6,4 %
3	Mini & Mikro Hidro	19.385 MW	197,4 MW	1,0 %
4	Bioenergi	32.654 MW	1.671,0 MW	5,1 %
5	Surya	207.898 MW (4,80 kWh/m^2/day)	78,5 MW	0,04%
6	Angin	60.647 MW (≥ 4 m/s)	3,1 MW	0,01%
7	Laut	17.989 MW	0,3 MW	0,002%
Total		443.208 MW	8.215,5	1,9%

Pemanfaatan EBT baru mencapai sekitar 2% dari total potensi EBT yang ada. Potensi tersebut menjadi dasar rencana pengembangan EBT paling sedikit 23% dari total bauran energi primer pada tahun 2025 dan paling sedikit 31% dari total bauran energi primer pada tahun 2050.

Kondisi energi nasional saat ini yang menjadi indikator energi dalam pemodelan dapat dilihat pada Tabel 7.

Tabel 7. ...

Tabel 7. Indikator Energi

No.	Indikator	Satuan	2013	2014
1	Bauran energi			
	a. Minyak bumi	%	46,6	43,0
	b. Batu bara	%	31,4	34,2
	c. Gas bumi	%	17,8	18,6
	d. EBT	%	4,2	4,2
	- Tenaga air	%	2,9	2,6
	- Panas bumi	%	0,8	1,1
	- ET lainnya	%	0,4	0,5
2	Pasokan energi primer	MTOE	176,3	196,6
3	Konsumsi energi final	MTOE	125,6	132,6
4	Rasio elektrifikasi	%	80,5	84,4
5	Konsumsi listrik	TWh	185,5	196,4
6	Pertumbuhan konsumsi listrik	%	7,7	5,9

c. Indikator Lingkungan Hidup

Beberapa indikator lingkungan hidup yang dipakai suatu negara adalah besarnya emisi Gas Rumah Kaca (GRK), emisi GRK per kapita, dan emisi GRK per PDB. Indikator lingkungan hidup Indonesia dapat dilihat pada Tabel 8.

Tabel 8. Emisi Gas Rumah Kaca dari Sektor Energi Tahun 2013–2014

No.	Indikator	Satuan	2013	2014
1	Emisi GRK	Juta ton CO_2	433,5	464,4
2	Emisi GRK per kapita	Ton CO_2/Kapita	1,8	1,9
3	Emisi GRK per PDB	Ton CO_2/Juta Rupiah	0,2	0,2

Emisi ...

Emisi GRK dari sektor energi meningkat 7,1% dari 433,5 juta ton CO_2 pada tahun 2013 menjadi 464,4 juta ton CO_2 pada tahun 2014. Sumber emisi GRK sektor energi terbesar berasal dari sektor pembangkit listrik (33%), diikuti oleh sektor industri (30%), transportasi (29%), dan sektor lainnya (8%). Besarnya emisi disebabkan karena penggunaan energi fosil batubara di sektor pembangkit dan industri, serta BBM pada sektor transportasi. GRK per PDB cenderung konstan karena pertumbuhan emisi CO_2 relatif meningkat seiring dengan peningkatan pertumbuhan PDB. Ini berarti sebagian besar emisi CO_2 berkaitan langsung dengan pertumbuhan ekonomi yang tidak disertai dengan efisiensi emisi CO_2.

2.3. Kondisi Energi Nasional di Masa Mendatang

Proyeksi pemodelan kebutuhan dan pasokan energi dibuat dengan mempertimbangkan:

1. Sasaran-sasaran yang diamanatkan dalam Kebijakan Energi Nasional, sebagaimana dapat dilihat pada Tabel 9;
2. Rencana pengembangan energi dari institusi terkait dan masukan dari pemangku kepentingan berdasarkan prediksi perkembangan teknologi di masa mendatang;
3. Perkembangan kondisi saat ini, meliputi indikator sosio-ekonomi, indikator energi, dan indikator lingkungan hidup.

Selain mempertimbangkan hal-hal tersebut di atas, proyeksi pemodelan kebutuhan dan pasokan energi juga dibuat dengan memperhatikan peraturan, pengalaman terbaik *(best practice)*, kajian, publikasi resmi, dan/atau realisasi.

Tabel 9. ...

Tabel 9. Sasaran – Sasaran yang diamanatkan dalam KEN

Tahun 2015–2050

No.	Sasaran KEN	Satuan	2015	2020	2025	2050
1	Penyediaan energi primer	MTOE			> 400	> 1.000
2	Target bauran energi:					
	a. EBT	%			> 23	> 31
	b. Minyak bumi	%			< 25	< 20
	c. Batubara	%			> 30	> 25
	d. Gas bumi	%			> 22	> 24
3	Penyediaan pembangkit tenaga listrik	GW			> 115	> 430
4	Rasio elektrifikasi	%	85	100		
5	Pemanfaatan energi primer per kapita	TOE			1,4	3,2
6	Pemanfaatan listrik per kapita	KWh			2.500	7.000
7	Elastisitas energi				< 1	
8	Penurunan intensitas energi final	%	1% per tahun			
9	Rasio penggunaan gas rumah tangga	%	85			

Target bauran energi tersebut merupakan realisasi dari prioritas pengembangan energi yang ditetapkan dalam KEN. Prioritas tersebut adalah memaksimalkan penggunaan energi terbarukan, sehingga porsi EBT paling sedikit 23% pada tahun 2025 dan paling sedikit 31% pada tahun 2050. Sedangkan minyak bumi, KEN mengamanatkan untuk meminimalkan penggunaannya, sehingga porsi minyak bumi paling banyak 25% pada tahun 2025 dan paling banyak 20% pada tahun 2050.

Akan tetapi gas bumi diamanatkan untuk digunakan secara optimum sehingga pemanfaatan gas bumi paling sedikit 22% pada tahun 2025, dan paling sedikit 24% pada tahun 2050. Setelah energi terbarukan dimanfaatkan secara maksimum, minyak bumi dimanfaatkan dengan minimal, dan gas bumi digunakan secara optimum, kekurangan kebutuhan energi akan dipasok dari batubara.

a. Struktur ...

a. Struktur Pemodelan dan Asumsi Dasar

Struktur model yang digunakan dalam perangkat lunak pemodelan terdiri dari asumsi dasar, kebutuhan, transformasi, dan sumber daya sebagai berikut:

1. Asumsi dasar yang digunakan meliputi pertumbuhan ekonomi, pertumbuhan penduduk, dan beberapa asumsi dasar lainnya dalam kurun tahun 2015-2050, sebagaimana dapat dilihat pada Tabel 10. Asumsi dasar ini digunakan untuk menyusun proyeksi pemodelan kebutuhan energi.

Tabel 10. Asumsi Dasar Tahun 2015–2050

No.	Indikator	Satuan	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
1	PDB*	Triliun Rupiah	3.075	3.238	3.468	3.728	4.026	4.348	6.388	9.257	18.553	35.121
2	Pertumbuhan ekonomi	%	4,8	5,3	7,1	7,5	8,0	8,0	8,0	7,5	7,0	6,3
3	PDB per Kapita*	Juta Rupiah	12,0	12,5	13,2	14,1	15,0	16,0	22,4	31,2	58,9	104,7
4	Pertumbuhan PDB perKapita*	%	3,8	4,0	5,8	6,2	6,7	6,8	7,0	6,7	6,3	5,7
5	Populasi	Juta Penduduk	255,5	258,6	261,7	264,8	267,9	271,1	284,8	296,4	315,2	335,3
6	Pertumbuhan Populasi	%	1,3	1,3	1,3	1,3	1,3	1,0	0,8	0,6	0,6	0,6
7	Populasi Urban	%	53,3	54,0	54,7	55,3	56,0	56,7	60,0	63,4	67,7	70,0
8	Jumlah Rumah Tangga	Juta RT	66,5	67,5	68,5	69,5	70,5	71,5	76,2	80,3	87,2	94,7

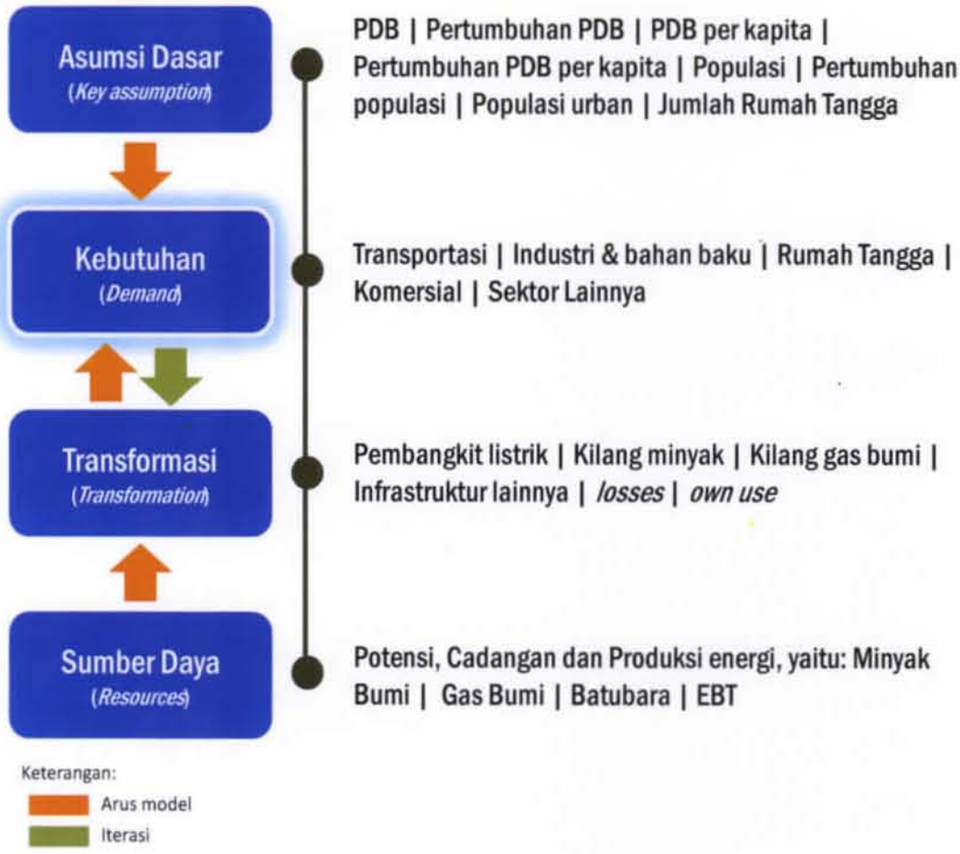
Catatan:
1) Angka PDB*: Atas dasar harga konstan tahun 2000;
2) Pertumbuhan ekonomi tahun 2015, berdasarkan realisasi tahun 2015;
3) Pertumbuhan ekonomi tahun 2016, berdasarkan asumsi dalam UU No. 14/2015 Tentang APBN tahun 2016;
4) Pertumbuhan ekonomi tahun 2017 s.d. 2019, berdasarkan asumsi dalam Perpres No. 2/2015 tentang RPJMN 2015-2019;
5) Pertumbuhan ekonomi tahun 2020 s.d. 2050, berdasarkan asumsi dalam KEN.

2. Proyeksi pemodelan kebutuhan energi tahun 2015-2050 disusun dengan mempertimbangkan asumsi dasar, asumsi pertumbuhan kebutuhan dan rencana pengembangan sektor pengguna yaitu industri (dan bahan baku), transportasi, rumah tangga, komersial, dan energi lainnya.
3. Transformasi merupakan proses yang mengubah energi primer menjadi energi final, seperti pembangkit listrik dan kilang minyak.

4. Sumber ...

4. Sumber daya energi meliputi potensi energi, cadangan energi dan produksi energi.

Secara lebih ringkas struktur pemodelan yang digunakan dapat dilihat pada Gambar 4.



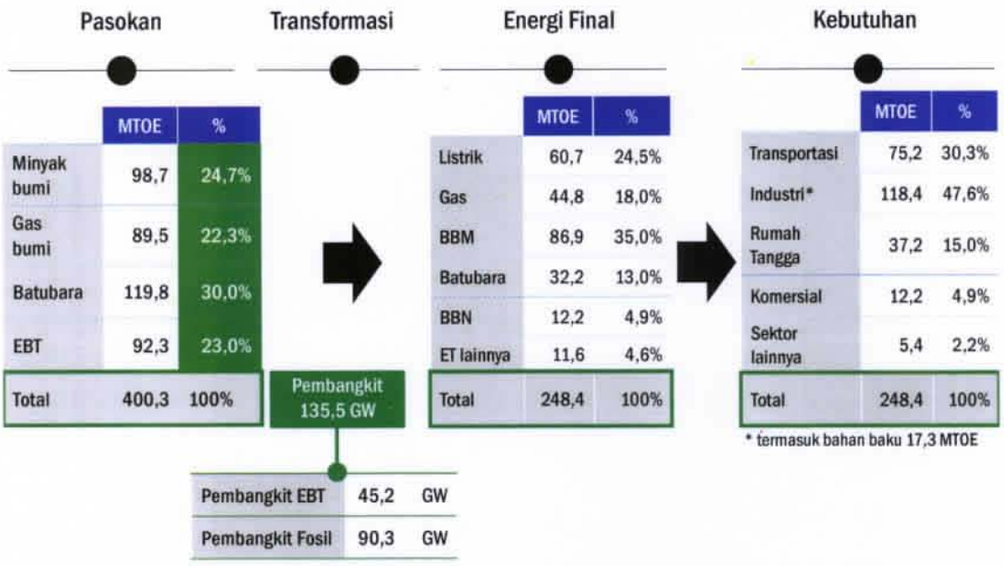
Gambar 4. Struktur Pemodelan KEN

b. Hasil Pemodelan KEN

1) Kebutuhan dan Pasokan Energi

Dengan mengacu pada sasaran yang terdapat pada KEN, dilakukan pemodelan dengan hasil sebagaimana ditampilkan pada Gambar 5.

Gambar 5. ...



Gambar 5. Hasil Pemodelan Kebutuhan dan Pasokan Energi Tahun 2025

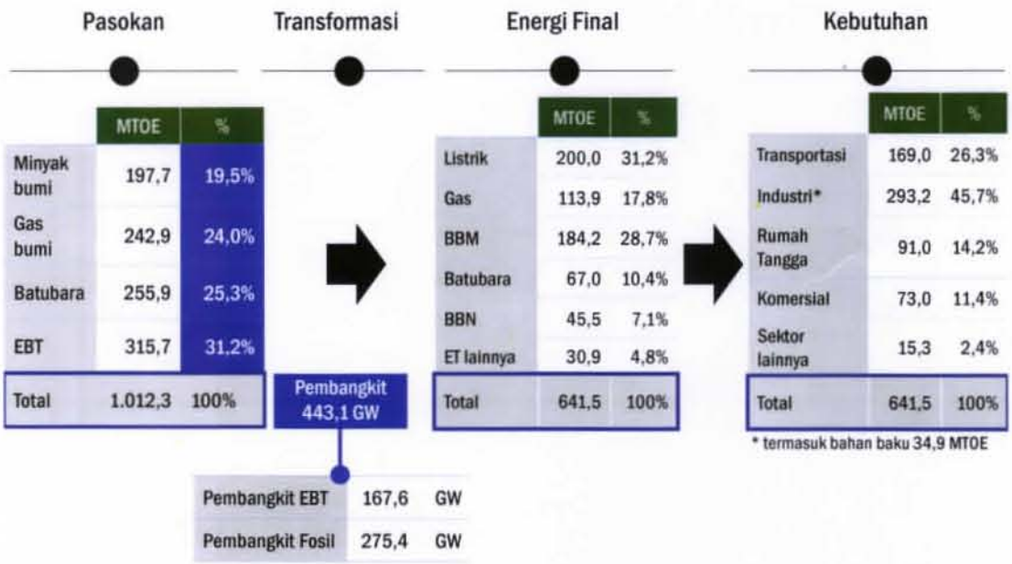
Hasil pemodelan kebutuhan energi final pada tahun 2025 diperkirakan mencapai 248,4 MTOE dengan sektor industri merupakan pengguna terbesar energi final yaitu sebesar 47,6% (termasuk untuk bahan baku), selanjutnya diikuti oleh sektor transportasi sebesar 30,3%. Sektor lain yang cukup besar menggunakan energi final adalah sektor rumah tangga 15,0% dan sektor komersial 4,9%, dan sisanya sebesar 2,2% dari sektor lainnya.

Hasil pemodelan pasokan energi primer pada tahun 2025 mencapai 400 MTOE. Proses transformasi atau perubahan dari energi primer menjadi energi final menyebabkan berkurangnya volume energi. Proses transformasi dari minyak mentah menjadi BBM memiliki efisiensi sekitar 73%-80%, pembangkit listrik tenaga uap (PLTU) sekitar 30%-36%, dan PLTU *Ultra Super Critical* (USC) sekitar 40%-42%, pembangkit listrik tenaga diesel (PLTD) sekitar 33%, serta pembangkit listrik tenaga panas bumi (PLTP) sekitar 33%. Atas dasar itu, rata-rata efisiensi dari energi primer ke energi final sebesar 62%. Angka ini cukup optimistis karena telah mempertimbangkan faktor peningkatan teknologi.

Hasil ...

Hasil pemodelan untuk bauran energi primer pada tahun 2025 sudah sesuai dengan KEN, yaitu EBT minimal 23%, minyak bumi di bawah 25%, serta gas bumi sekitar 22%, dan batubara sekitar 30%.

Adapun untuk tahun 2050, proyeksi kebutuhan energi final mencapai 641,5 MTOE dan pasokan energi primer mencapai 1.012,3 MTOE. Rincian bauran energi primer, energi final, dan sektor pengguna pada tahun 2050 dapat dilihat pada Gambar 6.



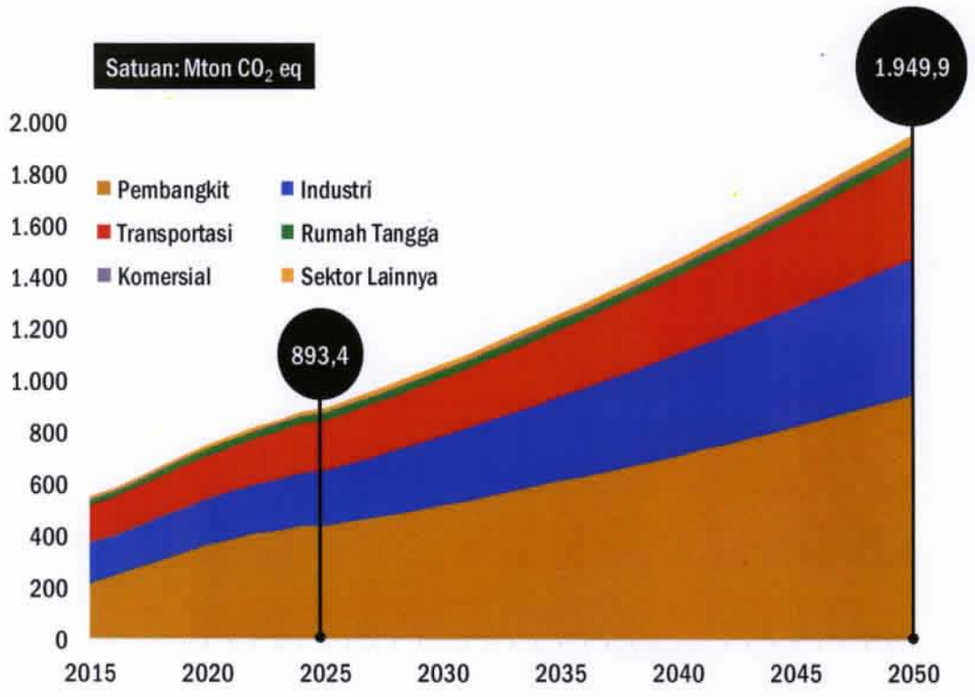
Gambar 6. Hasil Pemodelan Kebutuhan dan Pasokan Energi Tahun 2050

Seperti halnya pada hasil pemodelan tahun 2025, sektor pengguna energi final terbesar pada tahun 2050 adalah sektor industri dengan porsi 45,7% (termasuk untuk bahan baku). Selanjutnya diikuti oleh sektor transportasi sebesar 26,3%. Sektor lain yang cukup besar menggunakan energi final adalah sektor rumah tangga 14,2% dan sektor komersial 11,4%, dan sisanya sebesar 2,4% dari sektor lainnya.

2. Penurunan ...

2. Penurunan Dampak Emisi Gas Rumah Kaca (GRK)

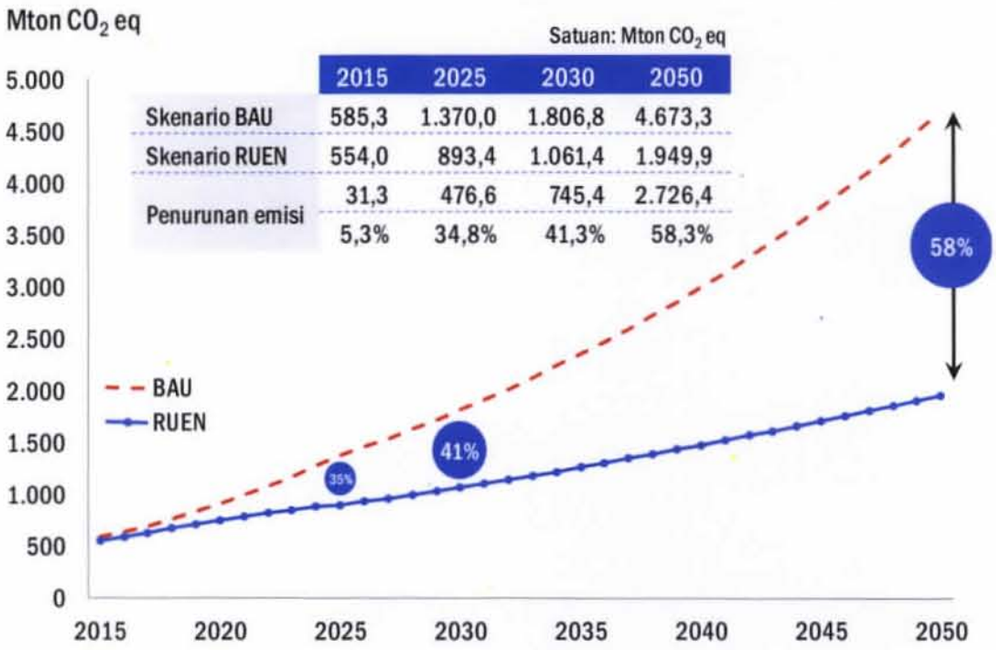
Sektor pembangkit listrik diproyeksikan akan menjadi penyumbang emisi terbesar, diikuti oleh sektor industri dan sektor transportasi. Proyeksi emisi GRK pada tahun 2025 sebesar 893 juta ton CO_2eq dan tahun 2050 sebesar 1.950 juta ton CO_2eq, sebagaimana dapat dilihat pada Gambar 7.



Gambar 7. Emisi Gas Rumah Kaca Tahun 2015–2050

Hasil pemodelan pencapaian sasaran KEN akan memberikan dampak penurunan GRK secara signifikan apabila dibandingkan dengan *Business as Usual* (BAU). Penurunan emisi GRK tahun 2025 sebesar 34,8% dan pada tahun 2050 sebesar 58,3%, sebagaimana dapat dilihat pada Gambar 8.

Gambar 8. ...



Gambar 8. Penurunan Emisi Gas Rumah Kaca Tahun 2015–2050

Penurunan emisi GRK disebabkan oleh empat faktor: *pertama*, diversifikasi energi, dengan meningkatkan porsi energi terbarukan dan mengurangi porsi energi fosil; *kedua*, pemanfaatan teknologi batubara bersih (*clean coal technology*) untuk pembangkitan tenaga listrik; *ketiga*, substitusi penggunaan energi dari BBM ke gas bumi; dan *keempat*, pelaksanaan program konservasi energi pada tahun-tahun mendatang.

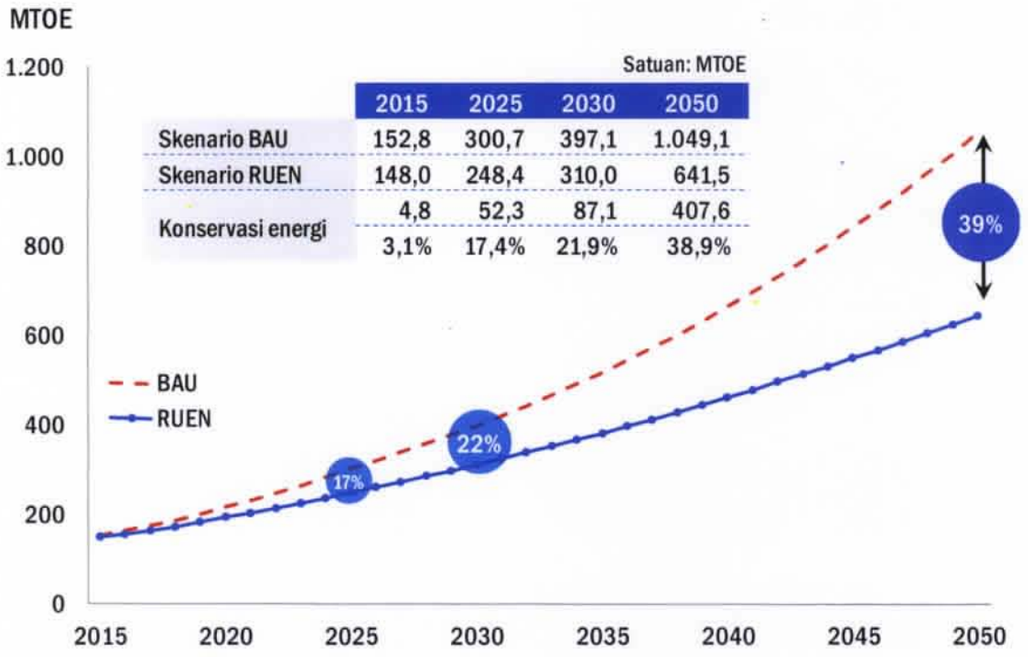
Penurunan emisi GRK dalam RUEN sudah sejalan dengan *Nationally Determined Contribution* (NDC) Indonesia sebesar 29% pada tahun 2030 yang merupakan bagian dari komitmen Indonesia untuk turut mendukung upaya pengendalian peningkatan suhu global rata-rata di bawah 2^0C.

3) Konservasi Energi

Proyeksi konservasi energi dilakukan pada semua sektor pengguna melalui:

- Implementasi manajemen energi.
- Penghematan bahan bakar.
- Efisiensi peralatan.
- Penggantian peralatan di sektor-sektor rumah tangga, industri, transportasi, komersial, dan sektor lainnya.

Upaya konservasi energi pada sektor pengguna menunjukkan adanya potensi efisiensi sekitar 52,3 MTOE di tahun 2025, yang setara dengan efisiensi 17,4% terhadap BAU. Sedangkan di tahun 2050, potensi efisiensi diperkirakan sebesar 407,6 MTOE, atau setara dengan efisiensi 38,9% terhadap BAU. Proyeksi konservasi energi dapat dilihat pada Gambar 9.

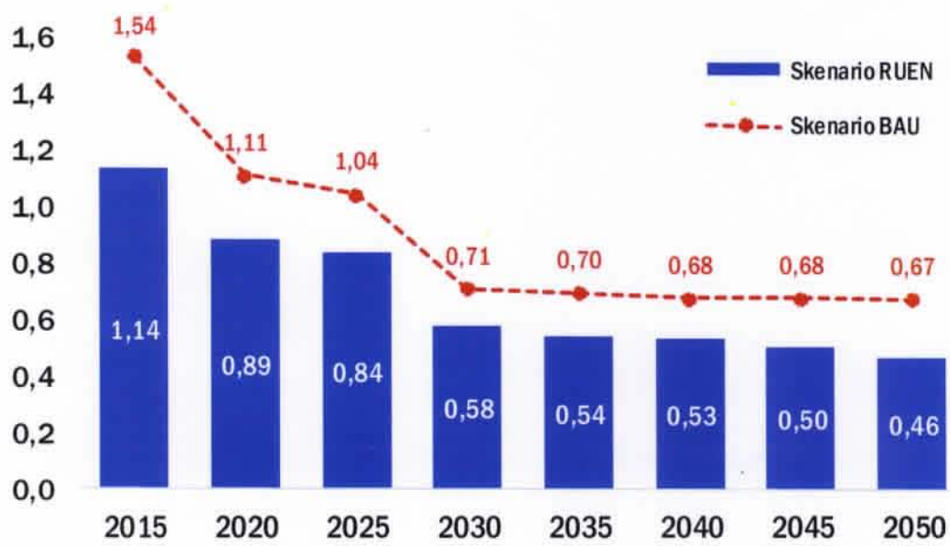


Gambar 9. Konservasi Energi pada Sisi Kebutuhan Tahun 2015–2050

4) Elastisitas Energi

Elastisitas energi merupakan rasio pertumbuhan konsumsi energi final dengan pertumbuhan PDB pada periode waktu yang sama. Elastisitas energi yang rendah atau di bawah satu, menunjukkan penggunaan energi yang efisien, karena untuk meningkatkan 1% pertumbuhan PDB, hanya dibutuhkan pertumbuhan kebutuhan energi di bawah 1%.

Sesuai dengan target KEN bahwa elastisitas energi harus di bawah satu mulai tahun 2025, maka elastisitas energi pada tahun 2025 diproyeksikan sebesar 0,84. Secara bertahap elastisitas energi akan menurun dari tahun ke tahun, dan pada tahun 2050 target elastisitas energi menjadi sebesar 0,46 yang menunjukkan penggunaan energi nasional akan semakin efisien, sebagaimana dapat dilihat pada Gambar 10.



Gambar 10. Elastisitas Energi Tahun 2015-2050

III. VISI, MISI, TUJUAN DAN SASARAN ENERGI NASIONAL

Bab ini menguraikan tentang visi, misi, tujuan, dan sasaran energi nasional yang diselaraskan dengan KEN.

3.1. Visi

Dengan mempertimbangkan masalah pokok energi nasional, tantangan pembangunan yang dihadapi dan capaian pembangunan nasional selama ini, maka Visi pengelolaan energi nasional adalah:

"TERWUJUDNYA PENGELOLAAN ENERGI YANG BERKEADILAN, BERKELANJUTAN, DAN BERWAWASAN LINGKUNGAN DENGAN MEMPRIORITASKAN PENGEMBANGAN ENERGI TERBARUKAN DAN KONSERVASI ENERGI DALAM RANGKA MEWUJUDKAN KEMANDIRIAN DAN KETAHANAN ENERGI NASIONAL"

Kemandirian dan ketahanan energi yang dimaksud adalah sebagai berikut:

- Kemandirian energi merupakan terjaminnya ketersediaan energi dengan memanfaatkan semaksimal mungkin potensi dari sumber dalam negeri.
- Ketahanan energi nasional adalah suatu kondisi ketersediaan energi, akses masyarakat terhadap energi pada harga yang terjangkau dalam jangka panjang dengan tetap memperhatikan perlindungan terhadap lingkungan hidup.

3.2. Misi

Untuk mewujudkan Visi tersebut di atas, maka Misi pengelolaan energi nasional adalah sebagai berikut:

a. Menjamin ketersediaan energi nasional.
b. Memaksimalkan potensi nasional berupa sumber daya alam dan sumber daya manusia untuk mencapai kemandirian energi.

c. Meningkatkan ...

c. Meningkatkan aksesibilitas energi dengan harga terjangkau kepada seluruh masyarakat.

d. Mengakselerasi pemanfaatan energi baru, energi terbarukan, dan konservasi energi.

e. Mengoptimalkan peningkatan nilai tambah penggunaan energi.

f. Mendorong pengelolaan energi yang berwawasan lingkungan.

3.3. Tujuan

Kemandirian dan ketahanan energi nasional dicapai dengan mewujudkan tujuan sebagai berikut:

a. Sumber daya energi tidak dijadikan sebagai komoditas ekspor semata tetapi sebagai modal pembangunan nasional.

b. Kemandirian pengelolaan energi.

c. Ketersediaan energi dan terpenuhinya kebutuhan sumber energi dalam negeri.

d. Pengelolaan sumber daya energi secara optimal, terpadu, dan berkelanjutan.

e. Pemanfaatan energi secara efisien di semua sektor.

f. Akses untuk masyarakat terhadap energi secara adil dan merata.

g. Pengembangan kemampuan teknologi, industri energi, dan jasa energi dalam negeri agar mandiri dan meningkatkan kapasitas sumber daya manusia.

h. Terciptanya lapangan kerja.

i. Terjaganya kelestarian fungsi lingkungan hidup termasuk terkendalinya dampak perubahan iklim.

3.4. Sasaran ...

3.4. Sasaran

Sasaran dalam rangka mewujudkan tujuan pengelolaan energi nasional sebagaimana tercantum dalam KEN, adalah sebagai berikut:

a. Terwujudnya paradigma baru bahwa energi sebagai modal pembangunan nasional.
b. Tercapainya bauran energi primer yang optimal:
   - EBT paling sedikit 23% pada tahun 2025 dan paling sedikit 31% pada tahun 2050.
   - Minyak bumi kurang dari 25% pada tahun 2025 dan kurang dari 20% pada tahun 2050.
   - Batubara minimal 30% pada tahun 2025 dan minimal 25% pada tahun 2050.
   - Gas Bumi minimal 22% pada tahun 2025 dan minimal 24% pada tahun 2050.
c. Terpenuhinya penyediaan energi primer pada tahun 2025 sekitar 400 MTOE (*Million Tonnes of Oil Equivalent*) dan pada tahun 2050 sekitar 1.000 MTOE.
d. Tercapainya pemanfaatan energi primer per kapita pada tahun 2025 sekitar 1,4 TOE (*Tonnes of Oil Equivalent*) dan pada tahun 2050 sekitar 3,2 TOE.
e. Terpenuhinya penyediaan kapasitas pembangkit listrik pada tahun 2025 sekitar 115 GW (Gigawatt) dan pada tahun 2050 sekitar 430 GW.
f. Tercapainya pemanfaatan listrik per kapita pada tahun 2025 sekitar 2.500 kWh (Kilowatt-hours) dan pada tahun 2050 sekitar 7.000 kWh.
g. Tercapainya elastisitas energi lebih kecil dari 1 (satu) pada tahun 2025 yang diselaraskan dengan target pertumbuhan ekonomi.
h. Tercapainya penurunan intensitas energi final sebesar 1 (satu) persen per tahun pada tahun 2025.
i. Tercapainya rasio elektrifikasi sebesar 85% pada tahun 2015 dan mendekati sebesar 100% pada tahun 2020.
j. Tercapainya rasio penggunaan gas rumah tangga pada tahun 2015 sebesar 85%.

IV. KEBIJAKAN DAN STRATEGI PENGELOLAAN ENERGI NASIONAL

4.1. Kebijakan dan Strategi

RUEN dilaksanakan dengan mengacu kepada PP Nomor 79 Tahun 2014 tentang KEN, yang memuat dua arah kebijakan yaitu kebijakan utama dan kebijakan pendukung sebagai berikut:

Kebijakan utama, meliputi:

1) Ketersediaan energi untuk kebutuhan nasional.
2) Prioritas pengembangan energi.
3) Pemanfaatan sumber daya energi nasional.
4) Cadangan energi nasional.

Kebijakan pendukung, meliputi:

1) Konservasi energi, konservasi sumber daya energi, dan diversifikasi energi.
2) Lingkungan hidup dan keselamatan.
3) Harga, subsidi, dan insentif energi.
4) Infrastruktur dan akses untuk masyarakat terhadap energi dan industri energi.
5) Penelitian, pengembangan, dan penerapan teknologi energi.
6) Kelembagaan dan pendanaan.

KEN mengamanatkan prioritas pemanfaatan sumber daya energi nasional dalam memenuhi kebutuhan energi nasional. Prioritas tersebut ditentukan berdasarkan beberapa faktor, di antaranya ketersediaan jenis/sumber energi, keekonomian, kelestarian lingkungan hidup, kecukupan untuk pembangunan yang berkelanjutan, dan kondisi geografis sebagai negara kepulauan. Prioritas pemanfaatan sumber daya energi nasional tersebut harus berujung pada tujuan utama KEN 2050 yaitu Kemandirian dan Ketahanan Energi Nasional.

Untuk ...

Untuk mencapai kemandirian dan ketahanan energi nasional, prioritas pengembangan energi didasarkan pada prinsip sebagai berikut:

Pertama, "Memaksimalkan penggunaan energi terbarukan dengan memperhatikan tingkat keekonomian". Tingkat keekonomian bukan saja dilihat dari harga, tetapi juga harus dilihat dampaknya pada hal-hal lain, diantaranya: lingkungan, peningkatan aktivitas ekonomi, dan penyerapan tenaga kerja. Dengan demikian maka pengembangan energi terbarukan ke depan harus tetap menjadi prioritas utama dengan tidak hanya mempertimbangkan aspek keekonomian semata.

Kedua, "Meminimalkan penggunaan minyak bumi". Indonesia juga harus mengurangi penggunaaan minyak bumi, karena kebutuhan minyak bumi nasional lebih besar daripada produksinya dan juga sumber daya minyak bumi nasional akan semakin menipis. Dengan demikian meminimalkan penggunaan minyak bumi akan mengurangi ketergantungan terhadap impor.

Ketiga, "Mengoptimalkan pemanfaatan gas bumi dan energi baru". Pemanfaatan gas bumi harus dioptimalkan untuk kebutuhan di dalam negeri sebagai bahan bakar pembangkit tenaga listrik, transportasi, rumah tangga, dan bahan baku industri. Indonesia juga memiliki potensi energi baru yang besar, antara lain: hidrogen, gas metana batubara (*coal bed methane/CBM*), batubara tercairkan (*liquified coal*), dan batubara tergaskan (*gasified coal*). Potensi energi baru ini cukup besar akan tetapi saat ini masih belum dikembangkan. Sementara itu, energi nuklir dapat dimanfaatkan dengan mempertimbangkan keamanan pasokan Energi Nasional dalam skala besar, mengurangi emisi karbon dan tetap mendahulukan potensi EBT sesuai dengan nilai keekonomiannya, serta mempertimbangkannya sebagai pilihan terakhir dengan memperhatikan faktor keselamatan secara ketat. Penjabaran lebih lanjut energi nuklir sebagai pilihan terakhir akan disusun dalam *roadmap* implementasi PLTN dengan mempersiapkan aspek teknologi, jenis bahan bakar, lokasi, keselamatan, pendanaan, dan kesiapan sumber daya manusia, disertai analisis multi kriteria.

Keempat, ...

Keempat, "Menggunakan batubara sebagai andalan pasokan energi nasional". Setelah memaksimalkan penggunaan energi terbarukan, meminimalkan penggunaan minyak bumi, dan mengoptimalkan pemanfaatan gas bumi dan energi baru, kekurangan kebutuhan dalam negeri dipenuhi dengan batubara khususnya dengan menggunakan teknologi bersih. Indonesia memiliki potensi sumber daya batubara yang cukup besar.

Selain prinsip-prinsip pengembangan energi di atas, karena Indonesia adalah negara kepulauan, maka kebutuhan energi di setiap pulau/daerah/wilayah, dipenuhi dengan memprioritaskan pemanfaatan potensi sumber daya energi setempat.

4.2. Pengembangan Energi Nasional

Amanat paling penting dari KEN adalah melaksanakan paradigma baru pengelolaan energi, bahwa energi tidak lagi dijadikan sebagai komoditas ekspor dan penghasil devisa melainkan sebagai modal pembangunan nasional. Selama ini, minyak bumi dan sumber daya energi lainnya lebih diutamakan sebagai komoditas penghasil devisa. Oleh karena itu, perlu kebijakan yang lebih komprehensif agar setiap barel minyak dan setiap ton energi lainnya yang keluar dari perut bumi bisa memberikan manfaat yang sebesar-besarnya untuk menggerakkan ekonomi nasional, baik sebagai bahan bakar maupun sebagai bahan baku industri.

Untuk mencapai amanat tersebut di atas, maka akan dilakukan kebijakan dan program, antara lain:

1. Peningkatan nilai tambah sumber daya energi dan sumber energi sebagai bahan bakar serta bahan baku industri nasional.
2. Penyelarasan target fiskal dengan kebijakan energi.
3. Pengurangan ekspor energi fosil (gas bumi, minyak bumi dan batubara) secara bertahap dan menetapkan batas waktu untuk memulai menghentikan ekspor.
4. Pencapaian maksimal penggunaan Energi Terbarukan dengan memperhatikan tingkat keekonomian.

5. Pencapaian ...

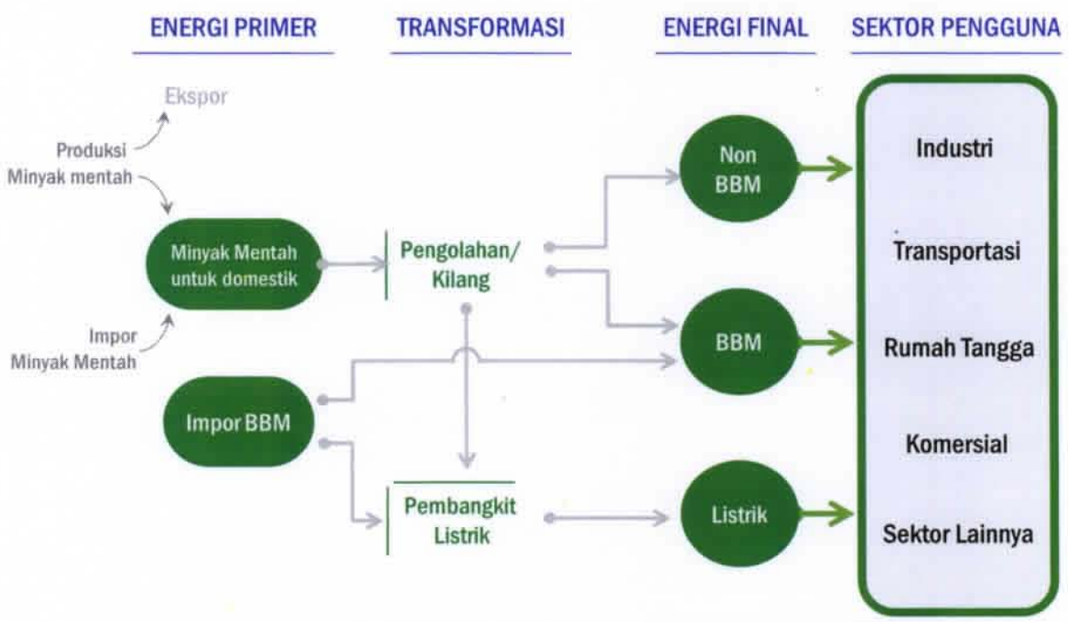
5. Pencapaian minimal penggunaan minyak bumi.
6. Pengoptimalan pemanfaatan gas bumi.
7. Penggunaan batubara sebagai andalan pasokan energi nasional, dengan menggunakan teknologi bersih.

Untuk mencapai tujuan KEN, akan dilaksanakan berbagai kebijakan, program dan kegiatan di sisi pasokan dan kebutuhan energi nasional, termasuk indikasi rencana pengembangan wilayah/provinsi sebagaimana diuraikan di bawah ini.

4.2.1. Pasokan Energi Primer

a. Minyak Bumi

Pasokan energi pimer untuk pemenuhan kebutuhan minyak bumi dalam negeri terdiri dari minyak mentah serta impor BBM. Minyak mentah untuk kebutuhan dalam negeri diperoleh dari sebagian produksi minyak dalam negeri dan impor. Kemudian minyak mentah tersebut diolah dalam kilang dalam negeri untuk menghasilkan BBM dan produk kilang lainnya (non BBM). Selanjutnya BBM dimanfaatkan sebagai bahan bakar pembangkit listrik dan sektor pengguna lainnya yaitu industri, transportasi, rumah tangga, komersial, dan sektor lainnya. Ilustrasi arus kebutuhan-pasokan minyak bumi dapat dilihat pada Gambar 11.



Gambar 11. Ilustrasi Arus Kebutuhan – Pasokan Minyak Bumi

Hasil ...

Hasil pemodelan pasokan energi primer minyak bumi dalam bauran energi primer tahun 2025 adalah sebesar 24,7% (98,7 MTOE) dan pada tahun 2050 sebesar 19,5% (197,7 MTOE). Porsi bauran energi primer minyak bumi tersebut sudah sesuai dengan target energi primer minyak bumi dalam KEN yaitu kurang dari 25% pada tahun 2025 dan kurang dari 20% pada tahun 2050. Proyeksi pasokan minyak bumi hingga tahun 2050 dapat dilihat pada Tabel 11.

Tabel 11. Hasil Pemodelan Pasokan Energi Primer – Minyak Bumi Tahun 2015–2050

Satuan: MTOE

Energi Primer	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Minyak bumi	75,7	76,4	77,7	79,3	81,4	82,8	98,7	112,9	150,9	197,7

Adapun pasokan minyak bumi yang harus dipenuhi pada tahun 2025 dan 2050 dapat dilihat pada Tabel 12.

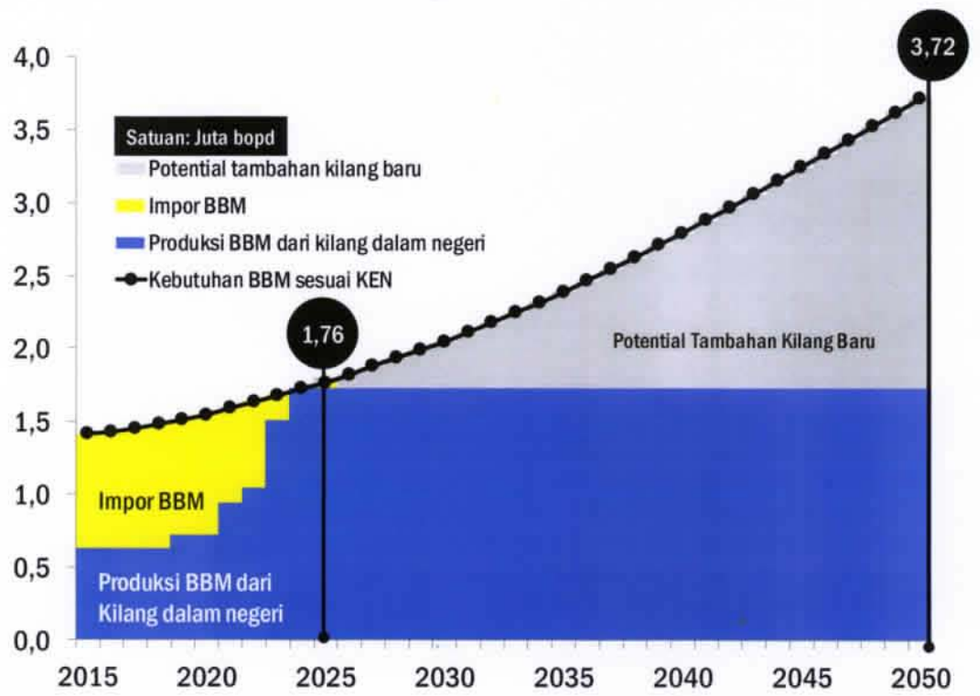
Tabel 12. Pasokan Energi Primer – Minyak Bumi Tahun 2025 dan 2050

Tahun	Pasokan Energi Primer	MTOE	Volume Kesetaraan		Bauran Energi Primer
2025	Minyak Bumi	98,7	1,9	Juta bopd	24,7%
2050	Minyak Bumi	197,7	3,9	Juta bopd	19,5%

Apabila minyak bumi tersebut telah diolah sepenuhnya menjadi BBM, maka volume pasokan BBM pada tahun 2025 yaitu sebesar 89,4 MTOE atau sekitar 1,76 juta BOPD dan pada tahun 2050 sebesar 188,4 MTOE atau sekitar 3,72 juta BOPD.

Kebutuhan ...

Kebutuhan BBM terus meningkat tiap tahun meskipun telah dilakukan pengendalian konsumsi dan diversifikasi BBM ke bahan bakar lain. Saat ini porsi impor BBM sekitar 52% dan akan dikurangi secara bertahap hingga tidak ada lagi impor BBM pada tahun 2025. Upaya tersebut dilakukan dengan peningkatan kapasitas kilang melalui pembangunan kilang baru dan revitalisasi kilang yang ada (*Refinery Development Master Plan*/RDMP) serta diversifikasi ke bahan bakar lain. Kebutuhan BBM dan produksi BBM oleh kilang nasional dapat dilihat pada Gambar 12.

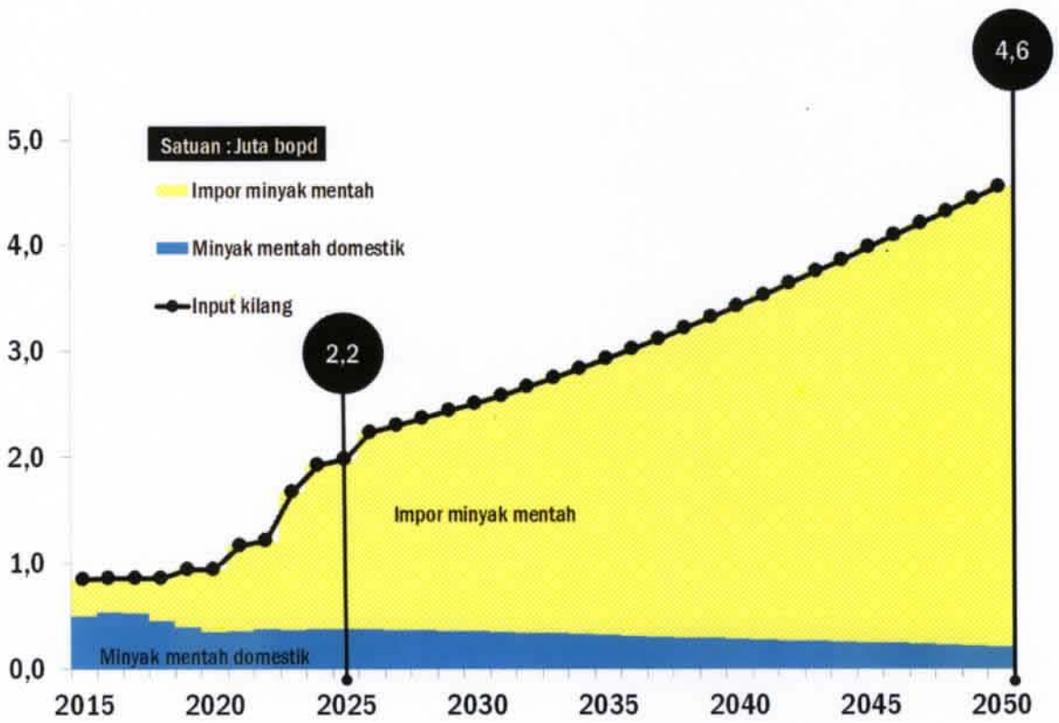


Gambar 12. Hasil Pemodelan Kebutuhan BBM Tahun 2015–2050

Peningkatan kapasitas kilang minyak berdampak pada peningkatan impor minyak mentah, jika kemampuan produksi lapangan minyak bumi dalam negeri semakin menurun. Peningkatan impor minyak mentah tersebut tetap mempunyai nilai strategis berupa peningkatan nilai tambah ekonomi dan lapangan kerja jika dibandingkan dengan impor BBM.

Impor ...

Impor minyak mentah yang meningkat dapat berkurang jika seluruh produksi minyak mentah dalam negeri digunakan untuk kebutuhan dalam negeri. Apalagi jika badan usaha migas milik negara yang mengusahakan blok migas di luar negeri membawa minyak mentahnya ke dalam negeri. Dalam Gambar 13 dapat dilihat perbandingan antara pasokan minyak mentah domestik dan impor minyak mentah dengan asumsi setelah tahun 2025, Pemerintah terus mengupayakan peningkatan kapasitas kilang sesuai dengan kebutuhan dalam negeri. Perbandingan ini telah memperhitungkan dampak diversifikasi ke bahan bakar lain.



Gambar 13. Pasokan Minyak Mentah Domestik dan Impor Minyak Mentah untuk Kilang Minyak Tahun 2015–2050

Kebutuhan minyak mentah untuk kilang domestik tahun 2025 mencapai sekitar 2,2 juta BOPD dan meningkat menjadi 4,6 juta BOPD tahun 2050, sebagaimana dapat dilihat di Tabel 13.

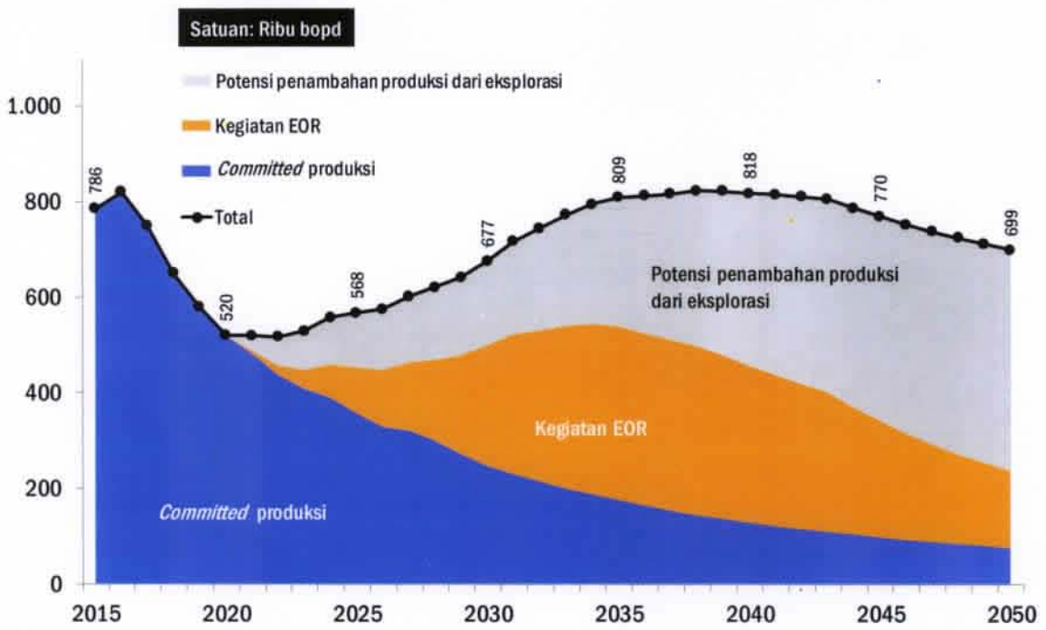
Tabel 13. Kebutuhan Minyak Mentah untuk Kilang Minyak Domestik Tahun 2015–2050

Satuan: Ribu bopd

Kebutuhan	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Minyak mentah domestik	487,9	552,3	503,5	442,1	400,2	365,0	471,2	575,1	695,3	594,0
Impor minyak mentah	445,5	386,5	435,3	496,7	618,6	653,8	1.725,4	1.963,2	2.775,9	4.025,9
Kebutuhan kilang minyak mentah	933,4	938,8	938,8	938,8	1.018,8	1.018,8	2.196,6	2.538,3	3.471,2	4.619,9

Kecenderungan produksi minyak bumi domestik diperkirakan menurun karena tambahan produksi dari lapangan baru belum dapat mengimbangi penurunan produksi dari lapangan lama dengan tingkat penurunan produksi (*production decline rate)* rata-rata sekitar 6% per tahun. Tambahan produksi diperkirakan akan diperoleh dari penemuan cadangan baru dan kegiatan *Enhanced Oil Recovery* (EOR), dengan asumsi: (a) pada tahun 2016 Rasio Pemulihan Cadangan (*Reserve Replacement Ratio* (RRR)) mencapai 60% dan terus meningkat hingga mencapai 100% pada tahun 2025; (b) dalam jangka waktu 5 tahun, 6,4% dari setiap penemuan cadangan baru dapat diproduksikan dengan tetap mempertimbangkan tingkat penurunan sebesar 10%; dan (c) kegiatan EOR mulai produksi tahun 2020 dengan jumlah cadangan yang bisa dipulihkan (*recovery*) sampai tahun 2050 sebesar 2,5 miliar barel dengan asumsi penurunan produksi sebesar 10%. Profil produksi minyak nasional dapat dilihat pada Gambar 14.

Gambar 14. ...



Gambar 14. Profil Produksi Minyak Bumi Tahun 2015–2050

Produksi minyak tersebut dimanfaatkan untuk kilang dalam negeri dan ekspor. Porsi ekspor direncanakan akan berkurang hingga sekitar 15% pada tahun 2030. Porsi ekspor minyak bumi dan pemanfaatan untuk kebutuhan dalam negeri dapat dilihat di Tabel 14.

Tabel 14. Produksi Minyak Bumi dan Porsi Pemanfaatan untuk Ekspor–Domestik Tahun 2015–2050

Satuan: Ribu bopd

Pemanfatan	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Domestik	487,9	552,3	503,5	442,1	400,2	365,0	471,2	575,1	695,3	594,0
	62%	67%	67%	68%	69%	70%	83%	85%	85%	85%
Ekspor	297,9	267,7	246,9	208,1	179,9	155,3	96,5	101,6	122,7	104,8
	38%	33%	33%	32%	31%	30%	17%	15%	15%	15%
Total produksi	785,8	820,0	750,4	650,2	580,1	520,3	567,7	676,5	818,0	698,8

Pada ...

Pada tahun 2015, Komite Eksplorasi Nasional mengusulkan tambahan potensi cadangan migas sebagai berikut:

- Potensi sumber daya migas sebesar 5,2 miliar BOE berasal dari *discovery*, yang dapat dipertimbangkan sebagai penambahan dalam cadangan migas tahun 2016; dan
- Potensi sumber daya migas sebesar 16,6 miliar BOE dari kegiatan eksplorasi awal, namun membutuhkan pengujian lebih lanjut.

Apabila temuan tersebut diupayakan dengan sungguh-sungguh melalui berbagai insentif, maka akan diperoleh tambahan cadangan, dan secara langsung dapat meningkatkan produksi minyak nasional.

Untuk mencapai sasaran pengembangan energi minyak bumi di atas, kegiatan yang dilakukan, antara lain:

1) Mengurangi ketergantungan impor BBM secara bertahap dan menghentikan impor BBM paling lambat tahun 2025.
2) Meningkatkan kapasitas kilang minyak nasional menjadi lebih dari 2 juta barel per hari pada tahun 2025, melalui pembangunan kilang baru dan Rencana Induk Pengembangan Kilang (*Refinery Development Master Plan*/RDMP), yang dapat dilakukan melalui:
    - Pembangunan 4 kilang minyak baru, dengan tambahan kapasitas sekitar 906 ribu BOPD; dan
    - RDMP yaitu peningkatan kapasitas 4 kilang Pertamina, dengan tambahan kapasitas sekitar 402 ribu BOPD;

Gambaran kapasitas terpasang dan pengembangan kilang minyak tahun 2015–2025 dapat dilihat pada Tabel 15.

Tabel 15. ...

Tabel 15. Kapasitas Terpasang dan Pengembangan Kilang Minyak Tahun 2015–2025

Satuan: Ribu bopd

No.	Nama Kilang	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1	Kilang baru	-	6	6	6	306	306	306	306	606	906	906
	a. Kilang Swasta PT. IKP		6	6	6	6	6	6	6	6	6	6
	b. GR *Refinery West*I (Tuban)							300	300	300	300	300
	c. Kilang Bontang Skema KPS									300	300	300
	d. *Grass Root Refinery West*II										300	300
2	RDMP	860	860	860	860	960	960	960	982	1.262	1.262	1.262
	a. Balikpapan	260	260	260	260	360	360	360	360	360	360	360
	b. Cilacap	348	348	348	348	348	348	348	370	370	370	370
	c. Dumai	127	127	127	127	127	127	127	127	257	257	257
	d. Balongan	125	125	125	125	125	125	125	125	275	275	275
3	Kilang saat ini	307	307	307	307	307	307	307	307	307	307	257
	a. Sungai Pakning	50	50	50	50	50	50	50	50	50	50	-
	b. Kasim	10	10	10	10	10	10	10	10	10	10	10
	c. Cepu (Pusdiklat)	3,8	3,8	3,8	3,8	3,8	3,8	3,8	3,8	3,8	3,8	3,8
	d. Tuban/TPPI	100	100	100	100	100	100	100	100	100	100	100
	e. TWU	6	6	6	6	6	6	6	6	6	6	6
	f. TWU II	10	10	10	10	10	10	10	10	10	10	10
	g. Plaju	127	127	127	127	127	127	127	127	127	127	127
	Total kapasitas	1.167	1.173	1.173	1.173	1.273	1.273	1.573	1.595	2.175	2.475	2.425
	Hasil produk kilang	782	786	786	786	853	853	1.091	1. 105	1.530	1.768	1.734

Catatan: Hasil produksi kilang telah mempertimbangkan kapasitas pengolahan kilang dan *losses* akibat proses pengolahan minyak mentah menjadi BBM dan produk kilang lainnya.

3) Mengurangi ekspor minyak mentah semaksimal mungkin dalam rangka memprioritaskan kebutuhan dalam negeri dan menghentikannya pada saat kilang dalam negeri sudah mampu menyerap seluruh produksi dalam negeri.

4) Meningkatkan rasio pemulihan cadangan minyak bumi hingga mencapai 100% pada tahun 2025, dengan meningkatkan kegiatan eksplorasi secara masif menjadi tiga kali lipat.

Gambaran cadangan minyak bumi per provinsi yang terdiri dari cadangan *proven*, *probable*, dan *possible* dapat dilihat pada Tabel 16.

Tabel 16. ...

Tabel 16. Cadangan Minyak Bumi Nasional per Provinsi

Satuan: Juta barel

No.	Wilayah/Provinsi	Cadangan			
		Proven	*Probable*	*Possible*	Total
1	Riau	1.190,9	997,0	687,3	2.875,2
2	Sumatera Selatan	660,2	181,8	249,9	1.091,9
3	Jawa Tengah	415,4	209,5	293,4	918,3
4	Jawa Barat	378,9	109,5	97,8	586,2
5	Kalimantan Timur	265,1	145,1	53,4	463,6
6	Jawa Timur	135,6	65,6	62,9	264,1
7	Kepulauan Riau	96,7	66,1	141,4	304,2
8	Papua-Papua Barat	87,5	8,0	0,5	96,0
9	Jambi	79,7	66,1	82,5	228,3
10	Aceh	78,8	23,8	12,5	115,0
11	Sumatera Utara	66,4	70,6	29,2	166,2
12	Lampung	51,0	0,2	-	51,2
13	Kalimantan Selatan	35,4	5,8	21,3	62,4
14	Sulawesi Tengah	30,2	2,5	1,0	33,7
15	DKI Jakarta	10,6	1,4	8,1	20,1
16	Sulawesi Selatan	10,5	2,7	-	13,2
17	Maluku	6,9	2,8	2,9	12,6
18	Bangka Belitung	2,7	-	-	2,7
19	Kalimantan Tengah	0,0005	0,0034	0,0004	0,0043
20	Timor-Maluku	-	-	-	-
	Total	3.602,5	1.958,3	1.744,2	7.305,0

5) Memastikan produksi minyak bumi tidak kurang dari 567,7 ribu BOPD pada tahun 2025.

6) Mengoptimalkan produksi lapangan minyak antara lain dengan memberlakukan kontrak bagi hasil (*Production Sharing Contract*/PSC) khusus untuk kegiatan *Enhanced Oil Recovery* (EOR) dan segera memutuskan status kontrak yang akan berakhir pada lapangan-lapangan yang mempunyai potensi EOR.

Beberapa ...

Beberapa lapangan minyak terkait dengan EOR dapat dilihat pada Tabel 17.

Tabel 17. Rencana Pilot Project EOR

No.	Lapangan	Wilayah/Provinsi
1	Gemah (Petrochina International Jabung Ltd.)	Jambi
2	Makmur (Petrochina International Jabung Ltd.)	Jambi
3	Minas (PT. Chevron Pacifik Indonesia /CPI)	Riau
4	Field Exclude Minas -6 lapangan (PT. CPI)	Riau
5	E-Main (PHE ONWJ)	*Offshore* Jawa Barat
6	Zulu (PHE ONWJ)	*Offshore* Jawa Barat
7	MQ (PHE ONWJ)	*Offshore* Jawa Barat
8	Zamrud (BOB CPP)	Riau
9	Pedada (BOB CPP)	Riau
10	Beruk (BOB CPP)	Riau
11	Pusaka (BOB CPP)	Riau
12	Melibur (EMP Mallaca Strait)	Riau
13	Rantau (PT. Pertamina EP)	Aceh
14	Tanjung (PT. Pertamina EP)	Kalimantan Selatan
15	Jirak (PT. Pertamina EP)	Sumatera Selatan
16	Limau (PT. Pertamina EP)	Sumatera Selatan
17	Rama (CNOOC SES Ltd.)	*Offshore* Sumatera Selatan, Lampung dan Banten
18	Krisna (CNOOC SES Ltd.)	*Offshore* Sumatera Selatan, Lampung dan Banten
19	Widuri (CNOOC SES Ltd.)	*Offshore* Sumatera Selatan, Lampung dan Banten
20	Kaji (Medco E&P Indonesia)	Sumatera Selatan
21	Semoga (Medco E&P Indonesia)	Sumatera Selatan
22	Semberah (VICO)	Kalimantan Timur
23	Beras (VICO)	Kalimantan Timur
24	Belida (ConocoPhilips)	Kepulauan Riau
25	Iliran High (Medco)	Sumatera Selatan
26	Sukowati (JOB PPEJ)	Jawa Timur
27	Mudi (JOB PPEJ)	Jawa Timur
28	KF (Starenergy)	Kepulauan Riau
29	KRA (Starenergy)	Kepulauan Riau
30	NE ASD (JOB PTOK)	Sumatera Selatan
31	Guruh (JOB PTOK)	Sumatera Selatan
32	Handil (Total)	Kalimantan Timur

7) Menyempurnakan sistem, syarat, dan ketentuan (*terms and conditions*) Kontrak Kerja Sama (KKS) migas konvensional dan non-konvensional yang lebih menarik bagi investasi.

8) Meningkatkan keterlibatan negara dalam pendanaan kegiatan eksplorasi melalui mekanisme pendanaan dari sebagian pendapatan negara dari migas (*petroleum fund*) yang merupakan bagian dari premi pengurasan (*depletion premium*) atau dari sumber pendanaan lainnya.

9) Meningkatkan ...

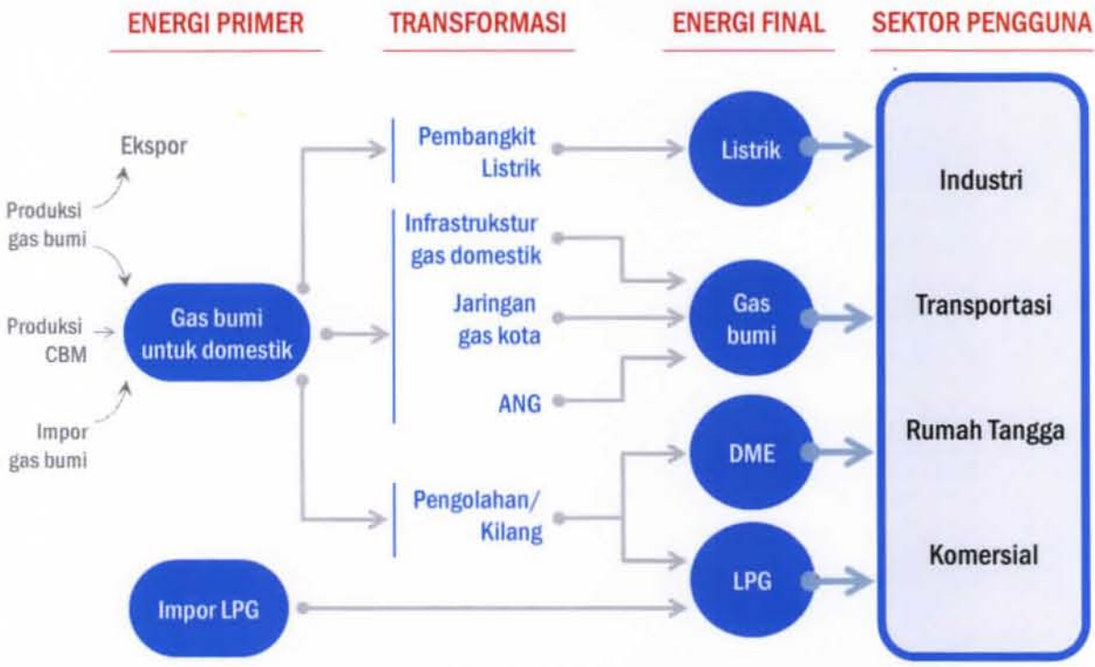
9) Meningkatkan tata kelola data hulu migas dalam rangka meningkatkan penawaran dan pengembangan WK migas, antara lain dengan menerapkan keterbukaan data migas dan tidak menjadikan data migas sebagai objek Penerimaan Negara Bukan Pajak (PNBP) semata.

10) Melakukan riset dasar eksplorasi migas dalam rangka meningkatkan cadangan migas, antara lain riset migas non-konvensional, riset sistem petroleum pra-tersier, riset sistem petroleum gunung api, dan riset gas biogenik.

b. Gas Bumi

Pasokan energi pimer untuk pemenuhan kebutuhan gas bumi dalam negeri terdiri dari sebagian produksi gas bumi dalam negeri dan impor LPG. Selanjutnya gas bumi tersebut dimanfaatkan setelah proses transformasi melalui kilang, fasilitas pengolahan, dan pembangkit listrik dan menghasilkan energi final berupa listrik, LPG, dan *Dimethyl Ether* (sebagai campuran LPG), yang dimanfaatkan oleh sektor pengguna. Sedangkan impor LPG langsung dimanfaatkan oleh sektor pengguna. Sektor pengguna gas bumi yaitu industri, transportasi, rumah tangga, komersial, dan sektor lainnya. Adapun pemanfaatan langsung gas bumi yaitu melalui jaringan gas kota dan tabung *Adsorbed Natural Gas* (ANG) yaitu tabung dengan teknologi khusus untuk menyimpan gas bumi dalam tekanan yang aman dan volume yang memadai. Ilustrasi arus kebutuhan-pasokan gas bumi dapat dilihat pada Gambar 15.

Gambar 15. ...



Gambar 15. Ilustrasi Arus Kebutuhan – Pasokan Gas Bumi

Pangsa gas bumi dalam bauran energi primer tahun 2025 sebesar 22,4% (89,5 MTOE) dan pada tahun 2050 sebesar 24,0% (242,9 MTOE), sesuai dengan sasaran energi primer gas bumi dalam KEN. Pasokan energi primer gas bumi terdiri dari pasokan gas bumi untuk domestik dan impor LPG. Hasil pemodelan pasokan energi primer gas bumi dapat dilihat pada Tabel 18.

Tabel 18. Hasil Pemodelan Pasokan Energi Primer – Gas Bumi Tahun 2015–2050

Satuan: MTOE

Pasokan Energi	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Gas bumi untuk domestik	39,2	41,7	44,9	48,3	51,3	55,5	84,7	104,2	166,6	237,7
	91%	91%	91%	91%	91%	91%	95%	96%	97%	98%
Impor LPG	3,8	4,2	4,5	4,8	5,2	5,5	4,8	4,9	5,0	5,2
	8,9%	9,1%	9,0%	9,1%	9,2%	9,1%	5,3%	4,5%	2,9%	2,1%
Total	43,0	45,9	49,4	53,1	56,5	61,0	89,5	109,1	171,6	242,9

Adapun ...

Adapun pasokan gas bumi dan LPG yang harus dipenuhi pada tahun 2025 dan 2050 dalam satuan juta standar kaki kubik per hari/*standard cubic feet per day* (MMSCFD) dan juta ton dapat terlihat dalam Tabel 19.

Tabel 19. Pasokan Energi Primer – Gas Bumi Tahun 2025 dan 2050

Tahun	Pasokan Energi Primer	MTOE	Volume Kesetaraan		Bauran Energi Primer
2025	**GAS BUMI**	**89,5**	**9.786,7**	**MMSCFD**	**22,4%**
	- Gas bumi untuk domestik	**84,7**	**9.221,1**	MMSCFD	
	- Impor LPG	**4,8**	**4,0**	Juta ton	
2050	**MINYAK BUMI**	**242,9**	**27.013,1**	**MMSCFD**	**24,0%**
	- Gas bumi untuk domestik	**237,7**	**25.869,1**	MMSCFD	
	- Impor LPG	**5,2**	**4,4**	Juta ton	

Berdasarkan sasaran KEN, pasokan energi primer gas bumi yang terdiri dari gas bumi untuk domestik dan impor LPG tahun 2025 sebesar 9.786,7 MMSCFD dan tahun 2050 sebesar 27.013,1 MMSCFD.

Adapun pasokan gas bumi untuk domestik, berasal dari:

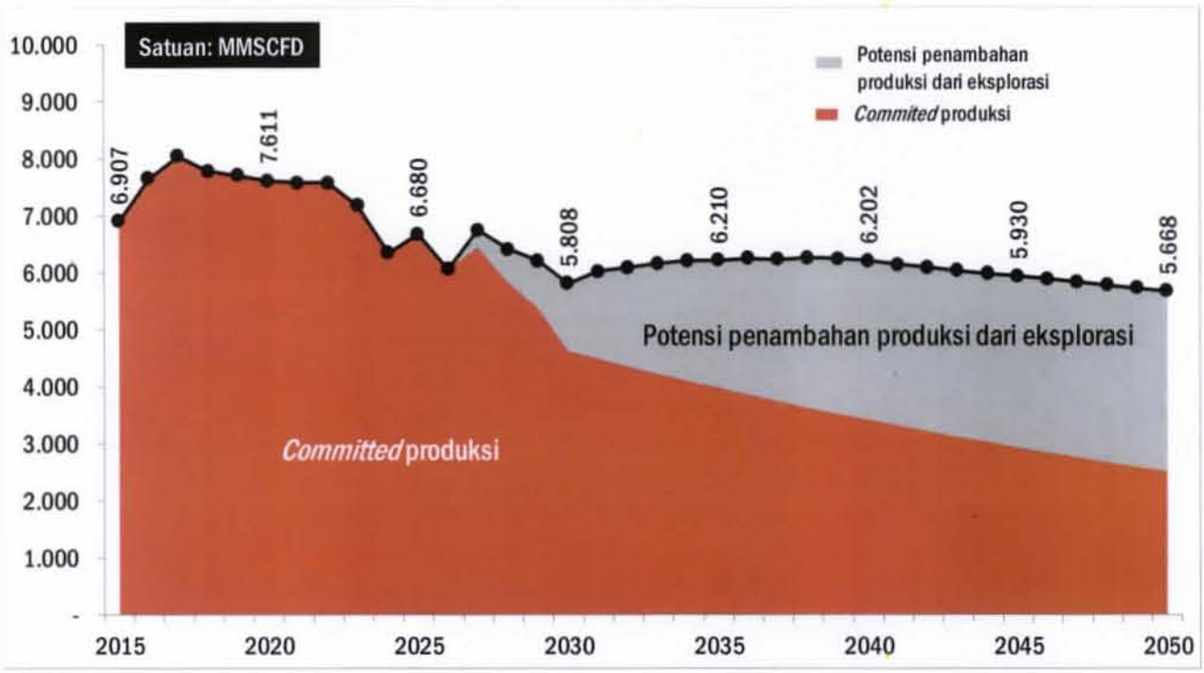
1. Sebagian produksi gas bumi nasional, mengingat produksi nasional tidak seluruhnya digunakan untuk dalam negeri karena masih ada komitmen ekspor gas bumi hingga tahun 2035, meskipun volumenya akan semakin berkurang secara signifikan, sebagaimana dapat dilihat pada Tabel 20.

Tabel 20. Produksi/*Lifting* Gas Bumi dan Pemanfaatan untuk Ekspor – Domestik Tahun 2015–2050

Satuan: MMSCFD

Keterangan	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Ekspor	2.786,0	2.561,0	2.464,0	2.010,0	2.041,0	1.975,0	948,0	707,2	-	-
	40,3%	33,5%	30,6%	25,8%	26,5%	25,9%	14,2%	12,2%	0%	0%
Domestik	4.121,0	5.094,0	5.578,0	5.774,0	5.667,0	5.636,0	5.732,0	5.100,9	6.202,4	5.668,1
	59,7%	66,5%	69,4%	74,2%	73,5%	74,1%	85,8%	87,8%	100%	100%
Total *lifting* gas bumi	6.907,0	7.655,0	8.042,0	7.784,0	7.708,0	7.611,0	6. 680,0	5.808,1	6.202,4	5.668,1

Profil produksi gas bumi nasional juga dapat dilihat pada Gambar 16.



Gambar 16. Profil Produksi Gas Bumi Tahun 2015–2050

2. Impor gas alam (*natural gas)* atau potensi produksi dari tambahan temuan cadangan, dengan mempertimbangkan adanya potensi defisit gas mulai tahun 2020 sekitar 401,8 MMSCFD dan semakin meningkat sampai dengan tahun 2050 sebesar 20.201,0 MMSCFD.

Kebutuhan dan rencana pasokan gas bumi untuk domestik, dapat dilihat pada Tabel 21 dan Gambar 17.

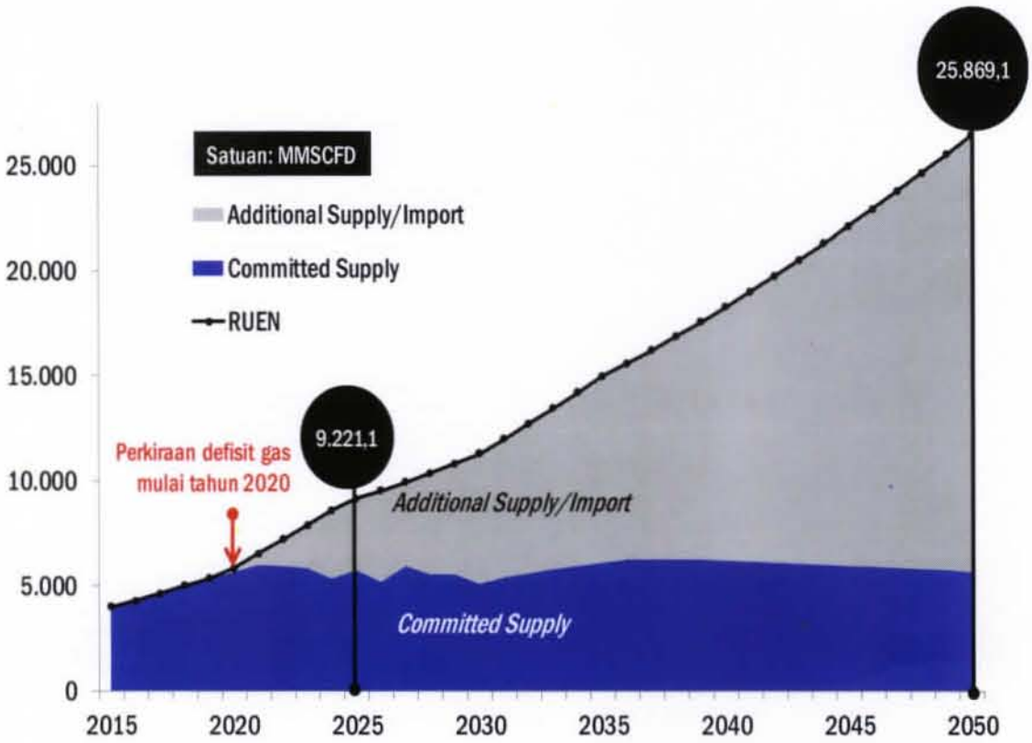
Tabel 21. Kebutuhan dan Rencana Pasokan Gas Bumi Tahun 2015–2050

Satuan: MMSCFD

Keterangan	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Kebutuhan gas bumi dalam negeri*	4.121,0	5.094,0	5.578,0	5.774,0	5.667,0	6.037,8	9.221,1	11.338,6	18.113,8	25.869,1
- *Committed production*	4.121,0	5.094,0	5.578,0	5.774,0	5.667,0	5.636,0	5.732,0	5.100,9	6.202,4	5.668,1
- Surplus/(defisit)	-	-	-	-	-	(401,8)	(3.489,1)	(6.237,7)	(11.931,4)	(20.201,0)

Catatan :
*) Tidak termasuk kebutuhan impor LPG

Gambar 17. ...

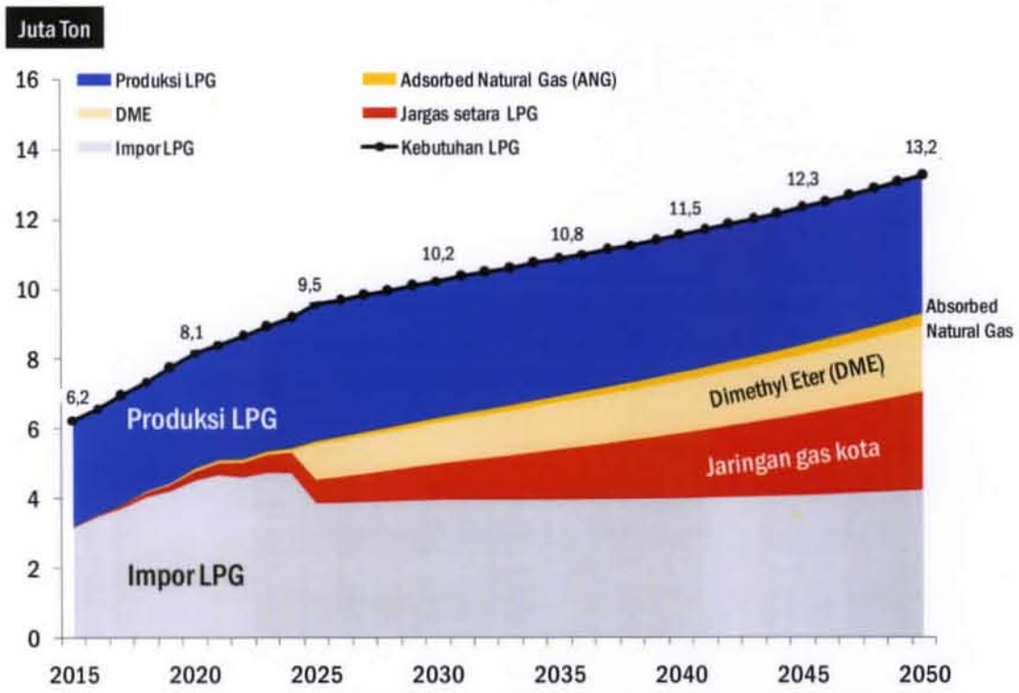


Gambar 17. Kebutuhan dan Rencana Pasokan Gas Bumi Tahun 2015–2050

Energi primer gas bumi juga mencakup kebutuhan LPG yang dipenuhi dari produksi kilang LPG dan impor LPG. Produksi LPG dalam negeri relatif tidak mengalami peningkatan akibat keterbatasan bahan baku LPG, sehingga lebih dari 50% pasokan LPG domestik saat ini dipenuhi dari impor.

Kebutuhan LPG tahun 2025 diproyeksikan sebesar 9,5 juta ton dan tahun 2050 sebesar 13,2 juta ton, apabila tidak dilakukan kebijakan terkait pengurangan impor. Kebutuhan LPG dan skenario pengurangan impor LPG melalui pengembangan jaringan gas kota, DME, dan tabung ANG secara lebih detail dapat dilihat pada Gambar 18.

Gambar 18. ...



Gambar 18. Hasil Pemodelan Kebutuhan dan Pasokan LPG Tahun 2015–2050

Pemodelan kebutuhan dan pasokan LPG beserta produk lainnya secara rinci dapat dilihat pada Tabel 22.

Tabel 22. Hasil Pemodelan Kebutuhan dan Pasokan LPG Tahun 2015–2050

Satuan: Juta ton

Keterangan	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Produksi LPG	3,0	3,0	3,1	3,1	3,1	3,1	3,7	3,7	3,7	3,7
Impor LPG	3,2	3,5	3,7	4,1	4,4	4,7	4,0	4,2	4,2	4,4
DEMAND LPG (dengan upaya pengurangan impor LPG)	6,2	6,5	6,8	7,2	7,5	7,8	7,8	7,9	7,9	8,1
- Jaringan gas kota	0,0	0,048	0,09	0,13	0,2	0,3	0,7	1,0	1,9	2,8
- DME	0,0	0,002	0,002	0,04	0,04	0,04	1,0	1,2	1,5	1,9
- Tabung ANG	-	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,2	0,4
DEMAND LPG (tanpa upaya pengurangan impor LPG)	6,2	6,55	6,9	7,3	7,7	8,1	9,5	10,2	11,5	13,2

Untuk ...

Untuk mencapai sasaran pengembangan energi gas bumi di atas, kegiatan yang dilakukan, antara lain:

1) Memastikan produksi gas bumi menjadi tidak kurang dari 6.700 juta kaki kubik per hari (MMSCFD) pada tahun 2025.
2) Mengurangi porsi ekspor gas bumi menjadi kurang dari 20% pada tahun 2025 dan menghentikan ekspor gas bumi paling lambat tahun 2036, dengan menjamin penyerapan produksi gas dalam negeri untuk industri yang terintegrasi hulu-hilir, transportasi dan sektor lainnya.
3) Menyelesaikan kebijakan harga gas bumi dengan membentuk badan penyangga gas nasional.
4) Meningkatkan rasio pemulihan cadangan gas bumi hingga mencapai 100% pada tahun 2025, dengan meningkatkan kegiatan eksplorasi secara masif menjadi tiga kali lipat.

Gambaran cadangan gas bumi per provinsi yang terdiri dari cadangan terbukti (*proven*), terukur (*probable*) dan tereka (*possible*) dapat dilihat pada Tabel 23.

Tabel 23. Cadangan Gas Bumi Nasional

Satuan: B*illion cubic feet* (BCF)

No.	Wilayah/Provinsi	Cadangan			
		Proven	*Probable*	*Possible*	Total
1	Kepulauan Riau	47.399,1	1.100,6	1.508,3	50.008,0
2	Papua-Papua Barat	16.627,4	4.377,0	5.201,7	26.206,1
3	Sumatera Selatan	8.659,8	2.191,0	2.735,1	13.585,9
4	Timor-Maluku	6.236,9	5.077,0	7.970,2	19.284,0
5	Kalimantan Timur	5.880,6	2.894,4	2.938,9	11.713,9
6	Jawa Timur	2.983,7	1.138,2	1.256,0	5.377,9
7	Jawa Barat	2.976,7	347,3	834,6	4.158,6
8	Sulawesi Tengah	1.729,3	233,2	67,8	2.030,3
9	Aceh	1.420,8	4.720,4	1.375,0	7.516,3
10	Jambi	1.137,4	1.323,4	3.057,0	5.517,8
11	Kalimantan Selatan	988,1	327,9	377,1	1.693,1
12	Jawa Tengah	512,3	110,0	374,3	996,5
13	Sumatera Utara	447,5	503,1	4,9	955,5
14	Sulawesi Selatan	392,7	120,1	21,2	534,0
15	Riau	290,0	325,1	478,6	1.093,8
16	Lampung	207,2	39,6	-	246,9
17	DKI Jakarta	63,1	14,1	46,5	123,7
18	Kalimantan Tengah	30,0	228,0	28,0	286,0
19	Bangka Belitung	3,2	-	-	3,2
	Total	97.985,9	25.070,3	28.275,2	151.331,4

5) Mempercepat ...

5) Mempercepat penyelesaian proyek gas bumi antara lain sebagaimana dapat dilihat pada Tabel 24.

Tabel 24. Target Proyek Hulu Gas Bumi

No.	Lapangan	Wilayah/Provinsi	Target Selesai
1	Blok Sengkang	Sulawesi Selatan	2016
2	Blok Matindok	Sulawesi Tengah	2016
3	Proyek IDD	Kalimantan Timur, Bangka	2016
4	Lapangan MDA-MBH (*Blok Offshore Madura Strait*)	Jawa Timur	2019
5	Blok A	Aceh	2017
6	Lapangan Jangkrik (Blok Muara Bakau)	Kalimantan Timur	2017
7	Lapangan Jambaran Tiung Biru (Blok Cepu)	Jawa Timur	2019
8	Proyek Tangguh Train-3	Papua Barat	2020
9	Lapangan Abadi (Blok Masela)	Maluku	2030
10	Blok East Natuna	Kepulauan Riau	2028

6) Mempercepat penyelesaian pembangunan infrastruktur gas bumi, antara lain sebagaimana dapat dilihat pada Tabel 25.

Tabel 25. Target Pembangunan Infrastruktur Hilir Gas Bumi

No.	Proyek	Provinsi	Target Selesai
1	LNG South Sulawesi	Sulawesi Selatan	2016
2	Pipa Muara karang-Muara Tawar-Tegal Gede	Jakarta-Jawa Barat	2016
3	Receiving Terminal Banten	Banten	2017
4	FSRU Jawa Tengah	Jawa Tengah	2017
5	Pipa Gresik Semarang	Jawa Tengah-Timur	2017
6	LNG Tangguh Train-3	Papua Barat	2020

7) Melakukan ...

7) Melakukan komersialisasi menara bor purwarupa (*prototype rig) Coal Bed Methane* (CBM) yang telah dibuat dengan target 2 unit per tahun, dalam rangka meningkatkan dan mengefisienkan kegiatan eksplorasi dan eksploitasi CBM.
8) Menetapkan harga gas yang kompetitif untuk konsumen dalam negeri, khususnya industri, dalam rangka meningkatkan nilai tambah.
9) Mengendalikan impor LPG menjadi di bawah 50% dari kebutuhan gas nasional pada tahun 2050, antara lain:
   - Membangun jaringan gas kota bagi 4,7 juta sambungan rumah tangga atau setara 0,7 juta ton LPG pada tahun 2025.
   - Membangun fasilitas pengolahan DME (sebagai campuran LPG) dengan rencana produksi sekitar 0,4 juta ton pada tahun 2025.
   - Mengembangkan tabung khusus (*absorbed natural gas*/ANG) dengan rencana pengembangan sebesar 0,1 juta ton pada tahun 2025.

Tabel 26. Rencana Pengembangan Jaringan Gas Kota Tahun 2015–2030

No.	Lapangan	Satuan	2015	2016	2017	2018	2019	2020	2025	2030
1	Sambungan rumah	Ribu SR	211	332	604	910	1.284	1.834	4.734	7.734
2	Indikasi kebutuhan gas	MMSCFD	3	5	10	15	21	30	77	126

Rencana pengembangan jaringan gas kota tahun 2015-2030 dapat dilihat pada Tabel 26. Indikasi lokasi pengembangan jaringan gas kota, sebagai berikut:

- Tahun 2015-2020: Surabaya, Sidoarjo, Gresik, Pasuruan, Batam, Cilegon, Bekasi, Karawang, Semarang, Lampung, Jambi, Sukabumi, Subang, Jombang, Ngoro-Mojokerto, Medan, Belawan, Pekalongan, Pati, Makassar, Indramayu, Purwakarta, Palembang, Solo Raya, Pekanbaru, Prabumulih, Jakarta;

• Tahun ...

- Tahun 2021-2025: Bandung, Arjawinangun, Wajo, Bontang, Majalengka, Malang, Balikpapan, Samarinda, Asahan, Langkat, Binjai, Tebing Tinggi, Aceh, Ogan Ilir, Jepara, Cianjur, Demak, Kudus, Grobogan, Bojonegoro, Kutai Timur, Banggai, Morowali, Seram, Ambon, Bintuni, Lamongan, Bangkalan; dan
- Tahun 2026-2030: Deli Serdang, Bandung Kabupaten, Cirebon, Probolinggo, Tuban, Yogyakarta.

c. Batubara

Hasil pemodelan pasokan energi primer batubara dalam bauran energi primer tahun 2025 adalah sebesar 30,0% (119,8 MTOE) dan pada tahun 2050 sebesar 25,3% (255,9 MTOE). Porsi bauran energi primer batubara tersebut sudah sesuai dengan target bauran energi primer batubara dalam KEN. Hasil pemodelan pasokan energi primer batubara dapat dilihat pada Tabel 27.

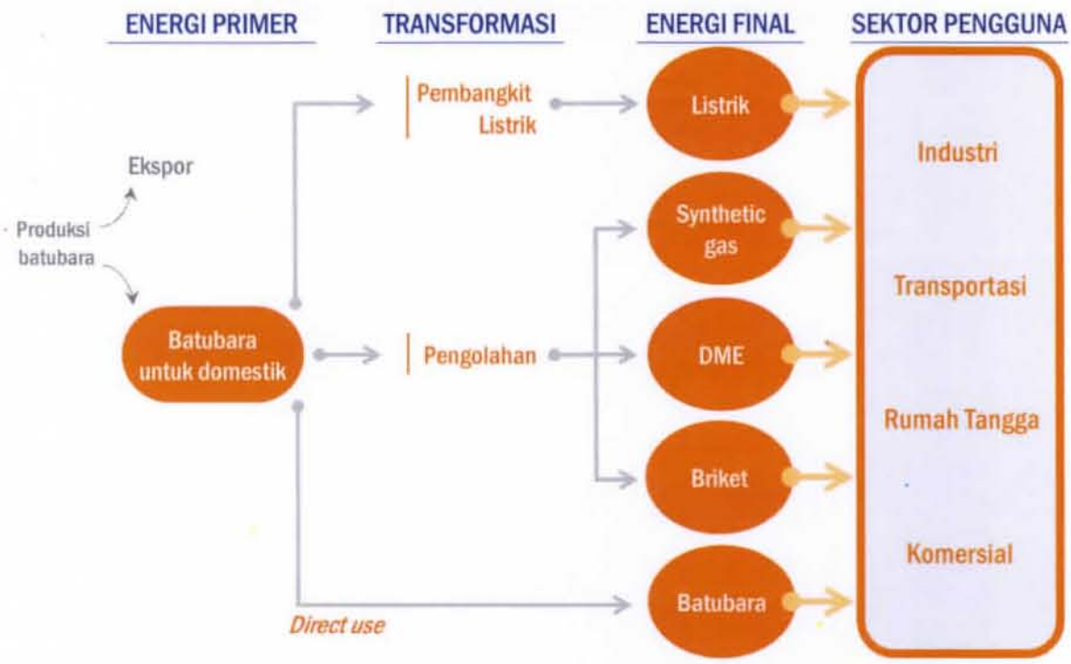
Tabel 27. Hasil Pemodelan Pasokan Energi Primer – Batubara Tahun 2015–2050

Satuan: MTOE

Energi Primer	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Batubara	67,6	73,5	80,7	88,4	97,6	104,8	119,8	147,5	198,4	255,9

Sebagian besar pasokan energi primer batubara tersebut dimanfaatkan langsung untuk pembangkit listrik dan sektor industri. Selebihnya diproses menjadi *synthetic gas* (melalui *coal gasification*), *Dimethyl Ether*, dan briket, yang dimanfaatkan antara lain oleh sektor rumah tangga, industri, dan komersial. Ilustrasi arus kebutuhan dan pasokan batubara dapat dilihat pada Gambar 1.

Gambar 19. ...



Gambar 19. Ilustrasi Arus Kebutuhan – Pasokan Batubara

Adapun pasokan batubara untuk kebutuhan domestik pada tahun 2025 dan 2050 dalam satuan juta ton dapat dilihat pada Tabel 28.

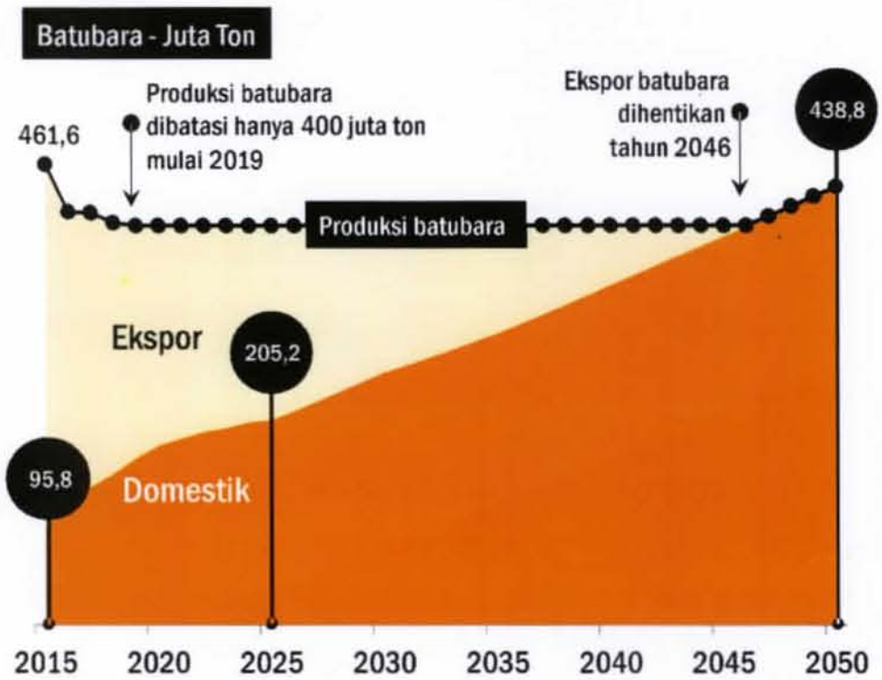
Tabel 28. Pasokan Energi Primer – Batubara Tahun 2025 dan 2050

Tahun	Pasokan Energi Primer	MTOE	Volume Kesetaraan		Bauran Energi Primer
2025	BATUBARA	119,8	205,3	Juta Ton	30,0%
2050	BATUBARA	255,9	438,8	Juta Ton	25,3%

Kebutuhan batubara domestik akan meningkat tiap tahun seiring dengan peningkatan kebutuhan domestik untuk bahan bakar pembangkit listrik dan sektor industri. Produksi batubara tahun 2015 mencapai sekitar 461,6 juta ton dan mulai tahun 2019 akan dikendalikan maksimal sebesar 400 juta ton kecuali kebutuhan domestik melebihi 400 juta ton.

Ekspor ...

Ekspor batubara akan dihentikan paling lambat pada tahun 2046 saat kebutuhan domestik mencapai lebih dari 400 juta ton. Profil kebutuhan dan produksi batubara dapat dilihat pada Gambar 20.



Gambar 20. Hasil Pemodelan Kebutuhan dan Produksi Batubara Domestik dan Ekspor

Secara lebih rinci, angka produksi batubara yang mencakup pemenuhan kebutuhan domestik dan ekspor dapat dilihat pada Tabel 29.

Tabel 29. Hasil Pemodelan Produksi Batubara Tahun 2015–2050

Satuan: Juta ton

Keterangan	2015	2016	2017	2018	2019	2020	2025	2030	2040	2045	2050
Domestik	95,8	125,9	138,2	151,4	167,1	179,6	205,2	252,7	340,1	388,6	438,7
	20,7%	30,4%	33,5%	37,6%	41,8%	44,9%	51,3%	63,2%	85,0%	97,2%	100%
Ekspor	365,8	288,1	274,8	251,6	232,9	220,4	194,8	147,3	59,9	11,4	0
Total Produksi	461,6	414,0	413,0	403,0	400,0	400,0	400,0	400,0	400,0	400,0	438,7

Untuk ...

Untuk mencapai sasaran pengembangan energi batubara di atas, kegiatan yang dilakukan, antara lain:

1) Mengendalikan produksi batubara maksimal sebesar 400 juta ton mulai tahun 2019.
2) Mengurangi porsi ekspor batubara secara bertahap dan menghentikan ekspor batubara paling lambat tahun 2046, dalam rangka memprioritaskan kebutuhan dalam negeri.
3) Moratorium pemberian Izin Usaha Pertambangan (IUP) dan Izin Usaha Pertambangan Khusus (IUPK) batubara di hutan alam primer dan lahan gambut yang berada di hutan konservasi, hutan lindung, hutan produksi, dan area penggunaan lain.
4) Mewajibkan pemanfaatan teknologi energi batubara yang ramah lingkungan (*Clean Coal Technology*/CCT) dan efisiensi tinggi (*Ultra Super Critical*/USC) secara bertahap.
5) Meningkatkan kualitas survei geologi oleh lembaga Pemerintah untuk eksplorasi sumber daya dan cadangan batubara.

Sumber daya dan cadangan batubara per provinsi dapat dilihat pada Tabel 30 di bawah ini.

Tabel 30. Sumber Daya dan Cadangan Batubara

Satuan: juta ton

No.	Provinsi	Sumber Daya	Cadangan		
		Total	Terkira	Terbukti	Total
1	Sumatera Selatan	50.226,3	9.944,8	2.053,5	11.998,3
2	Kalimantan Timur	48.180,2	11.918,5	3.188,4	15.106,8
3	Kalimantan Selatan	16.477,0	1.169,9	2.475,3	3.645,3
4	Kalimantan Tengah	3.426,6	234,3	440,5	674,8
5	Jambi	2.224,9	17,8	76,5	94,3
6	Riau	1.800,1	54,5	633,3	687,8
7	Sumatera Barat	795,5	-	158,4	158,4
8	Kalimantan Barat	491,5	-	-	-
9	Aceh	450,6	-	-	-
10	Sulawesi Selatan	231,1	0,1	0,1	0,1
11	Bengkulu	192,1	-	19,0	19,0
12	Papua Barat	126,5	-	-	-
13	Lampung	107,9	-	-	-
14	Sumatera Utara	27,2	-	-	-
15	Banten	18,8	-	-	-
16	Papua	9,3	-	-	-
17	Maluku Utara	8,2	-	-	-
18	Sulawesi Tengah	2,0	-	-	-
19	Jawa Tengah	0,8	-	-	-
20	Jawa Timur	0,1	-	-	-
Total		124.796,7	23.339,9	9.044,8	32.384,7

d. EBT

1. Pasokan Nasional

Hasil pemodelan pasokan energi primer EBT dalam bauran energi primer tahun 2025 sebesar 23,0% (92,3 MTOE) dan pada tahun 2050 sebesar 31,2% (315,7 MTOE). Porsi bauran energi primer EBT tersebut sudah sesuai dengan target energi primer EBT dalam KEN yaitu pada tahun 2025 paling sedikit 23% dan pada tahun 2050 paling sedikit 31%. Hasil pemodelan pasokan energi primer EBT dapat dilihat pada Tabel 31.

Tabel 31. Hasil Pemodelan Pasokan Energi Primer – EBT

Tahun 2015-2050

Satuan: MTOE

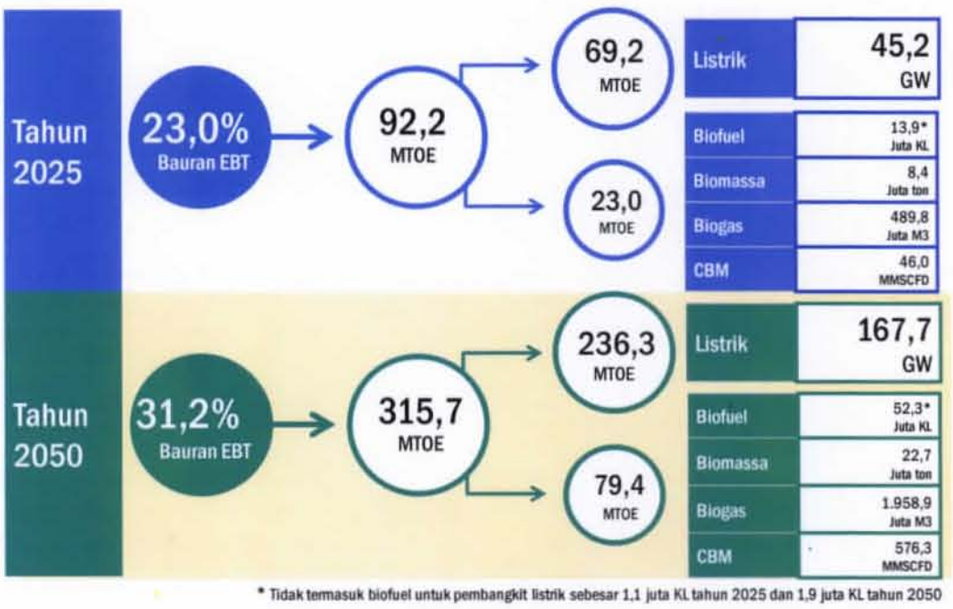
Energi	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Panas Bumi	2,6	3,5	4,4	5,5	6,8	8,9	21,8	28,0	42,7	58,8
	13,0%	15,3%	17,4%	18,9%	20,7%	23,0%	23,6%	21,5%	20,1%	18,6%
Air	6,9	6,9	7,0	7,3	7,5	7,8	24,9	29,3	39,7	55,3
	33,8%	30,4%	27,6%	25,1%	22,7%	20,2%	27,0%	22,4%	18,7%	17,5%
Minihidro dan Mikrohidro	0,3	0,3	0,5	0,8	1,1	1,6	5,2	6,2	8,0	10,2
	1,3%	1,4%	1,8%	2,7%	3,4%	4,1%	5,7%	4,8%	3,8%	3,2%
Bioenergi	10,4	11,9	13,3	15,0	16,8	19,1	33,8	49,8	83,0	124,2
	51,5%	52,4%	52,1%	51,5%	50,9%	49,6%	36,6%	38,2%	39,0%	39,3%
Surya	0,1	0,1	0,2	0,3	0,5	0,7	4,3	9,1	18,5	29,6
	0,4%	0,5%	0,8%	1,1%	1,4%	1,9%	4,6%	7,0%	8,7%	9,4%
Angin	0,0	0,0	0,1	0,2	0,3	0,5	1,8	6,7	16,4	27,6
	0,0%	0,0%	0,2%	0,5%	0,9%	1,2%	1,9%	5,2%	7,7%	8,7%
EBT Lainnya	0,0	0,0	0,0	0,0	0,0	0,0	0,5	1,3	4,3	9,9
	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,5%	1,0%	2,0%	3,1%
Total	20,3	22,8	25,5	29,0	32,9	38,5	92,2	130,5	212,6	315,7
- Listrik	11,6	12,9	14,6	16,8	19,3	23,3	69,2	98,4	160,4	236,3
- Bahan Bakar	8,7	9,9	10,9	12,2	13,6	15,2	23,0	32,1	52,2	79,4

Selain ...

Selain digunakan sebagai energi primer untuk pembangkit, EBT juga dikembangkan sebagai energi yang digunakan secara langsung oleh sektor pengguna yang dalam pemodelan dilakukan berdasarkan:

- Kebutuhan listrik dengan sasaran pemanfaatan listrik per kapita tahun 2025 sebesar 2.500 kWh/kapita dan tahun 2050 sebesar 7.000 kWh/kapita, dan rencana pengembangan EBT non-listrik berdasarkan realisasi produksi saat ini, dan rencana optimal pemanfaatan BBN di sektor pengguna; dan
- Keseimbangan sisi kebutuhan dan pasokan energi agar sasaran bauran EBT tahun 2025 sebesar paling sedikit 23% dan tahun 2050 sebesar paling sedikit 31% tetap tercapai.

Berdasarkan hasil pemodelan untuk mencapai sasaran bauran EBT dalam KEN, maka kapasitas penyediaan pembangkit listrik EBT tahun 2025 harus sekitar 45,2 GW dan pada tahun 2050 sekitar 167,7 GW. Adapun proyeksi pasokan EBT baik yang menghasilkan listrik maupun pemanfaatan langsung pada tahun 2025 dan tahun 2050 dapat dilihat pada Gambar 21.



Gambar 21. Pasokan Energi Primer – EBT Tahun 2025 dan 2050

Hasil ...

Hasil pemodelan pengembangan pembangkit listrik EBT per jenis pembangkit dapat dilihat sebagaimana pada Tabel 32.

Tabel 32. Hasil pemodelan Pengembangan Pembangkit Listrik EBT Tahun 2015–2050

Satuan: MW

Energi	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Panas Bumi	1.438,5	1.653,5	1.908,5	2.133,5	2.493,5	3.109,5	7.241,5	9.300,0	13.423,0	17.546,0
Air	4.826,7	4.871,7	4.928,7	5.103,7	5.468,2	5.615,2	17.986,7	21.989,4	29.994,7	38.000,0
Minihidro & Mikrohidro	197,4	230,5	313,7	520,0	750,0	1.000,0	3.000,0	3.800,0	5.400,0	7.000,0
Bioenergi	1.671,0	1.801,6	1.881,0	2.030,0	2.200,0	2.500,0	5.500,0	9.600,0	17.800,0	26.000,0
Surya	78,5	107,8	224,5	375,0	550,0	900,0	6.500,0	14.200,0	29.600,0	45.000,0
Angin	3,1	3,9	73,9	203,9	398,9	600,0	1.800,0	7.040,0	17.520,0	28.000,0
ET lainnya	372,0	809,8	1.232,6	1.675,4	2.059,2	2.433,0	3.125,0	3.722,4	4.911,2	6.100,0
Total	8.587,2	9.478,8	10.562,9	12.041,5	13.919,8	16.157,7	45.153,2	69.651,8	118.648,9	167.646,0

Rincian hasil pemodelan pengembangan pembangkit listrik EBT, sebagai berikut:

- **PLT Panas bumi**: Pengembangan panas bumi untuk tenaga listrik diproyeksikan sebesar 7,2 GW pada tahun 2025 dan 17,6 GW pada tahun 2050 atau 59% dari potensi panas bumi sebesar 29,5 GW. Potensi tersebut dapat meningkat seiring dengan peningkatan eksplorasi dan penemuan cadangan baru.
- **PLT Air**: Pengembangan tenaga air untuk tenaga listrik diproyeksikan sebesar 18,0 GW pada tahun 2025 dan 38 GW pada tahun 2050 atau sekitar 51% dari potensi tenaga air sebesar 75 GW.
- **PLT Minihidro dan Mikrohidro**: Pengembangan tenaga minihidro dan mikrohidro untuk tenaga listrik diproyeksikan sebesar 3 GW pada tahun 2025 dan 7 GW pada tahun 2050 atau 37% dari potensi minihidro dan mikrohidro sebesar 19 GW.

• PLT ...

- **PLT Bioenergi**: Pengembangan Bioenergi untuk tenaga listrik diproyeksikan sebesar 5,5 GW pada tahun 2025 dan 26,0 GW pada tahun 2050 atau 80% dari potensi bioenergi sebesar 32,7 GW.

- **PLT Surya**: Pengembangan tenaga surya untuk tenaga listrik diproyeksikan sebesar 6,5 GW pada tahun 2025 dan 45 GW pada tahun 2050 atau 22% dari potensi surya sebesar 207,9 GW. Proyeksi PLTS cukup optimis mengingat trend investasi dan harga listrik dari PLTS global semakin murah dari waktu ke waktu, seiring dengan kemajuan teknologi.

- **PLT Angin/Bayu**: Pengembangan tenaga bayu untuk tenaga listrik diproyeksikan sebesar 1,8 GW pada tahun 2025 dan 28,0 GW pada tahun 2050 atau 46% dari potensi bayu sebesar 60,6 GW.

- **PLT EBT lainnya**: Pengembangan energi terbarukan lainnya untuk tenaga listrik diproyeksikan sebesar 3,1 GW pada tahun 2025 dan 6,1 GW pada tahun 2050. PLT EBT lainnya antara lain PLTD dengan campuran bioenergi, PLT Arus Laut, PLT gelombang laut, PLT energi panas laut (*Ocean Thermal Energy*).

Pengembangan pembangkit listrik EBT per jenis EBT terdiri dari proyek yang sudah direncanakan untuk dikembangkan (*committed project*) dan proyek yang teridentifikasi memiliki prospek untuk dikembangkan (*potential project*) dapat dilihat pada Tabel 33.

Tabel 33. ...

Tabel 33. Hasil Pemodelan Indikasi Rencana Penyediaan Kapasitas Pembangkit Listrik EBT Tahun 2025–2050 (*Committed Project* dan *Potential Project*)

Satuan: MW

Energi	2015	2025	2050
A. *Committed project*	8.587,2	26.632,7	26.632,7
- Panas Bumi	1.438,5	7.241,5	7.241,5
- Air	4.826,7	13.986,7	13.986,7
- Minihidro & Mikrohidro	197,4	1.572,1	1.572,1
- Bioenergi	1.671,0	2.006,0	2.006,0
- Surya	78,5	540,5	540,5
- Angin	3,1	913,9	913,9
- EBT lainnya	372,0	372,0	372,0
B. *Potential Project*	-	18.520,5	141.013,3
Total	8.587,2	45.153,2	167.646,0

Rencana distribusi *potential project* EBT dalam RUEN

Satuan: MW

Energi	2015	2025	2050
Panas Bumi	1.438,5	7.241,5	17.546,0
Air	4.826,7	17.986,7	38.000,0
Minihidro & Mikrohidro	197,4	3.000,0	7.000,0
Bioenergi	1.671,0	5.500,0	26.000,0
Surya	78,5	6.500,0	45.000,0
Angin	3,1	1.800,0	28.000,0
EBT lainnya	372,0	3.125,0	6.100,0
Total (*Committed* dan *Potential*)	8.587,2	45.153,2	167.646,0

Saat ini Pemerintah telah merencankan proyek pembangunan pembangkit listrik yang bersumber dari EBT sampai dengan tahun 2025 (*committed project*). Namun kapasitas pembangkit yang direncanakan tersebut belum memenuhi kapasitas yang direncanakan pada tahun 2025 yaitu sebesar 45,2 GW dan tahun 2050 sebesar 167,7 GW. Untuk mencapai target-target tersebut, akan dibangun tambahan proyek pembangkit EBT sesuai dengan prospek peluang pengembangan EBT ke depan (*potential project*). Hal ini merupakan peluang bagi Pemerintah Daerah untuk mengembangkan potensi EBT lokal dan menyusun proyeksi pengembangannya dalam RUED.

Adapun pengembangan EBT sebagai energi untuk pemanfaatan langsung yang mencakup antara lain biofuel, biomassa, biogas dan CBM juga diproyeksikan meningkat, sebagaimana dapat dilihat pada Tabel 34.

Tabel 34. ...

Tabel 34. Hasil Pemodelan Pengembangan EBT untuk Pemanfaatan Langsung Tahun 2015-2050

Jenis	Satuan	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Biofuel*	Juta KL	2,3	3,4	4,3	5,4	6,6	8,0	13,9	20,8	34,1	52,3
Biomassa	Juta ton	5,6	5,7	5,9	6,2	6,4	6,7	8,4	10,7	16,3	22,7
Biogas	Juta m^3	25,2	35,4	49,6	69,0	95,6	131,9	489,8	783,5	1.346,3	1.958,9
CBM	MMSCFD	0,3	0,3	0,4	0,6	0,7	0,9	46,0	68,8	223,5	576,3

Catatan: *) Tidak termasuk produksi biofuel yang dimanfaatkan sebagai campuran BBM pada PLTD

Untuk mencapai sasaran pengembangan energi EBT di atas, kegiatan yang dilakukan, antara lain:

1) Membentuk badan usaha EBT tersendiri yang ditugasi Pemerintah untuk mengembangkan, memanfaatkan dan/atau membeli EBT.
2) Menerapkan dan menyempurnakan *feed in tariff* dari pembangkit EBT kepada badan usaha ketenagalistrikan yang berlaku selama harga listrik EBT lebih tinggi dari harga listrik dari sumber energi primer lainnya.
3) Menyusun pedoman pemberian subsidi energi oleh Pemerintah Daerah yang anggarannya dialokasikan dalam APBD.
4) Menganggarkan pembangunan infrastruktur EBT secara berkelanjutan untuk desa-desa yang tidak akan terlistriki dalam jangka panjang.
5) Menugaskan lembaga pembiayaan infrastruktur nasional untuk membiayai proyek pembangunan EBT.
6) Mengembangkan sistem tenaga listrik kecil berbasis EBT untuk penyediaan listrik di wilayah-wilayah yang tidak terjangkau oleh perluasan jaringan (*grid*).

Sebagai pedoman penyusunan RUED, telah disusun rencana pengembangan EBT per provinsi tahun 2016-2025 berdasarkan potensi, komersialisasi, dan kebutuhan energi, khususnya PLTP dan PLTA, sebagaimana diuraikan dalam sub bab berikut ini. Mayoritas pemenuhan sasaran penyediaan kapasitas pembangkit listrik EBT tahun 2025 disumbangkan oleh PLTP dan PLTA.

Rencana ...

Rencana pengembangan EBT tersebut merupakan arah indikatif prioritas pengembangan EBT per provinsi, agar semua pihak baik Pemerintah Pusat maupun Pemerintah Daerah berkolaborasi mendukung upaya pengembangan EBT berdasarkan prioritas provinsi tersebut.

2. Panas Bumi

Sebaran PLTP per provinsi dapat dilihat pada Tabel 35 di bawah ini.

Tabel 35. Potensi Panas Bumi per Provinsi

Satuan: MW

No.	Provinsi	Potensi						
		Sumber Daya			Cadangan			
		Speculative	*Hypothetical*	Total	*Possible*	*Probable*	*Proven*	Total
1	Jawa Barat	1.225	934	2.159	1.687	543	1.535	3.765
2	Sumatera Utara	300	134	434	1.996	-	320	2.316
3	Lampung	600	643	1.243	1.319	-	20	1.339
4	Sumatera Selatan	273	645	918	964	-	-	964
5	Jawa Tengah	130	387	517	949	115	280	1.344
6	Sumatera Barat	532	269	801	1.035	-	-	1.035
7	Nusa Tenggara Timur	226	403	629	748	-	15	763
8	Jawa Timur	105	257	362	1.012	-	-	1.012
9	Bengkulu	357	223	580	780	-	-	780
10	Aceh	640	340	980	332	-	-	332
11	Jambi	348	74	422	566	15	40	621
12	Sulawesi Utara	55	73	128	540	150	78	768
13	Maluku Utara	190	7	197	580	-	-	580
14	Sulawesi Tengah	349	36	385	368	-	-	368
15	Maluku	370	84	454	220	-	-	220
16	Banten	100	161	261	365	-	-	365
17	Sulawesi Barat	316	53	369	162	-	-	162
18	Sulawesi Selatan	172	120	292	163	-	-	163
19	Bali	70	22	92	262	-	-	262
20	Sulawesi Tenggara	200	25	225	98	-	-	98
21	Gorontalo	129	11	140	110	-	-	110
22	Nusa Tenggara Barat	-	6	6	169	-	-	169
23	Bangka Belitung	100	6	106	-	-	-	-
24	Papua Barat	75	-	75	-	-	-	-
25	Kalimantan Barat	65	-	65	-	-	-	-
26	Kalimantan Selatan	50	-	50	-	-	-	-
27	Kalimantan Utara	20	30	50	-	-	-	-
28	Riau	41	-	41	-	-	-	-
29	Kalimantan Timur	18	-	18	-	-	-	-
30	Yogyakarta	-	-	-	10	-	-	10
	Total	7.055	4.943	11.998	14.435	823	2.288	17.546

Acuan ...

Acuan indikasi rencana pengembangan panas bumi per provinsi berdasarkan potensi, komersialisasi, dan kebutuhan energi di setiap provinsi dapat dilihat pada Tabel 36.

Tabel 36. Indikasi Rencana Penyediaan Kapasitas Pembangkit Listrik Tenaga Panas Bumi per Provinsi Tahun 2015–2025

Satuan: MW

No.	Provinsi	Total Kapasitas Terpasang per Tahun										
		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1	Jawa Barat	1.164,0	1.194,0	1.194,0	1.194,0	1.269,0	1.449,0	1.569,0	1.767,0	1.767,0	1.917,0	1.972,0
2	Lampung	110,0	165,0	220,0	220,0	220,0	220,0	220,0	275,0	495,0	605,0	825,0
3	Sumatera Utara	12,0	122,0	232,0	342,0	347,0	507,0	587,0	587,0	587,0	717,0	717,0
4	Jawa Tengah	60,0	60,0	70,0	70,0	80,0	140,0	200,0	420,0	640,0	710,0	710,0
5	Jawa Timur		-	-	-	-	55,0	165,0	165,0	220,0	440,0	520,0
6	Bengkulu		-	-	55,0	110,0	140,0	140,0	255,0	255,0	340,0	505,0
7	Sumatera Selatan		-	55,0	110,0	110,0	201,0	201,0	256,0	371,0	371,0	505,0
8	Sumatera Barat		-	-	-	80,0	80,0	80,0	100,0	100,0	300,0	300,0
9	Sulawesi Utara	80,0	100,0	125,0	130,0	150,0	150,0	170,0	170,0	170,0	210,0	250,0
10	Aceh	-	-	-	-	10,0	10,0	10,0	65,0	65,0	120,0	230,0
11	Jambi		-	-	-	55,0	60,0	115,0	115,0	145,0	145,0	200,0
12	Banten		-	-	-	-	-	-	110,0	110,0	150,0	150,0
13	Nusa Tenggara Timur	12,5	12,5	12,5	12,5	42,5	77,5	82,5	92,5	102,5	102,5	117,5
14	Maluku Utara		-	-	-	-	-	-	20,0	20,0	55,0	70,0
15	Sulawesi Tengah		-	-	-	-	-	-	-	-	-	60,0
16	Nusa Tenggara Barat		-	-	-	-	-	-	-	-	20,0	40,0
17	Sulawesi Tenggara		-	-	-	-	-	-	-	-	-	20,0
18	Gorontalo		-	-	-	-	-	-	-	-	20,0	20,0
19	Maluku		-	-	-	20,0	20,0	20,0	20,0	20,0	20,0	20,0
20	Bali		-	-	-	-	-	-	-	-	-	10,0
21	Kalimantan Tengah		-	-	-	-	-	-	-	-	-	-
Total Kapasitas Terpasang		1.438,5	1.653,5	1.908,5	2.133,5	2.493,5	3.109,5	3.559,5	4.417,5	5.067,5	6.242,5	7.241,5
Total Tambahan/Tahun		-	215,0	255,0	225,0	360,0	616,0	450,0	858,0	650,0	1.175,0	999,0

Untuk mencapai sasaran pengembangan PLTP di atas, kegiatan yang dilakukan, antara lain:

1) Menugaskan Badan Usaha Milik Negara (BUMN)/Badan Layanan Umum (BLU) untuk mengembangkan PLTP.
2) Mengalokasikan pembiayaan pengembangan panas bumi melalui Penyertaan Modal Negara (PMN) dan pinjaman kepada BUMN.
3) Meningkatkan kualitas dan kuantitas survei potensi sumber daya dan cadangan panas bumi.
4) Melakukan pelelangan WK panas bumi minimal 7 WK per tahun.
5) Menyiapkan rekomendasi WK panas bumi minimal 4 WK per tahun.

6) Memberikan ...

6) Memberikan penugasan survei pendahuluan dan/atau eksplorasi kepada Badan Usaha.
7) Menyusun kebijakan harga jual listrik panas bumi.
8) Meningkatkan survei pendahuluan dan/atau eksplorasi oleh instansi Pemerintah.

3. Tenaga Air

Sebaran PLTA per provinsi dapat dilihat pada Tabel 37 di bawah ini.

Tabel 37. Potensi Tenaga Air per Wilayah

Satuan: MW

No.	Wilayah/Provinsi	Potensi
1	Papua	22.371
2	Kalsel, Kalteng, Kaltim	16.844
3	Sulsel, Sultra	6.340
4	Aceh	5.062
5	Kalimantan Barat	4.737
6	Sulut, Sulteng	3.967
7	Sumatera Utara	3.808
8	Sumatera Barat, Riau	3.607
9	Sumsel, Bengkulu, Jambi, Lampung	3.102
10	Jawa Barat	2.861
11	Jawa Tengah	813
12	Bali, NTB, NTT	624
13	Jawa Timur	525
14	Maluku	430
	Total	75.091

Acuan indikasi rencana pengembangan tenaga air per provinsi berdasarkan potensi, komersialisasi, dan kebutuhan energi di setiap provinsi dapat dilihat pada Tabel 38.

Tabel 38. ...

Tabel 38. Indikasi Rencana Penyediaan Kapasitas Pembangkit Listrik Tenaga Air per Provinsi Tahun 2015–2025

Satuan: MW

No.	Provinsi	Total Kapasitas Terpasang per Tahun										
		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1	Jawa Barat	1.991,9	1.991,9	2.038,9	2.038,9	2.148,9	2.148,9	2.148,9	2.148,9	2.148,9	2.148,9	3.116,6
2	Sulawesi Selatan	521,6	521,6	521,6	521,6	521,6	569,1	803,6	965,6	1.586,6	2.051,6	2.412,6
3	Sumatera Utara	922,5	967,5	967,5	967,5	1.204,0	1.211,5	1.211,5	1.241,5	1.916,5	1.916,5	2.269,8
4	Papua	3,9	3,9	3,9	3,9	3,9	3,9	3,9	3,9	27,9	47,9	2.208,9
5	Aceh	2,4	2,4	12,4	110,4	128,4	128,4	187,4	187,4	318,4	318,4	1.573,4
6	Nusa Tenggara Timur	-	-	-	-	-	10,0	16,5	16,5	16,5	16,5	929,9
7	Sulawesi Barat	-	-	-	-	-	-	-	28,0	56,0	206,0	847,8
8	Jawa Tengah	306,8	306,8	306,8	306,8	306,8	306,8	306,8	306,8	306,8	656,8	667,1
9	Kalimantan Timur	-	-	-	-	-	-	-	-	-	275,0	605,0
10	Jawa Timur	293,2	293,2	293,2	293,2	293,2	293,2	293,2	430,2	430,2	430,2	430,2
11	Sulawesi Tengah	195,0	195,0	195,0	195,0	195,0	265,0	265,0	265,0	265,0	345,0	425,0
12	Sumatera Barat	254,2	254,2	254,2	254,2	254,2	254,2	254,2	306,2	306,2	395,2	395,2
13	Jambi	-	-	-	-	-	-	-	175,0	350,0	350,0	370,7
14	Papua Barat	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	22,0	22,0	358,1
15	Bengkulu	248,0	248,0	248,0	269,0	269,0	269,0	269,0	296,5	321,5	321,5	348,5
16	Kalimantan Barat	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	243,5
17	Kalimantan Utara	-	-	-	-	-	-	-	-	-	110,0	220,0
18	Sulawesi Tenggara	1,6	1,6	1,6	1,6	1,6	1,6	1,6	1,6	146,6	182,6	182,6
19	Kalimantan Selatan	30,0	30,0	30,0	30,0	30,0	30,0	30,0	30,0	30,0	30,0	95,0
20	Sulawesi Utara	51,4	51,4	51,4	51,4	51,4	63,4	93,4	93,4	93,4	93,4	93,4
21	Lampung	-	-	-	56,0	56,0	56,0	56,0	83,0	83,0	83,0	83,0
22	Riau	-	-	-	-	-	-	-	-	-	-	76,4
23	Nusa Tenggara Barat	-	-	-	-	-	-	-	-	12,0	18,0	18,0
24	Maluku	-	-	-	-	-	-	-	-	16,0	16,0	16,0
Total Kapasitas Terpasang		4.826,7	4.871,7	4.928,7	5.103,7	5.468,2	5.615,2	5.945,2	6.583,7	8.455,7	10.036,7	17.986,7
Total Tambahan/Tahun		-	45,0	57,0	175,0	364,5	147,0	330,0	638,5	1.872,0	1.581,0	7.950,0

Untuk mencapai sasaran pengembangan PLTA di atas, kegiatan yang dilakukan, antara lain:

1) Meningkatkan kualitas dan kuantitas survei potensi energi air.
2) Menyempurnakan peraturan perundang-undangan terkait Sumber Daya Air.

Adapun indikasi rencana pengembangan EBT lainnya per provinsi tahun 2016-2025, selain PLTP dan PLTA, dilakukan dengan prinsip:

1) Prioritas pembangunan pembangkit listrik EBT dilakukan berdasarkan konsumsi listrik per kapita per provinsi/wilayah dan potensi EBT yang tersedia per provinsi.
2) Provinsi/wilayah dengan konsumsi listrik per kapita paling kecil mendapat prioritas untuk dilakukan pengembangan EBT.

3) Provinsi/wilayah ...

3) Provinsi/wilayah dengan potensi EBT terbesar mendapat prioritas untuk dilakukan pengembangan EBT.

Konsumsi listrik per kapita yang digunakan sebagai dasar untuk menentukan prioritas pembangunan pembangkit listrik EBT dapat dilihat pada Tabel 39 di bawah ini.

Tabel 39. Konsumsi Listrik per Kapita Tahun 2014

No.	Propinsi	Jumlah Penduduk (ribu)	Konsumsi Listrik (GWh)	Konsumsi Listrik per Kapita (kWh per kapita)
1	Nusa Tenggara Timur	5.015,8	702,3	140,0
2	Sulawesi Barat	1.264,1	238,0	188,3
3	Papua	3.089,6	724,8	234,6
4	Nusa Tenggara Barat	4.777,9	1.291,5	270,3
5	Maluku Utara	1.129,0	309,4	274,0
6	Sulawesi Tenggara	2.424,0	670,7	276,7
7	Maluku	1.646,9	480,1	291,5
8	Sulawesi Tengah	2.800,1	865,8	309,2
9	Jambi	3.331,6	1.037,4	311,4
10	Gorontalo	1.125,7	366,6	325,6
11	Bengkulu	1.861,2	729,6	392,0
12	Kalimantan Tengah	2.466,4	970,2	393,4
13	Kalimantan Barat	4.718,0	1.862,4	394,8
14	Aceh	4.889,6	1.965,6	402,0
15	Lampung	7.948,6	3.392,4	426,8
16	Sulawesi Selatan	8.522,8	4.339,2	509,1
17	Papua Barat	844,7	430,6	509,8
18	Sulawesi Utara	2.382,9	1.240,3	520,5
19	Riau	6.237,4	3.338,3	535,2
20	Kalimantan Selatan	3.901,7	2.093,0	536,4
21	Sumatera Selatan	7.922,4	4.432,0	559,4
22	Sumatera Barat	5.121,1	3.005,3	586,8
23	Jawa Tengah	33.304,4	19.631,5	589,5
24	Sumatera Utara	13.837,8	8.271,0	597,7
25	Bangka Belitung	1.334,2	805,4	603,7
26	Yogyakarta	3.606,2	2.369,6	657,1
28	Kalimantan Timur	3.333,6	2.378,9	713,6
29	Banten	11.753,9	8.391,4	713,9
30	Jawa Timur	38.439,4	30.524,0	794,1
31	Jawa Barat	46.528,0	42.885,9	921,7
27	Kalimantan Utara	612,0	636,0	1.039,2
32	Bali	4.129,1	4.335,0	1.049,9
33	Kepulauan Riau	1.922,8	2.618,5	1.361,8
34	Jakarta	10.002,7	41.269,0	4.125,8
	NASIONAL	252.225,5	198.601,8	787,4

4. Minihidro dan Mikrohidro

Potensi minihidro dan mikrohidro per provinsi dapat dilihat pada Tabel 40 di bawah ini.

Tabel 40. Potensi Minihidro dan Mikrohidro per Provinsi

Satuan: MW

No.	Provinsi	Potensi
1	Kalimantan Timur	3.562
2	Kalimantan Tengah	3.313
3	Aceh	1.538
4	Sumatera Barat	1.353
5	Sumatera Utara	1.204
6	Jawa Timur	1.142
7	Jawa Tengah	1.044
8	Kalimantan Utara	943
9	Sulawesi Selatan	762
10	Jawa Barat	647
11	Papua	615
12	Sumatera Selatan	448
13	Jambi	447
14	Sulawesi Tengah	370
15	Lampung	352
16	Sulawesi Tenggara	301

Satuan: MW

No.	Provinsi	Potensi
17	Riau	284
18	Maluku	190
19	Kalimantan Selatan	158
20	Kalimantan Barat	124
21	Gorontalo	117
22	Sulawesi Utara	111
23	Bengkulu	108
24	Nusa Tenggara Timur	95
25	Banten	72
26	Nusa Tenggara Barat	31
27	Maluku Utara	24
28	Bali	15
29	Sulawesi Barat	7
30	DI. Yogyakarta	5
31	Papua Barat	3
	Total	19.385

Acuan indikasi rencana pengembangan minihidro dan mikrohidro per provinsi berdasarkan konsumsi listrik provinsi per kapita dan ketersediaan potensi minihidro dan mikrohidro per provinsi dapat dilihat pada Tabel 41.

Tabel 41. ...

Tabel 41. Indikasi Rencana Penyediaan Kapasitas PLT Minihidro dan Mikrohidro per Provinsi Tahun 2015–2025

Satuan: MW

No.	Provinsi	Total Kapasitas Terpasang per Tahun										
		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1	Sumatera Utara	23,9	40,8	48,9	93,9	150,8	160,8	170,8	236,3	236,3	289,8	352,0
2	Kalimantan Tengah	0,5	0,5	0,5	28,9	28,9	59,5	93,3	122,3	164,8	199,5	243,9
3	Jawa Barat	18,3	23,3	48,3	91,3	113,8	132,1	167,6	178,1	195,3	219,7	237,4
4	Kalimantan Timur	0,7	0,8	0,8	13,4	13,4	32,7	71,5	97,8	144,9	173,9	173,9
5	Nusa Tenggara Timur	4,1	5,2	5,6	23,6	25,2	46,7	66,4	85,7	111,0	134,9	163,5
6	Sumatera Barat	18,8	20,1	37,8	37,8	77,8	91,2	91,2	111,8	117,8	142,5	142,5
7	Aceh	1,1	1,1	1,1	9,3	11,5	21,8	44,6	81,7	88,5	107,7	132,4
8	Papua	3,5	3,7	8,4	13,6	27,4	28,5	46,5	61,4	84,0	101,5	124,5
9	Sulawesi Selatan	39,1	39,4	48,6	68,9	97,3	107,3	107,3	109,0	109,0	122,3	122,3
10	Jawa Tengah	4,7	8,3	9,2	9,2	16,2	25,3	25,3	39,0	47,8	91,9	119,0
11	Sulawesi Barat	5,0	5,1	5,1	13,3	13,3	27,3	43,2	56,7	76,6	92,6	113,4
12	Bengkulu	0,7	0,7	0,7	0,7	0,7	0,7	7,4	13,4	29,4	34,4	95,4
13	Sulawesi Tengah	42,3	42,3	43,5	43,5	74,6	74,6	74,6	76,0	76,0	90,0	90,0
14	Sulawesi Tenggara	2,9	2,9	7,7	7,7	12,7	14,0	29,4	40,1	58,8	70,7	88,0
15	Jambi	0,3	0,3	0,3	4,4	4,4	11,4	27,4	37,9	57,3	68,7	86,0
16	Maluku	0,0	0,0	0,0	3,3	37,1	42,1	42,1	42,1	50,7	60,7	76,2
17	Nusa Tenggara Barat	13,2	13,3	13,3	14,6	32,0	32,0	32,0	32,3	49,0	58,7	73,6
18	Maluku Utara	0,0	0,0	0,0	3,2	3,2	8,7	22,5	31,2	47,8	57,2	71,8
19	Jawa Timur	1,7	1,7	1,7	1,7	1,7	4,5	4,5	8,9	37,1	49,2	63,0
20	Gorontalo	4,0	4,1	4,1	4,1	6,1	6,1	16,4	24,1	40,6	48,2	61,7
21	Banten	0,1	4,3	15,3	15,3	16,8	21,8	34,8	43,3	43,3	58,3	58,3
22	Lampung	0,6	0,6	0,6	0,6	0,6	0,6	10,1	31,8	35,1	41,2	54,4
23	Sumatera Selatan	1,3	1,3	1,3	2,7	2,7	2,7	20,2	30,2	30,2	36,2	52,4
24	Kalimantan Barat	0,9	0,9	1,0	2,3	17,5	17,5	17,5	17,5	29,7	34,7	46,2
25	Riau	0,2	0,2	0,2	0,2	0,2	0,2	0,2	2,4	20,5	22,9	33,8
26	Kalimantan Utara	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,1	14,4	14,4	28,4
27	Sulawesi Utara	8,2	8,2	8,2	8,7	16,4	16,4	19,7	19,7	19,7	26,1	26,1
28	Kalimantan Selatan	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	15,1	16,3	25,8
29	Bali	0,0	0,0	0,0	1,4	1,4	1,4	1,4	7,3	7,3	23,5	23,5
30	Papua Barat	1,0	1,0	1,0	2,0	11,0	11,0	11,0	11,0	11,1	11,5	19,8
31	Yogyakarta	0,2	0,2	0,2	0,2	0,2	0,8	0,8	0,8	0,8	0,8	0,8
Total Kapasitas Terpasang		197,4	230,5	313,7	520,0	815,1	1.000,0	1.300,0	1.650,0	2.050,0	2.500,0	3.000,0
Total Tambahan/Tahun		-	33,1	83,2	206,3	295,1	184,9	300,0	350,0	400,0	450,0	500,0

Untuk mencapai sasaran pengembangan PLT Minihidro dan Mikrohidro di atas, kegiatan yang dilakukan, antara lain:

1) Meningkatkan kualitas dan kuantitas survei potensi energi tenaga air dan melakukan pemetaan rinci untuk pengembangan pembangkit hidro skala kecil.

2) Meningkatkan implementasi peraturan perundang-undangan mengenai pembelian tenaga listrik dari pembangkit listrik tenaga air dengan kapasitas sampai dengan 10 MW oleh PT PLN (Persero).

5. Bioenergi ...

5. Bioenergi

Potensi bioenergi per provinsi dapat dilihat pada Tabel 42 di bawah ini.

Tabel 42. Potensi Bioenergi untuk Listrik per Provinsi

Satuan: MW

No.	Provinsi	Potensi		
		Biomass/Biofuel	Biogas	Total
1	Riau	4.157,4	37,7	4.195,1
2	Jawa Timur	2.851,3	569,6	3.420,9
3	Sumatera Utara	2.796,1	115,5	2.911,6
4	Jawa Barat	1.979,8	574,3	2.554,1
5	Jawa Tengah	1.884,1	348,4	2.232,5
6	Sumatera Selatan	2.061,4	71,2	2.132,6
7	Jambi	1.821,0	18,9	1.839,9
8	Kalimantan Tengah	1.486,7	12,2	1.498,9
9	Lampung	1.407,6	84,5	1.492,1
10	Kalimantan Barat	1.279,3	28,9	1.308,2
11	Kalimantan Selatan	1.266,3	23,6	1.289,9
12	Aceh	1.136,6	37,7	1.174,3
13	Kalimantan Timur/Utara	946,6	17,7	964,3
14	Sulawesi Selatan	890,3	69,1	959,4
15	Sumatera Barat	923,1	34,7	957,8
16	Bengkulu	633,0	11,8	644,8
17	Banten	346,5	118,6	465,1
18	Nusa Tenggara Barat	341,3	52,8	394,1
19	Sulawesi Tengah	307,4	19,5	326,9
20	Nusa Tenggara Timur	192,5	48,0	240,5
21	DI. Yogyakarta	183,1	41,1	224,2
22	Bangka Belitung	217,7	5,4	223,1
23	Sulawesi Barat	197,8	8,1	205,9
24	Bali	146,9	44,7	191,6
25	Sulawesi Utara	150,2	13,8	164,0
26	Sulawesi Tenggara	132,8	17,7	150,5
27	Gorontalo	119,1	11,5	130,6
28	DKI Jakarta	0,5	126,1	126,6
29	Papua	81,4	15,1	96,5
30	Papua Barat	50,8	4,1	54,9
31	Maluku Utara	27,5	7,0	34,5
32	Maluku	23,6	9,0	32,6
33	Kepulauan Riau	11,6	4,3	15,9
	Total	30.051,2	2.602,6	32.653,8

Catatan:

1) Biomassa dan biofuel antara lain terdiri dari sawit, tebu, karet, kelapa, padi, jagung, ubi kayu, dan kayu.
2) Biogas antara lain terdiri dari kotoran ternak dan sampah kota.

Acuan ...

Acuan indikasi rencana pengembangan bioenergi per provinsi berdasarkan konsumsi listrik provinsi per kapita dan ketersediaan potensi bioenergi per provinsi dapat dilihat pada Tabel 43.

Tabel 43. Indikasi Rencana Pengembangan Bioenergi per Provinsi Tahun 2015–2025

Satuan: MW

No.	Provinsi	Total Kapasitas Terpasang per Tahun										
		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1	Riau	179,4	183,4	193,4	195,4	195,4	195,4	195,4	220,7	260,9	306,8	359,0
2	Nusa Tenggara Timur	38,8	39,8	43,8	81,0	110,5	136,9	161,4	190,2	224,0	263,3	308,1
3	Jawa Timur	145,4	145,4	145,4	145,4	145,4	145,4	145,4	172,5	204,7	240,9	281,9
4	Sumatera Utara	126,0	174,5	174,5	176,5	176,5	176,5	176,5	176,5	192,2	226,1	264,5
5	Jambi	88,4	104,4	104,4	104,4	104,4	108,9	132,2	157,1	185,5	218,1	255,2
6	Sulawesi Barat	30,0	30,0	31,0	41,2	75,3	100,7	120,3	142,3	167,9	197,3	230,9
7	Jawa Tengah	98,5	98,5	98,5	98,5	98,5	98,5	111,3	134,5	159,6	187,8	219,8
8	Sumatera Selatan	94,6	98,6	101,1	101,1	101,1	101,1	110,0	132,7	157,4	185,2	216,7
9	Jawa Barat	109,3	121,8	121,8	121,8	121,8	121,8	121,8	131,7	157,0	184,9	216,4
10	Kalimantan Tengah	71,7	72,7	72,7	82,7	82,7	84,2	105,0	125,8	148,9	175,1	204,9
11	Lampung	70,6	70,6	70,6	70,6	70,6	79,5	100,2	120,4	142,6	167,7	196,3
12	Kalimantan Barat	63,9	63,9	85,9	105,9	105,9	105,9	105,9	117,6	139,2	163,8	191,7
13	Aceh	58,2	71,2	81,0	82,5	82,5	82,5	92,2	110,9	131,3	154,5	180,8
14	Papua Barat	10,2	10,2	10,2	10,8	49,8	75,5	92,0	109,5	129,3	152,0	177,9
15	Nusa Tenggara Barat	31,1	31,1	32,1	32,1	46,5	74,6	91,6	109,3	129,2	151,9	177,8
16	Kalimantan Selatan	60,4	66,8	66,8	66,8	66,8	66,8	81,9	99,6	118,4	139,4	163,1
17	Sulawesi Tenggara	20,8	20,8	20,8	20,8	38,0	65,5	81,1	97,0	114,7	134,9	157,9
18	Sulawesi Tengah	26,5	26,5	26,5	26,5	33,6	63,1	78,9	94,6	112,0	131,8	154,2
19	Maluku Utara	16,2	16,2	16,2	16,2	35,7	62,6	77,8	93,0	110,1	129,4	151,5
20	Bengkulu	36,8	42,8	42,8	42,8	42,8	58,2	74,8	90,4	107,3	126,2	147,7
21	Sulawesi Selatan	47,3	47,3	57,3	57,3	57,3	57,3	72,5	88,5	105,2	123,8	144,9
22	Maluku	15,2	15,2	21,2	21,2	30,5	58,1	72,8	87,4	103,5	121,7	142,4
23	Gorontalo	17,8	23,8	23,8	29,8	29,8	53,6	68,3	82,3	97,6	114,8	134,3
24	Sumatera Barat	46,1	46,1	47,1	47,1	47,1	47,6	66,2	81,6	97,4	114,7	134,2
25	Kalimantan Timur	45,2	46,2	58,3	67,8	67,8	67,8	67,8	67,8	67,8	76,7	89,8
26	Sulawesi Utara	14,5	14,5	14,5	14,5	14,5	28,9	43,2	54,2	64,9	76,5	89,6
27	Banten	24,8	24,8	24,8	24,8	24,8	24,8	41,2	53,2	64,1	75,7	88,6
28	Papua	21,2	21,2	21,2	31,2	31,2	31,2	41,8	52,4	62,8	74,1	86,7
29	Bangka Belitung	15,9	25,7	25,7	65,7	65,7	65,7	65,7	65,7	65,7	70,7	82,7
30	DI. Yogyakarta	15,4	15,4	15,4	15,4	15,4	20,2	35,7	46,3	56,0	66,1	77,3
31	Kalimantan Utara	-	-	-	-	-	9,0	29,8	42,1	51,8	61,4	71,8
32	Bali	11,7	12,1	12,1	12,1	12,1	12,1	19,2	29,7	37,3	44,3	51,8
33	Kepulauan Riau	13,0	14,0	14,0	14,0	14,0	14,0	14,0	16,2	22,1	26,6	31,1
34	DKI Jakarta	6,2	6,2	6,2	6,2	6,2	6,2	6,2	6,2	11,8	15,8	18,4
Total Kapasitas Terpasang		1.671,0	1.801,6	1.881,0	2.030,0	2.200,0	2.500,0	2.900,0	3.400,0	4.000,0	4.700,0	5.500,0
Total Tambahan/Tahun		-	130,6	79,4	149,0	170,0	300,0	400,0	500,0	600,0	700,0	800,0

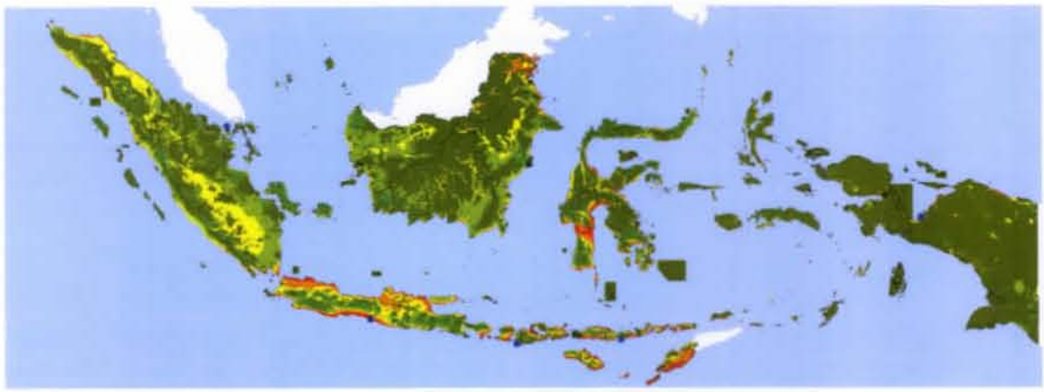
Untuk ...

Untuk mencapai sasaran pengembangan PLT Bioenergi di atas, kegiatan yang dilakukan, antara lain:

1) Menjamin ketersediaan *Crude Palm Oil* (CPO) untuk memenuhi kebutuhan CPO sebagai bahan bakar nabati (BBN) dalam negeri.
2) Meningkatkan kualitas dan kuantitas survei potensi bioenergi.
3) Meningkatkan produksi biodiesel sebesar 11,6 juta KL dan bioethanol sebesar 3,4 juta KL pada tahun 2025 sebagai campuran BBM untuk pemanfaatan sektor transportasi, industri dan pembangkit listrik.
4) Menugaskan BUMN dan/atau BUMD untuk memproduksi dan membeli BBN.
5) Mempercepat pembangunan pembangkit listrik berbasis sampah (PLTSa) di 7 kota (Jakarta, Tangerang, Bandung, Semarang, Surakarta, Surabaya, Makassar) melalui pemanfaatan sampah yang menjadi urusan Pemerintah.
6) Mengembangkan pembangkit listrik biogas dari *palm oil mill effluent* (POME) oleh setiap pabrik kelapa sawit dengan kewajiban pembelian produksi listrik oleh badan usaha penyedia tenaga listrik.
7) Menggalakkan budi daya tanaman-tanaman biomassa non-pangan.
8) Memprioritaskan anggaran Pemerintah dan Pemerintah Daerah untuk penelitian dan pengembangan di bidang energi.
9) Menyempurnakan harga patokan BBN/biofuel.
10) Mempercepat komersialisasi purwarupa pemanfaatan bioenergi.

6. Tenaga Surya

Peta potensi surya dapat dilihat pada Gambar 22 di bawah ini.



Gambar 22. Peta Potensi Surya

Adapun potensi teknis surya per provinsi dapat dilihat pada Tabel 44.

Tabel 44. Potensi Surya per Provinsi

Satuan: MW

No.	Provinsi	Potensi
1	Kalimantan Barat	20.113
2	Sumatera Selatan	17.233
3	Kalimantan timur	13.479
4	Sumatera Utara	11.851
5	Jawa Timur	10.335
6	Nusa Tenggara Barat	9.931
7	Jawa Barat	9.099
8	Jambi	8.847
9	Jawa Tengah	8.753
10	Kalimantan Tengah	8.459
11	Aceh	7.881
12	Kepulauan Riau	7.763
13	Sulawesi Selatan	7.588
14	Nusa Tenggara Timur	7.272
15	Papua Barat	6.307
16	Sulawesi Tengah	6.187
17	Kalimantan Selatan	6.031

Satuan: MW

No.	Provinsi	Potensi
18	Sumatera Barat	5.898
19	Kalimantan Utara	4.643
20	Sulawesi Tenggara	3.917
21	Bengkulu	3.475
22	Maluku Utara	3.036
23	Bangka Belitung	2.810
24	Banten	2.461
25	Lampung	2.238
26	Sulawesi Utara	2.113
27	Papua	2.035
28	Maluku	2.020
29	Sulawesi Barat	1.677
30	Bali	1.254
31	Gorontalo	1.218
32	DI. Yogyakarta	996
33	Riau	753
34	DKI Jakarta	225
	Total	207.898

Acuan ...

Acuan indikasi rencana pengembangan surya per provinsi berdasarkan konsumsi listrik provinsi per kapita dan ketersediaan potensi surya per provinsi dapat dilihat pada Tabel 45.

Tabel 45. Indikasi Rencana Pengembangan Surya per Provinsi Tahun 2015–2025

Satuan: MW

No.	Provinsi	Total Kapasitas Terpasang per Tahun										
		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1	Nusa Tenggara Timur	4,2	14,2	15,0	15,0	20,3	40,5	96,8	159,6	238,0	320,7	414,9
2	Kalimantan Barat	1,3	1,3	1,6	15,1	24,3	43,8	88,3	140,9	209,2	282,4	366,4
3	Gorontalo	0,7	4,7	9,7	9,7	19,7	19,7	35,7	65,4	128,8	218,6	343,3
4	Sumatera Selatan	1,1	1,1	1,1	12,8	20,0	35,8	71,7	114,1	169,3	228,5	296,6
5	Nusa Tenggara Barat	4,7	4,9	25,2	90,2	90,2	90,2	90,2	112,3	167,2	225,4	292,0
6	Sulawesi Barat	0,5	0,5	0,5	2,4	9,8	23,3	60,5	100,7	150,4	202,6	261,8
7	Jambi	1,0	1,0	3,0	7,1	13,6	27,1	60,7	98,6	146,7	197,9	256,3
8	Kalimantan Timur	1,6	1,9	2,0	8,4	15,3	27,7	56,1	89,3	132,5	178,9	232,1
9	Sumatera Utara	16,0	17,7	57,7	57,7	57,7	57,7	57,7	86,2	128,0	176,2	224,1
10	Sulawesi Tengah	1,4	1,4	11,4	11,4	31,4	31,4	52,7	86,2	128,4	173,1	224,1
11	Kalimantan Tengah	0,8	1,1	1,1	6,7	13,4	23,7	52,5	85,0	126,5	170,6	221,1
12	Papua	7,8	8,2	19,4	19,4	39,4	39,4	50,7	84,2	125,7	169,3	218,8
13	Sulawesi Tenggara	1,9	2,4	9,6	9,6	10,5	21,6	49,7	81,9	122,1	164,6	212,9
14	Aceh	0,8	0,8	2,8	6,2	12,7	22,5	50,2	81,3	121,0	163,2	211,4
15	Maluku Utara	4,5	4,6	9,6	9,6	9,7	18,9	47,3	78,3	116,8	157,3	203,5
16	Jawa Tengah	0,4	0,4	0,4	6,7	12,3	22,1	44,6	71,7	106,6	143,8	186,4
17	Jawa Timur	0,5	0,6	3,4	7,7	13,2	23,1	44,9	71,7	106,4	143,6	186,4
18	Sulawesi Selatan	3,9	7,0	8,1	8,1	11,5	21,2	43,8	70,8	105,2	142,0	184,0
19	Maluku	5,0	5,3	10,3	15,3	15,3	17,6	41,9	69,6	103,8	139,9	180,8
20	Papua Barat	1,8	4,1	4,1	5,0	15,0	19,0	39,8	64,6	96,1	129,5	167,8
21	Jawa Barat	0,3	0,3	0,4	6,8	11,5	20,2	39,3	62,7	93,1	125,6	163,0
22	Kalimantan Selatan	1,9	3,9	3,9	4,8	9,7	18,1	38,0	61,5	91,5	123,5	160,0
23	Bengkulu	0,6	0,7	0,7	3,1	8,2	16,5	37,3	61,2	91,3	123,0	159,2
24	Sumatera Barat	1,7	2,0	2,9	4,6	9,3	17,2	35,9	58,1	86,4	116,6	151,0
25	Lampung	1,3	1,6	1,6	2,1	6,5	13,5	31,3	51,6	77,0	103,8	134,3
26	Kepulauan Riau	1,1	1,1	1,1	5,8	9,5	16,5	31,5	50,2	74,4	100,5	130,4
27	Sulawesi Utara	3,8	3,8	3,8	3,8	5,6	11,5	26,5	43,7	65,1	87,8	113,6
28	Bangka belitung	1,6	1,6	3,6	3,6	5,9	11,7	25,9	42,4	63,2	85,2	110,3
29	Bali	4,4	7,5	8,2	8,2	8,2	108,2	108,2	108,2	108,2	108,2	108,2
30	Kalimantan Utara	0,4	0,6	0,6	3,6	6,6	12,0	24,3	39,1	58,1	78,5	101,7
31	Banten	0,2	0,2	0,3	2,1	5,1	10,0	22,2	36,3	54,0	72,9	94,3
32	Riau	0,9	1,0	1,0	1,0	4,1	9,0	21,8	36,2	54,1	72,8	94,2
33	DI. Yogyakarta	0,1	0,1	0,1	1,1	3,7	8,0	18,9	31,3	46,8	63,0	81,5
34	Jakarta	0,2	0,2	0,3	0,3	0,7	1,4	3,2	5,3	7,9	10,7	13,8
Total Kapasitas Terpasang		78,5	107,8	224,5	375,0	550,0	900,0	1.600,0	2.500,0	3.700,0	5.000,0	6.500,0
Total Tambahan/Tahun		-	29,3	116,6	150,5	175,0	350,0	700,0	900,0	1.200,0	1.300,0	1.500,0

Untuk ...

Untuk mencapai sasaran pengembangan PLTS di atas, kegiatan yang dilakukan, antara lain:

1) Memberlakukan kewajiban pemanfaatan sel surya minimum sebesar 30% dari luas atap untuk seluruh bangunan Pemerintah.
2) Memberlakukan kewajiban pemanfaatan sel surya minimum sebesar 25% dari luas atap (*rooftop*) bangunan rumah mewah, kompleks perumahan, apartemen, kompleks melalui Izin Mendirikan Bangunan (IMB).
3) Memfasilitasi pendirian industri hulu hilir PLTS.

7. Bayu

Peta potensi bayu dapat dilihat pada Gambar 23 di bawah ini.



Gambar 23. Peta Potensi Bayu

Adapun ...

Adapun potensi bayu dengan kecepatan ≥ 4 m/s dapat di lihat pada Tabel 46 di bawah ini.

Tabel 46. Potensi Bayu per Provinsi

Satuan: MW

No.	Provinsi	Potensi
1	Nusa Tenggara Timur	10.188
2	Jawa Timur	7.907
3	Jawa Barat	7.036
4	Jawa Tengah	5.213
5	Sulawesi Selatan	4.193
6	Maluku	3.188
7	Nusa Tenggara Barat	2.605
8	Bangka Belitung	1.787
9	Banten	1.753
10	Bengkulu	1.513
11	Sulawesi Tenggara	1.414
12	Papua	1.411
13	Sulawesi Utara	1.214
14	Lampung	1.137
15	DI. Yogyakarta	1.079
16	Bali	1.019
17	Kalimantan Selatan	1.006

Satuan: MW

No.	Provinsi	Potensi
18	Kepulauan Riau	922
19	Sulawesi Tengah	908
20	Aceh	894
21	Kalimantan Tengah	681
22	Kalimantan Barat	554
23	Sulawesi Barat	514
24	Maluku Utara	504
25	Papua Barat	437
26	Sumatera Barat	428
28	Sumatera Utara	356
29	Sumatera Selatan	301
30	Kalimantan timur	212
31	Gorontalo	137
27	Kalimantan Utara	73
32	Jambi	37
33	Riau	22
34	DKI Jakarta	4
	Total	60.647,0

Acuan ...

Acuan indikasi rencana pengembangan PLTB per provinsi berdasarkan konsumsi listrik provinsi per kapita dan ketersediaan potensi bayu per provinsi dapat dilihat pada Tabel 47.

Tabel 47. Indikasi Rencana Pengembangan Bayu per Provinsi Tahun 2015–2025

Satuan: MW

No.	Provinsi	Total Kapasitas Terpasang per Tahun										
		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
1	Jawa Barat	0,0	0,9	0,9	80,9	160,9	250,9	250,9	250,9	250,9	250,9	410,9
2	Nusa Tenggara Timur	0,1	0,1	0,1	0,1	5,1	31,2	131,1	175,0	216,7	261,1	266,1
3	Sulawesi Selatan	0,5	0,5	70,5	70,5	130,5	170,5	170,5	170,5	230,5	230,5	230,5
4	Banten	0,0	0,0	0,0	0,0	35,0	70,0	70,0	70,0	70,0	70,0	150,0
5	Maluku	0,0	0,0	0,0	0,0	5,0	10,0	41,3	67,8	86,9	108,8	113,8
6	Sulawesi Barat	-	-	-	-	-	-	33,1	52,1	66,3	82,4	82,4
7	Nusa Tenggara Barat	0,0	0,0	0,0	0,0	5,0	5,0	23,2	43,5	56,7	72,4	72,4
8	Papua	-	-	-	-	-	-	23,1	41,6	54,0	68,5	68,5
9	DI. Yogyakarta	0,1	0,1	0,1	50,1	50,1	50,1	50,1	50,1	50,1	50,1	60,1
10	Sulawesi Tenggara	0,0	0,0	0,0	0,0	0,0	0,0	14,4	32,6	43,4	56,6	56,6
11	Jawa Timur	0,1	0,1	0,1	0,1	0,1	0,1	0,1	14,6	27,6	46,8	46,8
12	Jawa Tengah	0,1	0,1	0,1	0,1	0,1	0,1	0,1	12,3	22,3	36,9	36,9
13	Kalimantan Tengah	-	-	-	-	-	-	-	14,7	22,9	34,2	34,2
14	Aceh	-	-	-	-	-	-	-	13,3	21,3	32,4	32,4
15	Bengkulu	-	-	-	-	-	-	-	10,4	17,6	27,8	27,8
16	Kalimantan Barat	-	-	-	-	-	-	-	10,2	17,4	27,6	27,6
17	Lampung	-	-	-	-	-	-	-	5,9	12,4	22,2	22,2
18	Sulawesi Utara	0,5	0,5	0,5	0,5	0,5	0,5	0,5	2,8	9,9	20,8	20,8
19	Bali	1,5	1,5	1,5	1,5	6,5	11,5	11,5	11,5	11,5	11,5	11,5
20	Papua Barat	-	-	-	-	-	-	-	-	1,4	10,5	10,5
21	Bangka Belitung	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	9,1	9,1
22	Kalimantan Selatan	-	-	-	-	-	-	-	-	-	8,8	8,8
23	DKI Jakarta	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
24	Maluku Utara	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Total Kapasitas Terpasang		3,1	3,9	73,9	203,9	398,9	600,0	820,0	1.050,0	1.290,0	1.540,0	1.800,0
Total Tambahan/Tahun		-	0,9	70,0	130,0	195,0	201,1	220,0	230,0	240,0	250,0	260,0

Untuk mencapai sasaran pengembangan PLTB di atas, kegiatan yang dilakukan, antara lain:

1) Meningkatkan kualitas dan kuantitas survei dan pemetaan potensi tenaga angin/bayu.
2) Melakukan survei potensi tenaga angin/bayu untuk daerah atau wilayah yang belum mempunyai pengukuran potensi.

3) Melakukan ...

3) Melakukan pra-studi kelayakan untuk daerah yang sudah mempunyai pengukuran potensi angin/bayu dan dilanjutkan dengan studi kelayakan pembangunan pembangkit listrik tenaga bayu.

4) Membangun unit pembangkit PLT Bayu di daerah terpencil, pulau terluar dan perbatasan NKRI.

5) Mewajibkan Pemerintah Daerah membangun dan mengelola PLT Bayu melalui BUMD.

8. Arus, gelombang dan perbedaan suhu lapisan laut

Potensi energi laut per wilayah/provinsi dapat dilihat pada Tabel 48 di bawah ini.

Tabel 48. Potensi Energi Laut per Provinsi

Satuan: MW

No.	Wilayah/Provinsi	Potensi		
		Teoritis	Teknis	Praktis
1	Nusa Tenggara Barat	138.308	34.577	8.644
2	Kepulauan Riau	96.432	24.108	6.027
3	Jawa Barat-Lampung	36.367	9.092	2.273
4	Papua Barat	6.261	1.565	391
5	Nusa Tenggara Timur	5.335	1.334	333
6	Bali	5.119	1.280	320
	Total	287.822	71.955	17.989

Kegiatan untuk pengembangan PLT Arus, gelombang dan perbedaan suhu lapisan laut, antara lain:

1) Melakukan survei potensi tenaga arus, gelombang dan perbedaan suhu lapisan laut untuk wilayah yang belum mempunyai data potensi.

2) Melakukan pra-studi kelayakan untuk wilayah/daerah yang sudah mempunyai pengukuran potensi dan dilanjutkan dengan studi kelayakan pembangunan PLT arus, gelombang, dan perbedaan suhu lapisan laut.

3) Menetapkan ...

3) Menetapkan kebijakan terkait kegiatan usaha dan harga pembangkit listrik tenaga arus, gelombang, dan perbedaan suhu lapisan laut.

4.2.2. Transformasi Energi

Di dalam struktur pemodelan, transformasi energi mencakup kegiatan pembangkitan tenaga listrik, kilang, penggunaan sendiri (*own use*) dan rugi-rugi (*losses*). Di dalam sub bab ini hanya dibahas kebijakan dan program mengenai penyediaan kapasitas pembangkit listrik. Kegiatan pengembangan kilang migas telah dijelaskan pada sub bab tentang minyak dan gas bumi. Kegiatan yang terkait dengan *own use* dan *losses* sudah dijelaskan pada Subbab Pasokan Energi Primer Minyak Bumi sehubungan dengan penggunaan teknologi konversi energi.

Asumsi khusus untuk perhitungan proyeksi penyediaan kapasitas pembangkit listrik, adalah populasi, pertumbuhan populasi, pertumbuhan ekonomi, rasio elektrifikasi dan konsumsi listrik per kapita sebagaimana dapat dilihat pada Tabel 49.

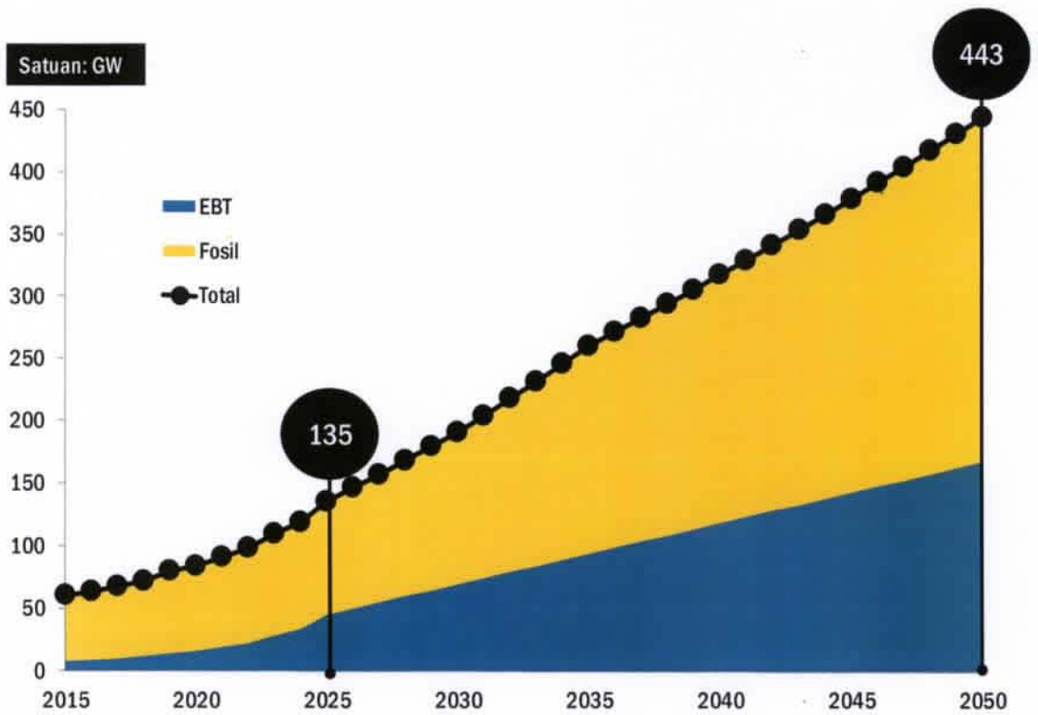
Tabel 49. Asumsi untuk Pemodelan Pembangkit Tenaga Listrik Tahun 2015-2050

Keterangan	Satuan	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Populasi	Juta Jiwa	256	259	262	265	268	271	285	296	315	335
Pertumbuhan populasi	%	1,3	1,3	1,3	1,3	1,3	1	0,8	0,6	0,6	0,6
Pertumbuhan ekonomi	%	4,8	5,3	7,1	7,5	8,0	8,0	8,0	7,5	7,0	6,3
Rasio Elektrifikasi*	%	87	90	93	95	97	~ 100	~ 100	~ 100	~ 100	~ 100
Konsumsi listrik per kapita	kWh/ kapita	952	1.059	1.182	1.316	1.462	1.618	2.500	3.201	4.953	7.000

Catatan: *) sesuai KEN, target rasio elektrifikasi tahun 2020 mendekati 100%

Dalam ...

Dalam KEN, sasaran utama pemenuhan penyediaan pembangkit tenaga listrik tahun 2025 sebesar 115 GW dan tahun 2050 sekitar 430 GW. Dari hasil perhitungan pemodelan, penyediaan pembangkit listrik tahun 2025 diperkirakan sebesar 135 GW dan tahun 2050 diperkirakan sebesar 443 GW. Hal ini berarti penyediaan energi listrik menjadi lebih tinggi dari sasaran KEN. Meningkatnya kapasitas terpasang pembangkit tersebut disebabkan penyesuaian indikator faktor kapasitas (*capacity factor*) per jenis pembangkit, khususnya pembangkit listrik EBT. Proyeksi pembangunan tenaga listrik dapat dilihat pada Gambar 24.



Gambar 24. Hasil Pemodelan Penyediaan Kapasitas Pembangkit Listrik Tahun 2015–2050

Porsi ...

Porsi energi fosil dalam penyediaan kapasitas pembangkit listrik terus dikurangi. Berdasarkan kapasitas terpasang pembangkit listrik, porsi pembangkit fosil pada tahun 2015 sekitar 85,7% dan akan diturunkan menjadi 66,7% pada tahun 2025 dan 62,2% pada tahun 2050, sebagaimana dapat dilihat pada Tabel 50.

Tabel 50. Hasil Pemodelan Penyediaan Kapasitas Pembangkit Listrik Tahun 2015–2050

Satuan: GW

Pembangkit	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
EBT	8,6	9,5	10,6	12,0	13,9	16,2	45,2	69,7	118,6	167,6
	14,3%	14,9%	15,6%	16,7%	17,5%	19,4%	33,3%	36,6%	37,4%	37,8%
Fosil	51,5	54,1	56,9	60,1	65,5	67,3	90,4	120,6	198,6	275,4
	85,7%	85,1%	84,4%	83,3%	82,5%	80,6%	66,7%	63,4%	62,6%	62,2%
Total	60,1	63,6	67,5	72,1	79,4	83,4	135,5	190,2	317,2	443,1

Kegiatan pengembangan energi untuk penyediaan kapasitas pembangkit listrik, antara lain:

1) Menyusun mekanisme pemanfaatan lahan untuk menjamin penyediaan energi pada lahan yang tumpang tindih dengan kebutuhan lain.
2) Memfasilitasi proses layanan penerbitan izin pemanfaatan kawasan hutan (pinjam pakai, kerja sama, pemanfaatan jasa lingkungan, atau pelepasan kawasan hutan) untuk sarana dan prasarana, dan instalasi pembangkit, transmisi dan distribusi listrik.
3) Membentuk wilayah usaha baru ketenagalistrikan tersendiri di luar Jawa, Madura, Bali.
4) Mengatur harga jual tenaga listrik secara regional berdasarkan tingkat keekonomian berkeadilan.
5) Menerapkan tarif dasar listrik progresif kepada masing-masing konsumen dengan perhitungan yang berbeda.

6) Mengembangkan ...

6) Mengembangkan penjaminan proyek infrastruktur energi yang strategis.
7) Melakukan pembatasan pemanfaatan BBM secara bertahap untuk pembangkit listrik.
8) Mengembangkan purwarupa pembangkit listrik tenaga uap dengan TKDN 100% sampai dengan kapasitas 200 MW hingga siap komersial.
9) Mendorong pembentukan konsorsium perusahaan industri, perbankan, *Engineering Procurement Construction* (EPC) dalam negeri dalam membangun proyek ketenagalistrikan berkapasitas di bawah 200 MW.

4.2.3. Kebutuhan Energi Final

a. Sektor Transportasi

Beberapa asumsi yang digunakan dalam pemodelan kebutuhan energi final sektor transportasi antara lain pertumbuhan PDB, jumlah penduduk, jumlah kendaraan, dan intensitas energi transportasi.

Hasil Pemodelan kebutuhan energi final sektor transportasi pada tahun 2025 sebesar 75,2 MTOE (30,3%) dan pada tahun 2050 sebesar 169,0 MTOE (26,3%). Hasil pemodelan kebutuhan energi sektor transportasi tiap jenisnya dapat dilihat pada Tabel 51.

Tabel 51. Hasil Pemodelan Kebutuhan Energi Final – Sektor Transportasi per Jenis Energi Tahun 2015–2050

Satuan: MTOE

Jenis Energi	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
BBM	47,6	48,7	50,1	51,7	53,3	54,7	62,8	71,5	94,8	123,2
	96,0%	94,3%	93,1%	91,8%	90,5%	89,0%	83,5%	79,7%	76,2%	72,9%
BBN	1,8	2,6	3,2	3,9	4,6	5,5	9,6	14,0	21,3	31,2
	3,6%	5,0%	5,9%	6,8%	7,9%	9,0%	12,8%	15,6%	17,1%	18,5%
Gas	0,2	0,4	0,5	0,7	0,9	1,2	2,6	3,7	7,0	11,9
	0,4%	0,7%	1,0%	1,3%	1,6%	1,9%	3,4%	4,2%	5,6%	7,0%
Listrik	0,02	0,02	0,03	0,03	0,04	0,1	0,2	0,5	1,3	2,7
	0,03%	0,04%	0,05%	0,06%	0,06%	0,1%	0,3%	0,5%	1,0%	1,6%
Total	49,6	51,7	53,8	56,3	58,9	61,5	75,2	89,7	124,4	169,0

Jenis ...

Jenis energi dengan porsi terbesar yang dibutuhkan sektor transportasi adalah BBM yang mencapai 96,0% pada tahun 2015 dan diproyeksikan akan menurun menjadi 83,5% pada tahun 2025 dan 72,9% pada tahun 2050, seiring dengan diversifikasi atau peningkatan penggunaan pada jenis energi lainnya seperti BBN, gas bumi dan listrik.

Adapun kebutuhan energi final sektor transportasi pada tahun 2025 dan tahun 2050 dapat dilihat pada Tabel 52.

Tabel 52. Kebutuhan Energi Final Sektor Transportasi Tahun 2025 dan 2050

Tahun	Kebutuhan Energi Final	MTOE	Volume Kesetaraan	Bauran Energi Final
2025	TRANSPORTASI	75,2		30,3%
	- Listrik	0,2	2,3 TWh	
	- Gas	2,6	282,1 MMSCFD	
	- BBM	62,8	75,3 Juta KL	
	- Bioenergi	9,6	11,0 Juta KL	
2050	TRANSPORTASI	169,0		26,3%
	- Listrik	2,7	31,6 TWh	
	- Gas	11,9	1.290,9 MMSCFD	
	- BBM	123,2	148,0 Juta KL	
	- Bioenergi	31,2	36,6 Juta KL	

Untuk mencapai sasaran pemenuhan kebutuhan energi final sektor transportasi sesuai dengan bauran energi di atas, kegiatan yang dilakukan, antara lain:

1) Membangun secara bertahap SPBG sebanyak 632 unit dengan total kapasitas 282 MMSCFD di 15 kota sampai dengan tahun 2025, dan

meningkat ...

meningkat menjadi 2.888 unit dengan total kapasitas 1.291 MMSCFD pada tahun 2050 dalam rangka percepatan pelaksanaan subtitusi BBM dengan gas di sektor transportasi. Rencana pengembangan SPBG tahun 2015–2050 ditunjukkan pada Tabel 53.

Tabel 53. Rencana Pengembangan SPBG Tahun 2015–2050

Keterangan	Satuan	2015	2016	2017	2018	2019	2020	2025	2030	2050
SPBG	Unit	60	70	90	140	231	287	632	908	2.888
Kebutuhan gas	MMSCFD	19	38	58	80	103	128	282	405	1.291

2) Mengembangkan kendaraan bertenaga listrik/hybrid pada tahun 2025 sebesar 2.200 unit untuk roda 4 dan 2,1 juta unit untuk kendaraan roda 2.

3) Menyiapkan kebijakan pemanfaatan kendaraan bermotor berbahan bakar bensin dan ethanol (*flexi-fuel engine*).

4) Menyusun kebijakan insentif fiskal untuk produksi mobil/motor listrik bagi pabrikan sesuai ketentuan peraturan perundang-undangan.

5) Menyusun peta jalan (*roadmap*) penggunaan BBN sebagai campuran BBM pada transportasi baik pada transportasi darat, laut, udara dan kereta api sampai dengan tahun 2050.

Rencana penyediaan BBN untuk transportasi tahun 2016–2050 ditampilkan pada Tabel 54.

Tabel 54. ...

Tabel 54. Rencana Penyediaan BBN untuk Transportasi Tahun 2016–2050

Jenis		2016	2025	2050
Biodiesel	Campuran	20%	30%	30%
	Volume (Juta KL)	2,5	6,9	17,1
Bioethanol	Campuran	5%	20%	20%
	Volume (Juta KL)	0,1	2,6	11,4
Bioavtur	Campuran	2%	5%	10%
	Volume (Juta KL)	0,0	0,1	2,7

6) Menyusun peta jalan penerapan kebijakan pajak karbon atas konsumsi energi fosil.
7) Mengembangkan sistem angkutan umum massal perkotaan, termasuk jaringan kereta api ke bandara dan pelabuhan (kereta api dan bus) sehingga pangsa angkutan umum meningkat menjadi 30% dari total moda pada 2025.
8) Mengembangkan angkutan kereta api cepat terpadu (*Mass Rapid Transit*/MRT), kereta api ringan (*Light Rail Transit*/LRT), dan Trem di 13 wilayah perkotaan serta kereta api bandara.
9) Mengembangkan manajemen transportasi dengan membangun sistem transportasi cerdas (*Intelligent Transport System*/ITS) di 24 kota dan sistem pengendalian lalu lintas (*Area Traffic Control System*/ATCS) di 50 lokasi serta pembatasan angkutan barang masuk kota.
10) Menyusun kebijakan dan penerapan biaya preservasi jalan yang dananya dipungut melalui mekanisme pendapatan pemerintah.
11) Mengembangkan standar keekonomian bahan bakar (*fuel-economy standard*) untuk kendaraan bermotor khususnya kendaraan pribadi sebelum tahun 2020.

12) Membangun ...

12) Membangun sistem tol laut (angkutan laut utama reguler untuk barang) dengan menyediakan 150 kapal.

b. Sektor Industri

Total kebutuhan energi final untuk sektor industri dari keseluruhan bauran energi masing-masing sebesar 118,4 MTOE (47,7%) untuk tahun 2025 dan 293,2 MTOE (45,7%) pada tahun 2050.

Dari total kebutuhan energi final untuk industri, sebesar 101,2 MTOE (40,7%) untuk bahan bakar dan 17,3 MTOE (6,9%) untuk bahan baku pada tahun 2025. Selanjutnya pada tahun 2050 dari total kebutuhan energi final untuk industri, sebesar 258,3 MTOE (40,3%) untuk bahan bakar dan 34,9 MTOE (5,4%) untuk bahan baku.

Kebutuhan bahan bakar untuk industri tersebut di atas terdiri dari listrik, pembakaran (*heating process*), dan pemakaian sendiri. Hasil pemodelan kebutuhan energi final untuk bahan bakar industri dapat terlihat pada Tabel 55.

Tabel 55. Hasil Pemodelan Kebutuhan Energi Final – Bahan Bakar Sektor Industri per Jenis Energi Tahun 2015–2050

Satuan: MTOE

Jenis Energi	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Listrik	7,1	8,0	9,1	10,3	11,8	13,4	24,4	31,0	45,5	57,1
	12,0%	13,1%	14,2%	15,3%	16,5%	17,6%	24,1%	24,0%	23,6%	22,1%
Gas (termasuk LPG dan Syngas)	14,5	15,2	16,1	17,2	18,3	19,5	26,6	34,6	54,4	77,2
	24,6%	24,9%	25,1%	25,4%	25,6%	25,8%	26,3%	26,9%	28,1%	29,9%
BBM	5,6	5,5	5,5	5,6	5,6	5,7	6,5	8,9	15,3	23,7
	9,5%	9,0%	8,7%	8,2%	7,8%	7,5%	6,4%	6,9%	7,9%	9,2%
Batubara	25,2	25,4	26,0	26,6	27,4	28,2	32,2	39,3	54,2	67,0
	42,7%	41,6%	40,5%	39,4%	38,3%	37,2%	31,8%	30,5%	28,1%	25,9%
Bioenergi	6,6	7,0	7,4	7,9	8,5	9,0	11,5	15,1	23,8	33,3
	11,2%	11,4%	11,5%	11,7%	11,8%	11,9%	11,4%	11,7%	12,3%	12,9%
Total	59,2	61,1	64,1	67,6	71,6	75,8	101,2	128,9	193,2	258,3

Proyeksi ...

Proyeksi kebutuhan energi final untuk bahan bakar sektor industri telah mempertimbangkan pertumbuhan PDB sektor industri dan intensitas energi pada kegiatan atau proses produksi seperti hemat energi pada ketel uap (*boiler*), pada tungku pembakaran (*furnace*), maupun pada penanganan material dan proses pendinginan.

Adapun kebutuhan energi final untuk bahan bakar sektor industri pada tahun 2025 dan 2050 dapat dilihat pada Tabel 56.

Tabel 56. Kebutuhan Energi Final – Bahan Bakar Sektor Industri Tahun 2025 dan 2050

Tahun	Kebutuhan Energi Final	MTOE	Volume Kesetaraan		Bauran Energi Final
2025	INDUSTRI	101,2			40,7%
	- Listrik	24,4	286,1	TWh	
	- Gas Bumi		2.880,2	MMSCFD	
	- LPG	26,6	0,1	Juta ton	
	- Syngas		1,3	MMSCFD	
	- BBM	6,5	7,2	Juta KL	
	- Batubara	32,2	55,2	Juta ton	
	- BBN	2,1	2,3	Juta KL	
	- ET Lainnya	9,4	13,6	Juta ton	
2050	INDUSTRI	258,3			40,3%
	- Listrik	57,1	670,5	TWh	
	- Gas Bumi		8.381,4	MMSCFD	
	- LPG	77,2	0,1	Juta ton	
	- Syngas		3,3	MMSCFD	
	- BBM	23,7	26,3	Juta KL	
	- Batubara	67,0	114,8	Juta ton	
	- BBN	9,9	11,0	Juta KL	
	- ET Lainnya	23,4	34,0	Juta ton	

Hasil pemodelan kebutuhan energi final untuk bahan baku industri pada tahun 2025 sebesar 17,3 MTOE dan tahun 2050 sebesar 34,9 MTOE.

Jenis ...

Jenis energi final-nya antara lain gas bumi dan minyak bumi non BBM misalnya LNG, *lube base oil, asphalt, wax/parafine, naptha, High Octane Mogas Component* (HOMC), *propylene* dan kondensat lainnya sebagaimana dapat dilihat pada Tabel 57.

Tabel 57. Hasil Pemodelan Energi Final – Bahan Baku Industri Tahun 2015–2050

Satuan: MTOE

Jenis Energi	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Gas bumi	4,1	4,2	4,2	4,4	4,5	4,6	5,2	5,9	7,5	9,2
	31,9%	31,8%	31,7%	31,5%	31,3%	31,1%	30,2%	29,4%	27,9%	26,5%
Non BBM	8,7	8,9	9,2	9,5	9,8	10,1	12,1	14,2	19,3	25,7
	68,1%	68,2%	68,3%	68,5%	68,7%	68,9%	69,8%	70,6%	72,1%	73,5%
Total	12,8	13,0	13,4	13,8	14,3	14,7	17,3	20,1	26,8	34,9

Catatan: Belum memperhitungkan potensi pemanfaatan gas sintetis dari batubara sebagai bahan baku industri

Adapun kebutuhan energi final untuk bahan baku industri pada tahun 2025 dan tahun 2050 dapat dilihat pada Tabel 58.

Tabel 58. Kebutuhan Energi Final – Bahan Baku Industri Tahun 2025 dan 2050

Tahun	Kebutuhan Energi Final	MTOE	Volume Kesetaraan	Bauran Energi Final
2025	BAHAN BAKU	17,3		6,9%
	- Gas bumi*	5,2	560,4 MMSCFD	
	- Non-BBM	12,1	87,4 Juta KL	
2050	BAHAN BAKU	34,9		5,4%
	- Gas bumi*	9,2	993,4 MMSCFD	
	- Non-BBM	25,7	186,5 Juta KL	

Catatan: *) belum memperhitungkan potensi pemanfaatan syngas dari batubara sebagai bahan baku industri

Untuk ...

Untuk mencapai sasaran pemenuhan kebutuhan energi final sektor industri sesuai dengan target bauran energi di atas, kegiatan yang dilakukan, antara lain:

1) Memprioritaskan penggunaan sumber energi dan sumber daya energi fosil untuk bahan bakar dan bahan baku industri nasional.
2) Meningkatkan pembangunan infrastruktur energi di luar Jawa dalam rangka meningkatkan porsi investasi industri pengolahan non-migas luar Jawa dengan Jawa menjadi 40% : 60% pada tahun 2035.
3) Menetapkan prioritas lokasi kawasan industri berkebutuhan energi tinggi di daerah mendekati sumber daya energi.
4) Meningkatkan pemanfaatan batubara untuk sektor industri dengan target mencapai 55,2 juta ton pada tahun 2025 dan 115 juta ton pada tahun 2050.
5) Mengembangkan industri gasifikasi batubara sebagai bahan baku industri petrokimia dan industri pupuk.
6) Menerapkan manajemen dan audit energi sesuai standar internasional untuk sektor industri.

c. Sektor Rumah Tangga

Hasil pemodelan kebutuhan energi final sektor rumah tangga pada tahun 2025 mencapai sebesar 37,2 MTOE (15%) dan tahun 2050 sebesar 91,0 MTOE (14,2%). Volume dan porsi jenis energi final yang dimanfaatkan oleh sektor rumah tangga dapat dilihat pada Tabel 59.

Tabel 59. ...

Tabel 59. Hasil Pemodelan Kebutuhan Energi Final – Sektor Rumah Tangga Tahun 2015–2050

Satuan: MTOE

Jenis Energi	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Listrik	9,5	11,0	12,7	14,4	16,1	18,0	26,1	34,6	53,9	76,4
	55,1%	58,1%	60,7%	62,9%	64,5%	65,9%	70,1%	74,4%	80,3%	84,0%
Gas	7,1	7,5	7,9	8,3	8,8	9,3	10,7	11,2	12,0	12,8
	41,2%	39,4%	37,8%	36,5%	35,0%	33,7%	28,7%	24,1%	17,9%	14,1%
BBM (minyak tanah)	0,6	0,5	0,3	0,1	0,03	-	-	-	-	-
	3,6%	2,4%	1,3%	0,3%	0,1%	0,0%	0,0%	0,0%	0,0%	0,0%
Bioenergi	0,02	0,03	0,04	0,06	0,08	0,1	0,4	0,7	1,2	1,8
	0,1%	0,2%	0,2%	0,3%	0,3%	0,4%	1,2%	1,5%	1,8%	1,9%
Total	17,2	19,0	20,9	22,8	25,0	27,4	37,2	46,5	67,1	91,0

Porsi terbesar jenis energi yang digunakan pada sektor rumah tangga adalah energi listrik yaitu mencapai 55,1% pada tahun 2015, dan diproyeksikan meningkat menjadi 70,1% pada tahun 2025, dan meningkat lagi menjadi 84,0% pada tahun 2050. BBM untuk sektor rumah tangga, yaitu minyak tanah, diproyeksikan tidak ada lagi mulai tahun 2020, seiring dengan beralihnya penggunaan energi di sektor rumah tangga dari BBM ke gas dan peningkatan penggunaan bioenergi. Porsi bioenergi dalam hasil pemodelan ini masih konservatif. Porsi ini akan meningkat seiring dengan diversifikasi pemanfaatan bioenergi skala rumah tangga antara lain biomassa hutan, limbah industri kecil, dan bioetanol.

Hasil pemodelan intensitas energi final sektor rumah tangga dilakukan dengan mempertimbangkan, antara lain: rasio elektrifikasi dan konversi minyak tanah ke gas mendekati 100% pada tahun 2020, pemanfaatan *Dimethyl Ether* (DME), *Adsorbed Natural Gas* (ANG), jaringan gas kota, dan penggunaan peralatan rumah tangga yang hemat energi semakin meningkat, seiring dengan berkembangnya teknologi.

Adapun ...

Adapun kebutuhan energi final sektor rumah tangga pada tahun 2025 dan tahun 2050 dapat dilihat pada Tabel 60.

Tabel 60. Kebutuhan Energi Final – Sektor Rumah Tangga Tahun 2025 dan 2050

Tahun	Kebutuhan Energi Final	MTOE	Volume Kesetaraan		Bauran Energi Final
2025	RUMAH TANGGA	37,2			15,0%
	- Listrik	26,1	306,6	TWh	
	- Gas Bumi	10,7	78,4	MMSCFD	
	- LPG		7,3	Juta ton	
	- ANG		0,1	Juta ton	
	- *Dimethyl Ether*		128,9	MMSCFD	
	- Bioenergi	0,4	489,8	Juta M^3	
2050	RUMAH TANGGA	91,0			14,2%
	- Listrik	76,4	897,9	TWh	
	- Gas bumi	12,8	326,7	MMSCFD	
	- LPG		6,0	Juta ton	
	- ANG		0,4	Juta ton	
	- *Dimethyl Ether*		239,6	MMSCFD	
	- Bioenergi	1,8	1.958,9	Juta M^3	

Untuk mencapai sasaran pemenuhan kebutuhan energi final sektor rumah tangga sesuai dengan bauran energi di atas, kegiatan yang dilakukan, antara lain:

1) Membangun jaringan gas kota bagi 4,7 juta sambungan rumah tangga pada tahun 2025.
2) Membangun fasilitas pengolahan Dimethyl Ether/DME (sebagai campuran LPG) dengan rencana produksi sekitar 1 juta ton pada tahun 2025.
3) Memperluas wilayah konversi penggunaan minyak tanah ke gas dan bioenergi pada sektor rumah tangga.
4) Mengadakan digester biogas dengan target 1,7 juta rumah tangga pada tahun 2025.

5) Memberlakukan ...

5) Memberlakukan kewajiban pemanfaatan sel surya minimum sebesar 25% dari luas atap bangunan rumah mewah, kompleks perumahan, apartemen, melalui Izin Mendirikan Bangunan (IMB).
6) Menerapkan SNI atas peralatan pemanfaat energi di sektor rumah tangga.
7) Mengembangkan tabung khusus (*Absorbed Natural Gas*/ANG) dengan rencana pengembangan sebesar 0,1 juta ton pada tahun 2025.

d. Sektor Komersial

Sektor Komersial mencakup antara lain: gedung pemerintahan, hotel, rumah makan (restoran), rumah sakit, penerangan jalan, bangunan sosial, dan rumah ibadah. Hasil pemodelan kebutuhan energi final sektor komersial pada tahun 2025 mencapai sebesar 12,2 MTOE (4,9%) dan tahun 2050 sebesar 73,0 MTOE (11,4%) sebagaimana dapat dilihat pada Tabel 61.

Tabel 61. Hasil Pemodelan Kebutuhan Energi Final – Sektor Komersial per Jenis Energi Tahun 2015–2050

Satuan: MTOE

Jenis Energi	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
Listrik	4,5	4,8	5,1	5,6	6,1	6,7	10,1	15,3	32,7	63,8
	77,0%	77,7%	78,4%	79,0%	79,7%	80,3%	82,9%	84,7%	86,7%	87,4%
Gas	0,4	0,4	0,5	0,5	0,5	0,6	0,9	1,3	2,7	5,1
	7,2%	7,2%	7,2%	7,2%	7,2%	7,2%	7,4%	7,3%	7,1%	7,0%
BBM	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,6	0,5	0,5
	12,2%	11,4%	10,6%	9,9%	9,1%	8,4%	5,4%	3,5%	1,4%	0,6%
Bioenergi	0,002	0,003	0,01	0,01	0,01	0,01	0,03	0,06	0,14	0,2
	0,0%	0,1%	0,1%	0,1%	0,1%	0,2%	0,3%	0,3%	0,4%	0,3%
ET lainnya	0,2	0,2	0,3	0,3	0,3	0,3	0,5	0,8	1,7	3,4
	3,7%	3,7%	3,7%	3,8%	3,8%	3,9%	4,1%	4,2%	4,4%	4,7%
Total	5,8	6,1	6,6	7,1	7,6	8,3	12,2	18,1	37,7	73,0

Jenis ...

Jenis energi terbesar yang dibutuhkan sektor komersial adalah listrik dengan pangsa sebesar 77,0% pada tahun 2015 dan diproyeksikan pada tahun 2025 dan tahun 2050 terbesar pada kisaran 83% sampai dengan 87%. Kebijakan utama untuk pemanfaatan energi pada sektor komersial adalah menurunkan penggunaan BBM dan meningkatkan pemanfaatan energi terbarukan.

Hasil pemodelan intensitas energi final sektor komersial dilakukan dengan mempertimbangkan peningkatan pemakaian teknologi hemat energi masa mendatang, disertai penerapan audit dan manajemen energi. Adapun kebutuhan energi final sektor komersial pada tahun 2025 dan tahun 2050 dapat dilihat pada Tabel 62.

Tabel 62. Kebutuhan Energi Final - Sektor Komersial

Tahun 2025 dan 2050

Tahun	Kebutuhan Energi Final	MTOE	Volume Kesetaraan	Bauran Energi Final
2025	KOMERSIAL	12,2		4,9%
	- Listrik	10,1	118,5 TWh	
	- Gas Bumi	0,9	51,5 MMSCFD	
	- LPG		0,4 Juta ton	
	- BBM	0,7	0,7 Juta KL	
	- Bioenergi	0,03	0,04 Juta KL	
	- ET lainnya	0,5	0,7 Juta ton	
2050	KOMERSIAL	73,0		11,4%
	- Listrik	63,8	749,1 TWh	
	- Gas Bumi	5,1	293,3 MMSCFD	
	- LPG		2,0 Juta ton	
	- BBM	0,5	0,5 Juta KL	
	- Bioenergi	0,2	0,2 Juta KL	
	- ET lainnya	3,4	5,0 Juta ton	

Untuk ...

Untuk mencapai sasaran pemenuhan kebutuhan energi final sektor komersial sesuai dengan bauran energi di atas, kegiatan yang dilakukan, antara lain:

1) Menerapkan SNI atas peralatan pemanfaat energi di sektor komersial.
2) Menerapkan manajemen dan audit energi sesuai standar internasional untuk sektor komersial.
3) Menyusun standar terkait rancang bangun gedung hemat energi.

e. Sektor Lainnya

Sektor lainnya adalah sektor-sektor pengguna energi di luar sektor transportasi, rumah tangga, komersial dan industri, seperti sektor konstruksi, pertanian dan pertambangan. Hasil pemodelan kebutuhan energi final sektor lainnya pada tahun 2025 sebesar 5,4 MTOE (2,2%) dan tahun 2050 sebesar 15,3 MTOE (2,4%) sebagaimana dapat dilihat pada Tabel 63.

Tabel 63. Hasil Pemodelan Kebutuhan Energi Final – Sektor Lainnya Tahun 2015–2050

Satuan: MTOE

Jenis Energi	2015	2016	2017	2018	2019	2020	2025	2030	2040	2050
BBM	3,5	3,5	3,7	3,8	3,9	4,1	4,9	6,0	8,4	11,2
	99,1%	98,6%	97,9%	96,9%	96,1%	94,9%	91,0%	87,4%	80,1%	72,9%
Bioenergi	0,03	0,05	0,08	0,12	0,16	0,22	0,5	0,9	2,1	4,1
	0,8%	1,5%	2,2%	3,0%	4,0%	5,0%	9,0%	12,7%	19,9%	27,0%
Total	3,5	3,6	3,7	3,9	4,1	4,3	5,4	6,8	10,4	15,3

Pada tahun 2015, penggunaan BBM masih merupakan energi utama pada sektor lainnya dengan proporsi sebesar 99,1%. Kegiatan diversifikasi energi di sektor lainnya diproyeksikan akan meningkatkan proporsi BBN di masa mendatang dengan proporsi sebesar 9,0% pada tahun 2025, dan 27,0% di tahun 2050.

Adapun ...

Adapun kebutuhan masing-masing jenis energi final sektor lainnya pada tahun 2025 dan 2050 dapat dilihat pada Tabel 64.

Tabel 64. Kebutuhan Energi Final Sektor Lainnya Tahun 2025 dan 2050

Tahun	Kebutuhan Energi Final	MTOE	Volume Kesetaraan	Bauran Energi Final
2025	SEKTOR LAINNYA	5,4		2,2%
	- BBM	4,9	5,6 Juta Kl	
	- Bioenergi	0,5	0,6 Juta Kl	
2050	SEKTOR LAINNYA	15,3		2,4%
	- BBM	11,2	12,7 Juta Kl	
	- Bioenergi	4,1	4,6 Juta Kl	

Untuk mencapai sasaran pemenuhan kebutuhan energi final sektor lainnya sesuai dengan bauran energi di atas, kegiatan yang dilakukan, antara lain:

Membangun infrastruktur penyediaan energi untuk sektor pertanian yang belum memiliki akses terhadap energi.

4.2.4. Konservasi dan efisiensi pemanfaatan energi

Kebijakan tentang konservasi dan efisiensi pemanfaatan energi sudah tercakup dalam sub bagian kebutuhan energi untuk masing-masing sektor. Beberapa kegiatan wajib adalah sebagai berikut:

1) Mengembangkan kebijakan Usaha Jasa Konservasi Energi (*Energy Service Company*/ESCO) untuk implementasi proyek efisiensi energi.
2) Melaksanakan program audit dan manajemen energi.
3) Restrukturisasi permesinan industri dan pemberian fasilitas insentif (fiskal dan nonfiskal) bagi industri yang melaksanakan efisiensi energi.
4) Melakukan sosialisasi dan edukasi hemat energi melalui media elektronik dan media sosial untuk meningkatkan kesadaran pelaku usaha dan masyarakat terhadap hemat energi.

4.3. Kelembagaan ...

4.3. Kelembagaan dan Instrumen Kebijakan

Pelaksanaan pencapaian sasaran KEN yang dijabarkan dalam RUEN melibatkan Kementerian Negara/Lembaga yang menjadi Anggota Dewan Energi Nasional, yaitu: Kementerian Energi dan Sumber Daya Mineral, Kementerian Lingkungan Hidup dan Kehutanan, Kementerian Perindustrian, Kementerian Perhubungan, Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional, Kementerian Pertanian, Kementerian Keuangan, Kementerian Riset, Teknologi dan Pendidikan Tinggi. Selain itu, beberapa Kementerian Negara/Lembaga yang tugas dan fungsinya berkaitan dengan kebijakan energi juga berperan serta di dalam pencapaian sasaran KEN yaitu: Kementerian Dalam Negeri, Kementerian Badan Usaha Milik Negara, Kementerian Agraria dan Tata Ruang, Kementerian Pekerjaan Umum dan Perumahan Rakyat, Kementerian Kelautan dan Perikanan, Kementerian Desa, Pembangunan Daerah Tertinggal dan Transmigrasi, serta Pemerintah Daerah.

Di dalam Matriks Program RUEN, terdapat Kementerian Negara/Lembaga yang menjadi koordinator atas masing-masing kegiatan. Dalam pelaksanaan kegiatan yang dimaksud, Kementerian Negara/Lembaga koordinator bertanggungjawab mengkoordinasikan dan mensinkronkan kegiatan bersama Kementerian Negara/Lembaga dan pihak lainnya yang terkait. Koordinasi dan sinkronisasi ini sangat diperlukan karena berbagai sasaran pengembangan energi mendatang hanya dapat dicapai melalui dukungan dalam bentuk berbagai kebijakan dan regulasi lintas sektor. Beberapa kebijakan yang perlu disinkronkan misalnya, kebijakan harga energi, kebijakan tata ruang, kebijakan pemanfaatan hutan dan tata kelola air, kebijakan transportasi massal, kebijakan manajemen lalu lintas, kebijakan perindustrian, kebijakan retribusi, pajak, dan iuran daerah, kebijakan perizinan baik perizinan usaha maupun perizinan lokasi, standardisasi, perdagangan energi, kebijakan penerapan teknologi, serta berbagai kebijakan lain.

Peran ...

Peran Pemerintah Daerah sangat dibutuhkan, terutama untuk menjabarkan RUEN dalam Rencana Umum Energi Daerah (RUED) serta mengimplementasikan program dan kegiatan di daerah.

Selain koordinasi dan sinkronisasi lintas Kementerian Negara/Lembaga tersebut di atas, untuk mensukseskan pencapaian target bauran energi dalam KEN diperlukan peningkatan perbaikan kelembagaan dalam pengelolaan energi termasuk pembentukan lembaga baru.
Untuk mencapai target KEN melalui berbagai kegiatan yang dijabarkan di dalam RUEN dibutuhkan sejumlah instrumen kebijakan yaitu peraturan perundang-undangan dan instrumen kebijakan lainnya, seperti Renstra dan RKA.

Kegiatan terkait peningkatan perbaikan kelembagaan dalam pengelolaan energi, antara lain:

1) Menyederhanakan perizinan yang semula 89 perizinan menjadi 10 perizinan.
2) Memperkuat kapasitas kelembagaan di tingkat provinsi/kabupaten/kota yang akan bertanggung jawab terhadap perencanaan, pengembangan, dan pengelolaan energi.
3) Memperkuat kapasitas organisasi di tingkat provinsi, kabupaten/kota yang akan bertanggung jawab terhadap perencanaan, pengembangan, dan pengelolaan energi.
4) Memfasilitasi kerja satuan kerja yang bertugas memantau dan mengkoordinasikan penyelesaian masalah birokrasi dan/atau tumpang tindih kewenangan di daerah.

Kebijakan utama dan pendukung serta kegiatan-kegiatan tersebut di atas dijabarkan secara lebih rinci, konkret, dan terarah dalam bentuk strategi, program dan kegiatan disertai lembaga koordinator, instrumen pelaksanaan, dan periode capaian sebagaimana disajikan dalam Lampiran II (Matrik Program RUEN).

V. PENUTUP ...

V. PENUTUP

RUEN merupakan penjabaran dan rencana pelaksanaan KEN yang bersifat lintas sektor. Penjabaran dalam RUEN memuat hasil pemodelan kebutuhan dan pasokan energi tahun 2015-2050 yang juga mencakup kebijakan, strategi, program pengembangan energi, serta kegiatan yang mengacu pada sasaran KEN.

Pengembangan energi nasional mengacu pada prinsip KEN yang berkeadilan, berkelanjutan, dan berwawasan lingkungan guna terciptanya kemandirian dan ketahanan energi nasional.

Sebagai perwujudan pengembangan energi yang memperhatikan keseimbangan keekonomian energi, keamanan pasokan energi, dan pelestarian fungsi lingkungan, maka prioritas pengembangan energi nasional didasarkan pada prinsip:

1. Memaksimalkan energi terbarukan dengan memperhatikan tingkat keekonomian;
2. Meminimalkan penggunaan minyak bumi;
3. Mengoptimalkan pemanfaatan gas bumi dan energi baru; dan
4. Memanfaatkan potensi sumber daya batubara sebagai andalan pasokan energi nasional dengan mempertimbangkan dampak sosial dan lingkungan.

Pengelolaan ...

Pengelolaan energi nasional yang digariskan dalam RUEN ini akan menjadi pedoman bagi setiap daerah untuk menyusun dokumen Rencana Umum Energi Daerah (RUED), baik di tingkat provinsi maupun kabupaten/kota. Selain itu, RUEN menjadi rujukan bagi Kementerian Negara/Lembaga terkait dan Pemerintah Daerah untuk menyusun dan merevisi rencana strategis dan rencana kerja.

PRESIDEN REPUBLIK INDONESIA,

ttd.

JOKO WIDODO

Salinan sesuai dengan aslinya
SEKRETARIAT KABINET RI
Deputi Bidang Kemaritiman,

Satya Bhakti Parikesit

PRESIDEN
REPUBLIK INDONESIA

LAMPIRAN II
PERATURAN PRESIDEN REPUBLIK INDONESIA
NOMOR 22 TAHUN 2017
TENTANG
RENCANA UMUM ENERGI NASIONAL

MATRIK PROGRAM

RENCANA UMUM ENERGI NASIONAL

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
Perubahan Paradigma Pengelolaan Energi					
1 Sumber daya energi tidak dijadikan sebagai komoditas ekspor semata tetapi sebagai modal pembangunan nasional	1 Peningkatan nilai tambah sumber daya energi dan sumber energi sebagai bahan bakar serta bahan baku industri nasional	1 Memprioritaskan penggunaan sumber energi dan sumber daya energi fosil untuk bahan bakar dan bahan baku industri nasional	Kementerian Energi dan Sumber Daya Mineral	Perpres terkait penggunaan energi fosil untuk industri dalam negeri	2016-2050
		2 Meningkatkan kapasitas industri kimia dasar berbasis migas dan batubara untuk peningkatan nilai tambah dan substitusi impor	Kementerian Perindustrian	PP Nomor 14 Tahun 2015 tentang RIPIN	2016-2050
		3 Menyelesaikan kebijakan harga gas bumi dengan membentuk badan penyangga gas nasional	Kementerian Energi dan Sumber Daya Mineral	Perpres terkait tata kelola gas bumi	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		4 Menyusun kebijakan baru tata kelola gas bumi yang kondusif untuk percepatan pengembangan infrastruktur gas	Kementerian Energi dan Sumber Daya Mineral	Perpres terkait tata kelola gas bumi	2016-2019
		5 Meningkatkan kapasitas kilang minyak nasional menjadi lebih dari 2 juta barel per hari pada tahun 2025, melalui pembangunan kilang baru dan Rencana Induk Pengembangan Kilang (*Refinery Development Master Plan*/RDMP)	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		6 Mengurangi porsi ekspor minyak mentah dalam rangka memprioritaskan kebutuhan dalam negeri	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		7 Mengurangi porsi ekspor gas bumi menjadi kurang dari 20% pada tahun 2025 dan menghentikan ekspor gas bumi paling lambat tahun 2036, dengan menjamin penyerapan produksi gas dalam negeri untuk industri yang terintegrasi hulu-hilir, transportasi dan sektor lainnya	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2036
		8 Mengendalikan produksi batubara maksimal sebesar 400 juta ton mulai tahun 2019	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait pengendalian produksi dan penjualan batubara	2016-2046
		9 Mengurangi porsi ekspor batubara secara bertahap dan menghentikan ekspor batubara paling lambat tahun 2046, dalam rangka memprioritaskan kebutuhan dalam negeri	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait pengendalian produksi dan penjualan batubara	2016-2046

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		10 Menghentikan ekspor batubara pada saat kebutuhan dalam negeri mencapai 400 juta ton	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait pengendalian produksi dan penjualan batubara	2016-2045
		11 Menjamin ketersediaan *Crude Palm Oil* (CPO) untuk memenuhi kebutuhan CPO sebagai Bahan Bakar Nabati (BBN) dalam negeri	Kementerian Perindustrian, Kementerian Pertanian	Rencana Strategis Kementerian/ Lembaga	2016-2050
	2 Penyelarasan target fiskal dengan kebijakan energi	1 Memberikan insentif fiskal dan non fiskal untuk penjualan energi dalam negeri, khususnya pada kegiatan industri	Kementerian Keuangan	Perpres/Permen/ Kepmen terkait harga energi untuk kebutuhan industri	2016-2050
		2 Menetapkan harga energi yang kompetitif untuk konsumen dalam negeri, khususnya industri, dalam rangka meningkatkan nilai tambah	Kementerian Energi dan Sumber Daya Mineral	Perpres/Permen/ Kepmen terkait harga energi untuk kebutuhan dalam negeri	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
Kebijakan Utama-1: Ketersediaan Energi untuk Kebutuhan Nasional					
1 Meningkatkan eksplorasi sumber daya, potensi dan/atau cadangan terbukti energi, baik dari jenis fosil maupun Energi Baru dan Energi Terbarukan (EBT)	1 Peningkatan eksplorasi sumber daya dan cadangan minyak dan gas bumi (migas)	1 Meningkatkan eksplorasi sumber daya dan cadangan migas konvensional dan non konvensional	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2 Meningkatkan tata kelola data hulu migas dalam rangka meningkatkan penawaran dan pengembangan Wilayah Kerja (WK) Migas antara lain dengan menerapkan keterbukaan data migas dan tidak menjadikan data migas sebagai objek Penerimaan Negara Bukan Pajak (PNBP) semata	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019
		3 Melakukan riset dasar eksplorasi migas dalam rangka meningkatkan cadangan migas antara lain riset migas non-konvensional, riset sistem petroleum pra-tersier, riset sistem petroleum gunung api, dan riset gas biogenik	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		4 Menyiapkan WK Migas konvensional minimal 9 WK per tahun dan penandatanganan WK Migas konvensional minimal 6 WK per tahun	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		5 Menyiapkan WK Migas non konvensional minimal 3 WK per tahun dan penandatanganan WK Migas non konvensional minimal 2 WK per tahun	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		6 Melakukan survei umum migas minimal 3 wilayah per tahun	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		7 Melakukan *assessment* prospek migas dan *shale gas* minimal 6 wilayah per tahun	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		8 Melakukan evaluasi area migas di Kawasan Indonesia Timur minimal 3 wilayah per tahun	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		9 Melakukan survei seismik *offshore* minimal 1.500 km *line* per tahun	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		10 Melakukan evaluasi WK gagal lelang minimal 5 wilayah per tahun	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		11 Mempercepat peningkatan status eksplorasi migas menjadi komersial	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		12 Meningkatkan pengawasan dan memperketat pelaksanaan eksplorasi (*firm commitment)* Kontraktor Kontrak Kerja Sama (KKKS) dan memastikan fluktuasi harga minyak tidak mempengaruhi realisasi pemboran eksplorasi yang sudah direncanakan	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
2 Peningkatan eksplorasi sumber daya dan cadangan batubara	1 Meningkatkan kualitas survei geologi oleh lembaga Pemerintah untuk eksplorasi sumber daya dan cadangan batubara		Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		2 Meningkatkan kerja sama Pemerintah dan badan usaha dalam melakukan eksplorasi sumber daya dan cadangan batubara	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
	3 Peningkatan eksplorasi sumber daya dan cadangan panas bumi	1 Meningkatkan kualitas dan kuantitas survei potensi sumber daya dan cadangan panas bumi	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2 Melakukan pelelangan WK Panas Bumi minimal 7 WK per tahun	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3 Menyiapkan rekomendasi WK Panas Bumi minimal 4 WK per tahun	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
	4 Peningkatan potensi dan kualitas data EBT	1 Meningkatkan kualitas dan kuantitas survei potensi energi air, bioenergi, surya, dan angin	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2 Melakukan survei potensi arus, gelombang dan perbedaan suhu lapisan laut, serta EBT lainnya	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		3 Meningkatkan survei potensi dan cadangan uranium serta melakukan survei potensi dan cadangan thorium	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050
2 Meningkatkan produksi energi dan sumber energi dalam negeri dan/atau dari sumber luar negeri	1 Optimalisasi produksi minyak dan gas bumi (migas)	1 Memastikan produksi minyak bumi tidak kurang dari 567,7 ribu *barrel oil per day* (bopd) dan produksi gas bumi menjadi tidak kurang dari 6.700 juta kaki kubik per hari (mmscfd) pada tahun 2025	Kementerian Energi dan Sumber Daya Mineral	Revisi Inpres Nomor 2 Tahun 2012 tentang Peningkatan Produksi Minyak Bumi Nasional	2016-2025
		2 Mengoptimalkan produksi lapangan migas antara lain dengan memberlakukan kontrak bagi hasil (PSC) khusus untuk kegiatan *Enhanced Oil Recovery* (EOR) dan segera memutuskan status kontrak yang akan berakhir pada lapangan-lapangan yang mempunyai potensi EOR	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		3 Mempercepat penyelesaian proyek gas bumi, antara lain Blok Sengkang, Blok Matindok, Proyek IDD, Lapangan MDA-MBH, Blok A, Lapangan Jangkrik, Lapangan Jambaran Tiung Biru, Proyek Tangguh Train-3, Lapangan Abadi (Masela), dan Blok East Natuna	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2027
		4 Melakukan komersialisasi menara bor purwarupa (*prototype rig*) *Coal Bed Methane* (CBM) yang telah dibuat dengan target 2 unit per tahun, dalam rangka meningkatkan dan mengefisienkan kegiatan eksplorasi dan eksploitasi CBM	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019
2 Peningkatan iklim investasi migas		1 Memperbaharui prosedur pelayanan perizinan di bidang energi	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		2 Menyempurnakan sistem, syarat dan ketentuan (*terms and conditions)* Kontrak Kerja Sama (KKS) migas konvensional dan non-konvensional yang lebih menarik bagi investasi	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019
		3 Memfasilitasi permasalahan tumpang tindih lahan dan pembebasan lahan untuk optimalisasi produksi migas	Kementerian Agraria dan Tata Ruang	Rencana Strategis Kementerian/ Lembaga	2016-2050
	3 Pengembangan lapangan migas tidak aktif (*idle*)	Mengevaluasi efektifitas kebijakan pengembangan lapangan migas tidak aktif	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait Insentif Pengembangan Lapangan Minyak Bumi Marginal dan Permen ESDM terkait Pedoman Pengusahaan Minyak Bumi pada Sumur Tua	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	4 Peningkatan investasi dan pengembangan sumber energi di luar negeri oleh Badan Usaha Milik Negara (BUMN)	1 Menyusun strategi kerja sama internasional bidang energi yang bertujuan menjamin ketahanan energi nasional dan ketersediaan energi dalam negeri serta meningkatkan perekonomian nasional	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019
		2 Meningkatkan kerja sama antar negara (*Government to Government*) dalam investasi dan pengembangan lapangan migas di luar negeri	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3 Meningkatkan kerja sama internasional dalam investasi dan pengembangan energi	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
	5 Peningkatan produksi BBN untuk pemanfaatan di sektor transportasi, industri dan pembangkit listrik	1 Meningkatkan produksi biodiesel sebesar 11,6 juta kl pada tahun 2025 sebagai campuran Bahan Bakar Minyak (BBM) untuk pemanfaatan sektor transportasi, industri dan pembangkit listrik	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		2 Meningkatkan produksi bioethanol sebesar 3,4 juta kl pada tahun 2025 sebagai campuran BBM untuk pemanfaatan sektor transportasi	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
3 Meningkatkan keandalan sistem produksi, transportasi dan distribusi penyediaan energi	1 Pembangunan infrastruktur migas	1 Meningkatkan kapasitas kilang minyak nasional menjadi lebih dari 2 juta barel per hari pada tahun 2025, melalui pembangunan kilang baru dan Rencana Induk Pengembangan Kilang (*Refinery Development Master Plan*/RDMP)	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2 Meningkatkan panjang pipa transmisi/distribusi gas bumi menjadi 18.322 km	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		3 Mempercepat penyelesaian pembangunan infrastruktur gas bumi, antara lain Kilang *Liquefied Natural Gas* (LNG) *South Sulawesi* (2016), Pipa transmisi Muara Karang-Muara Tawar-Tegal Gede (2016), *Receiving Terminal Banten* (2017), Unit Regasifikasi dan Penyimpanan Terapung (*Floating Storage Regasification Unit*/ FSRU) Jawa Tengah (2017), Pipa transmisi Gresik-Semarang (2017), Kilang LNG Tangguh Train-3 (2020), dan jaringan gas kota bagi 4,7 juta rumah tangga (2025)	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		4 Membangun fasilitas pengolahan *Dimethyl Ether*/ *DME* (sebagai campuran LPG) dengan rencana produksi sekitar 1 juta ton pada tahun 2025	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		5 Menyusun kebijakan pengembangan fasilitas transportasi (kapal, pelabuhan, dan kereta api) dikaitkan dengan jaringan dan distribusi energi (BBM dan gas)	Kementerian Perhubungan	Permen Perhubungan terkait pengembangan fasilitas transportasi	2016-2019
	2 Pembangunan infrastruktur ketenagalistrikan	Membangun infrastruktur ketenagalistrikan hingga penyediaan kapasitas terpasang pembangkit listrik, mencapai: a. 135,5 GW pada tahun 2025, terdiri dari pembangkit listrik fosil sebesar 90,4 GW dan pembangkit listrik EBT sebesar 45,1 GW b. 443,1 GW pada tahun 2050, terdiri dari pembangkit listrik fosil sebesar 275,4 GW dan pembangkit listrik EBT sebesar 167,6 GW	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	3 Penyehatan BUMN energi	1 Menyelenggarakan pembinaan BUMN energi dalam rangka regionalisasi usaha, penguatan manajemen usaha maupun permodalan yang sehat dan menerapkan kaidah standar internasional	Kementerian Badan Usaha Milik Negara	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2 Memberikan kesempatan seluas-luasnya kepada BUMN energi untuk memperluas kegiatan usaha energi nasional dan mampu berdaya saing internasional	Kementerian Badan Usaha Milik Negara	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3 Membentuk badan usaha EBT tersendiri yang ditugasi Pemerintah untuk mengembangkan, memanfaatkan, dan/atau membeli EBT	Kementerian Badan Usaha Milik Negara	Rencana Strategis Kementerian/ Lembaga	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	4 Peningkatan penyediaan energi untuk menunjang penyebaran dan pengembangan industri ke luar Jawa	Meningkatkan pembangunan infrastruktur energi di luar Jawa dalam rangka meningkatkan porsi investasi industri pengolahan non-migas luar Jawa dengan Jawa menjadi 40% : 60% pada tahun 2035	Kementerian Energi dan Sumber Daya Mineral, Kementerian Perindustrian, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2035
4 Mengurangi ekspor energi fosil secara bertahap terutama gas dan batubara dan menetapkan batas waktu untuk memulai menghentikan ekspor	1 Pengurangan ekspor gas bumi	Mengurangi porsi ekspor gas bumi menjadi kurang dari 20% pada tahun 2025 dan menghentikan ekspor gas bumi paling lambat tahun 2036, dengan menjamin penyerapan produksi gas dalam negeri untuk industri yang terintegrasi hulu-hilir, transportasi, dan sektor lainnya	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2036
	2 Pengurangan ekspor batubara	Mengurangi porsi ekspor batubara secara bertahap dan menghentikan ekspor batubara paling lambat tahun 2046, dalam rangka memprioritaskan kebutuhan dalam negeri	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait pengendalian produksi dan penjualan batubara	2016-2046

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	3 Pengurangan ekspor minyak mentah	Mengurangi ekspor minyak mentah semaksimal mungkin dalam rangka memprioritaskan kebutuhan dalam negeri dan menghentikannya pada saat kilang dalam negeri sudah mampu menyerap seluruh produksi dalam negeri	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
5 Mewujudkan keseimbangan antara laju penambahan cadangan energi fosil dengan laju produksi maksimum	Peningkatan Rasio Pemulihan Cadangan (*Reserve Replacement Ratio*/RRR)	1 Meningkatkan rasio pemulihan cadangan migas hingga mencapai 100% pada tahun 2025, dengan meningkatkan kegiatan eksplorasi secara masif menjadi tiga kali lipat	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2 Meningkatkan rasio pemulihan cadangan batubara hingga mencapai 5% per tahun	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		3 Meningkatkan keterlibatan negara dalam pendanaan kegiatan eksplorasi melalui mekanisme pendanaan dari sebagian pendapatan negara dari migas (*petroleum fund*) yang merupakan bagian dari premi pengurasan (*depletion premium*) atau dari sumber pendanaan lainnya	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
6 Memastikan terjaminnya daya dukung lingkungan untuk menjamin ketersediaan sumber energi air dan panas bumi	Pemeliharaan dan pemulihan area tangkapan air di kawasan hutan konservasi dan hutan lindung untuk menjamin ketersediaan sumber energi air dan panas bumi	1 Menyiapkan dan memelihara lokasi sumber energi air dan panas bumi di kawasan hutan konservasi dan hutan lindung	Kementerian Lingkungan Hidup dan Kehutanan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2 Merehabilitasi lingkungan di daerah sumber energi panas bumi dan air	Kementerian Lingkungan Hidup dan Kehutanan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		3	Menyempurnakan peraturan perundang-undangan terkait sumber daya air	Kementerian Pekerjaan Umum dan Perumahan Rakyat, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2019
7 Dalam mewujudkan ketersediaan energi untuk kebutuhan nasional, jika terjadi tumpang tindih pemanfaatan lahan dalam penyediaan energi maka didahulukan yang memiliki nilai ketahanan nasional dan/atau nilai strategis lebih tinggi	Pemanfaatan lahan untuk penyediaan energi didasarkan pada Rencana Tata Ruang Wilayah (RTRW)	1	Menyelaraskan pemanfaatan lahan untuk penyediaan energi dengan RTRW	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2	Menyusun mekanisme pemanfaatan lahan untuk menjamin penyediaan energi pada lahan yang tumpang tindih dengan kebutuhan lain	Kementerian Agraria dan Tata Ruang, Pemerintah Daerah	Perubahan peraturan perundang-undangan terkait penataan ruang	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
Kebijakan Utama-2: Prioritas Pengembangan Energi					
1 Pengembangan energi dengan mempertimbangkan keseimbangan keekonomian energi, keamanan pasokan energi, dan pelestarian fungsi lingkungan	1 Pencapaian maksimal penggunaan Energi Terbarukan dengan memperhatikan tingkat keekonomian	Mencapai target bauran energi primer dari sumber EBT paling sedikit 23% pada tahun 2025 dan paling sedikit 31% pada tahun 2050	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
	2 Pencapaian minimal penggunaan minyak bumi	Menekan penggunaan energi primer minyak bumi menjadi kurang dari 25% pada tahun 2025 dan kurang dari 20% pada tahun 2050	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
	3 Pengoptimalan pemanfaatan gas bumi	Mengoptimalkan pemanfaatan energi primer gas bumi sebesar minimal 22% pada tahun 2025 dan minimal 24% pada tahun 2050	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
	4 Penggunaan batubara sebagai andalan pasokan energi nasional, dengan menggunakan teknologi bersih	Memanfaatkan batubara sebagai andalan untuk menyeimbangkan pasokan energi primer sebesar minimal 30% pada tahun 2025 dan minimal 25% pada tahun 2050, dengan menggunakan teknologi bersih	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
2 Pengutamaan penyediaan energi bagi masyarakat yang belum memiliki akses terhadap energi listrik, gas rumah tangga, dan energi untuk transportasi, industri, dan pertanian	1 Peningkatan konversi BBM ke gas untuk rumah tangga	Memperluas wilayah konversi penggunaan minyak tanah ke gas dan bioenergi pada sektor rumah tangga	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2020
	2 Peningkatan rasio elektrifikasi	Meningkatkan rasio elektrifikasi mendekati 100% pada tahun 2020	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2020
	3 Pembangunan infrastruktur energi	Membangun infrastruktur penyediaan energi untuk sektor transportasi, industri dan pertanian yang belum memiliki akses terhadap energi	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
3 Pengembangan energi dengan mengutamakan sumber daya energi setempat	1 Peningkatan pemanfaatan EBT	1 Mengembangkan sistem tenaga listrik kecil berbasis EBT untuk penyediaan listrik di wilayah-wilayah yang tidak terjangkau oleh perluasan jaringan (*grid*)	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		2	Memanfaatkan sumber energi tenaga panas bumi, air, bioenergi, surya, angin, dan EBT lainnya sesuai dengan potensi energi setempat	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3	Membangun dan mengembangkan pasokan dan pemanfaatan EBT untuk masyarakat desa yang belum memiliki akses terhadap energi	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		4	Meningkatkan kualitas dan kuantitas survei potensi energi tenaga air dan melakukan pemetaan rinci untuk pengembangan pembangkit hidro skala kecil	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		5	Mewajibkan Pemerintah Daerah membangun dan mengelola Pembangkit Listrik Tenaga Bayu (PLTB) melalui Badan Usaha Milik Daerah (BUMD)	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	2 Pemanfaatan tenaga panas bumi untuk non ketenagalistrikan	1	Menyusun kebijakan pemanfaatan tenaga panas bumi untuk non ketenagalistrikan	Kementerian Energi dan Sumber Daya Mineral	PP terkait pemanfaatan langsung panas bumi	2016-2019
		2	Melakukan penelitian dan pengembangan pemanfaatan tenaga panas bumi untuk pemanfaatan agrobisnis, wisata, dan industri	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3	Menerapkan hasil penelitian dan pengembangan pemanfaatan tenaga panas bumi untuk dimanfaatkan agrobisnis, wisata, dan industri	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		4	Menyusun peraturan terkait keekonomian pemanfaatan tenaga panas bumi	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
4 Pengembangan energi dan sumber daya energi diprioritaskan untuk memenuhi kebutuhan energi dalam negeri	Peningkatan ketahanan energi nasional	1	Mengurangi ketergantungan impor BBM secara bertahap dan menghentikan impor BBM paling lambat tahun 2025	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2	Mengendalikan impor LPG menjadi dibawah 50% dari kebutuhan gas nasional pada tahun 2050	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3	Meningkatkan pemanfaatan EBT	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		4	Menetapkan harga energi sesuai keekonomian berkeadilan	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		5	Menyediakan subsidi energi secara tepat sasaran untuk golongan masyarakat tidak mampu	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		6 Mengembangkan dan meningkatkan kehandalan infrastruktur energi	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
5 Pengembangan industri dengan kebutuhan energi yang tinggi diprioritaskan di daerah yang kaya sumber daya energi	Memprioritaskan kawasan industri yang berkebutuhan energi tinggi berlokasi dekat dengan sumber daya energi	Menetapkan prioritas lokasi kawasan industri berkebutuhan energi tinggi di daerah mendekati sumber daya energi	Kementerian Perindustrian, Pemerintah Daerah	Permen Perindustrian terkait pedoman teknis penentuan lokasi kawasan industri	2016-2019
6 Pengembangan energi nuklir yang dimanfaatkan dengan mempertimbangkan keamanan pasokan energi nasional dalam skala besar, mengurangi emisi karbon dan tetap mendahulukan	Pengkajian pemanfaatan Pembangkit Listrik Tenaga Nuklir (PLTN)	1 Meneliti pengembangan teknologi PLTN disertai aspek-aspek keekonomian dan keselamatan	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2 Mendorong penguasaan teknologi PLTN sejalan dengan perkembangan terkini kemajuan teknologi PLTN di dunia	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
potensi energi baru dan energi terbarukan sesuai nilai keekonomiannya, serta mempertimbangkan-nya sebagai pilihan terakhir dengan memperhatikan faktor keselamatan secara ketat		3	Membangun kerja sama internasional terkait studi pengembangan PLTN	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		4	Melakukan analisis multi kriteria terhadap implementasi PLTN mencakup kepentingan mendesak, skala besar, jaminan pasokan, keseimbangan pasokan energi, pengurangan emisi karbon, faktor keselamatan, dan skala keekonomian dengan melibatkan berbagai pandangan dari berbagai *stakeholder*	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019
		5	Menyusun peta jalan (*roadmap*) implementasi PLTN sebagai pilihan terakhir dalam prioritas pengembangan energi nasional	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
Kebijakan Utama-3: Pemanfaatan Sumber Daya Energi Nasional					
1 Pemanfaatan sumber energi terbarukan dari jenis energi air, energi panas bumi, energi laut, dan energi angin diarahkan untuk ketenagalistrikan	1 Peningkatan peran EBT dalam bauran energi	Meningkatkan peran EBT: a. Menjadi paling sedikit 23% sampai dengan tahun 2025, dengan penyediaan kapasitas pembangkit listrik EBT paling sedikit 45,1 GW: 1) PLTP 7,2 GW (16%) 2) PLTA 18 GW (39,8%) 3) PLTM dan PLTMH 3 GW (6,6%) 4) PLT Bioenergi 5,5 GW (12,2%) 5) PLTS 6,5 GW (14,4%) 6) PLTB 1,8 GW (4%) 7) PLT EBT lainnya 3,1 GW (6,9%) b. Menjadi paling sedikit 31% sampai dengan tahun 2050, dengan penyediaan kapasitas pembangkit listrik EBT paling sedikit 167,6 GW: 1) PLTP 17,5 GW (10,5%) 2) PLTA 38 GW (22,7%) 3) PLTM dan PLTMH 7 GW (4,2%) 4) PLT Bioenergi 26 GW (15,5%) 5) PLTS 45 GW (26,8%) 6) PLTB 28 GW (16,7%) 7) PLT EBT lainnya 6,1 GW (3,6%)	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	2 Pembangunan Pembangkit Listrik Tenaga Panas Bumi (PLTP)	1	Meningkatkan kualitas dan kuantitas survei potensi sumber daya dan cadangan panas bumi	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2	Mengoptimalkan pemanfaatan panas bumi khususnya pada WK Panas Bumi yang mempunyai cadangan terbukti	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		3	Mempercepat lelang WK Panas Bumi	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		4	Mengalokasikan pembiayaan pengembangan panas bumi melalui Penyertaan Modal Negara (PMN) dan pinjaman kepada BUMN	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		5	Menugaskan BUMN/Badan Layanan Umum (BLU) untuk mengembangkan PLTP	Kementerian Energi dan Sumber Daya Mineral	PP terkait pemanfaatan tidak langsung sumber daya panas bumi (listrik)	2016-2019

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		6	Menyusun kebijakan harga jual listrik (*feed-in tariff*) panas bumi	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait harga jual listrik panas bumi dengan mekanisme *feed-in tariff*	2016-2019
		7	Memberikan Penugasan Survei Pendahuluan (PSP) dan/atau eksplorasi kepada Badan Usaha	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		8	Meningkatkan survei pendahuluan dan/atau eksplorasi oleh instansi Pemerintah	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
	3 Pembangunan Pembangkit Listrik Tenaga Air, Minihidro, dan Mikrohidro	1	Menyempurnakan peraturan perundang-undangan terkait sumber daya air	Kementerian Pekerjaan Umum dan Perumahan Rakyat, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2019

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		2	Meningkatkan kualitas dan kuantitas survei potensi energi tenaga air dan melakukan pemetaan rinci untuk pengembangan pembangkit hidro skala kecil	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3	Meningkatkan implementasi peraturan perundang-undangan mengenai pembelian tenaga listrik dari pembangkit listrik tenaga air dengan kapasitas sampai dengan 10 MW oleh PT PLN (Persero).	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
	4 Pembangunan pembangkit listrik tenaga arus, gelombang, dan perbedaan suhu lapisan laut	1	Melakukan survei potensi tenaga arus, gelombang, dan perbedaan suhu lapisan laut untuk wilayah yang belum mempunyai data potensi	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		2	Melakukan pra-studi kelayakan untuk wilayah/daerah yang sudah mempunyai pengukuran potensi dan dilanjutkan dengan studi kelayakan pembangunan PLT arus, gelombang, dan perbedaan suhu lapisan laut	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
	5 Pembangunan Pembangkit Listrik Tenaga Angin	1	Meningkatkan kualitas dan kuantitas survei dan pemetaan potensi tenaga angin	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2	Melakukan survei potensi tenaga angin untuk daerah atau wilayah yang belum mempunyai pengukuran potensi	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3	Melakukan pra-studi kelayakan untuk daerah yang sudah mempunyai pengukuran potensi angin dan dilanjutkan dengan studi kelayakan pembangunan PLTB	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		4	Mewajibkan Pemerintah Daerah membangun dan mengelola PLT Bayu melalui BUMD	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
2 Pemanfaatan sumber energi terbarukan dari jenis energi sinar matahari (surya) diarahkan untuk ketenagalistrikan, dan energi non listrik untuk industri, rumah tangga, dan transportasi	1 Pengembangan kebijakan pemanfaatan sumber energi sinar matahari untuk ketenagalistrikan dan non ketenagalistrikan	1	Menyusun peta jalan (*roadmap*) pemanfaatan energi sinar matahari untuk ketenagalistrikan dan non listrik	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019
		2	Menyempurnakan harga dan skema pembelian tenaga listrik dari Pembangkit Listrik Tenaga Surya (PLTS)	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Permen ESDM terkait pembelian tenaga listrik dari PLTS	2016-2019
		3	Memfasilitasi pendirian industri hulu hilir PLTS	Kementerian Perindustrian, Pemerintah Daerah	Permen Perindustrian terkait pengembangan hulu hilir PLTS	2019-2025

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		4 Mengembangkan pemanfaatan energi panas matahari (*solar thermal*)	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		5 Membangun PLTS bagi fasilitas transportasi (terminal, stasiun, pelabuhan, bandara, peralatan bongkar muat, dan lain-lain)	Kementerian Perhubungan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		6 Menerapkan kebijakan pemanfaatan energi surya untuk moda transportasi	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2025-2050
		7 Memfasilitasi alih teknologi industri sel surya melalui pembelian lisensi dan/atau akuisisi	Kementerian Perindustrian	Perpres terkait pengadaan teknologi melalui proyek putar kunci (*turn key project)* dan Permen Perindustrian terkait pengalihan hak melalui lisensi dan/atau akuisisi teknologi	2016-2019

PERIODE (Kegiatan)
2016-2050
2016-2050
2016-2050
2016-2019

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		8	Memfasilitasi penelitian dan pengembangan teknologi sel surya	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050
		9	Menerapkan hasil penelitian dan pengembangan sel surya menjadi produk industri	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2050
3 Pemanfaatan sumber energi terbarukan dari jenis BBN diarahkan untuk menggantikan BBM terutama untuk transportasi dan industri	1 Konversi pemanfaatan BBM ke BBN untuk sektor transportasi, industri, dan pembangkit	1	Menerapkan Standar Nasional Indonesia (SNI) untuk produk bioenergi khususnya BBN	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2	Menyusun peta jalan (*roadmap*) penggunaan BBN sebagai campuran BBM pada transportasi baik pada transportasi darat, laut, udara, dan kereta api sampai dengan 2050	Kementerian Perhubungan	Permen Perhubungan terkait penggunaan BBN pada transportasi	2016-2019

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		3	Menerapkan kebijakan pemanfaatan BBN di sektor transportasi darat khususnya angkutan umum kota/perkotaan, transportasi laut termasuk kapal nelayan, dan transportasi udara sampai 2025	Kementerian Perhubungan, Pemerintah Daerah	Permen Perhubungan terkait pemanfaatan BBN di sektor transportasi darat, laut, dan udara	2016-2025
		4	Menyiapkan kebijakan pemanfaatan kendaraan bermotor berbahan bakar bensin dan ethanol (*flexi-fuel engine*)	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2019
		5	Menyiapkan peta jalan (*roadmap*) pembangunan infrastruktur bioenergi termasuk skema pendanaan pembangunan pabrik komersial biodiesel dan bioethanol dengan kapasitas masing-masing sebesar 11,6 juta kl per tahun dan 3,4 juta kl per tahun serta pabrik bioavtur sebesar 0,1 juta kl per tahun di tahun 2025	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2017

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		6 Memenuhi target produksi BBN/biofuel minimal tahun 2025 sebesar 15,6 juta kl (termasuk untuk pembangkit listrik) dengan target pencampuran BBN dan BBM sebesar 30% biodiesel (11,6 juta kl), 20% ethanol (3,4 juta kl), dan 5% Bioavtur (0,1 juta kl) sedangkan target produksi biofuel tahun 2050 sebesar 54,2 juta kl	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2019-2050
		7 Menyempurnakan harga patokan BBN/biofuel	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait pengaturan pengusahaan biofuel	2016-2019
		8 Melaksanakan pencampuran BBN pada PLTD yang beroperasi setara 3,1 GW pada tahun 2025	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	2 Peningkatan produksi dan pemanfaatan BBN	1	Menugaskan BUMN dan/atau BUMD untuk memproduksi dan membeli BBN	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Permen ESDM terkait penugasan kepada BUMN untuk memproduksi dan membeli BBN	2016-2019
		2	Menyusun peta jalan penyiapan jenis tanaman prioritas untuk bahan baku BBN	Kementerian Pertanian, Kementerian Lingkungan Hidup dan Kehutanan	Rencana Strategis Kementerian/ Lembaga	2016-2019
	3 Penyediaan lahan khusus untuk kebun energi	1	Menyediakan lahan seluas 4 juta hektar secara bertahap untuk memenuhi kebutuhan bahan baku BBN untuk menghasilkan 15,6 juta kl biofuel	Kementerian Agraria dan Tata Ruang, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2	Menyusun peraturan terkait penetapan dan alih fungsi pemanfaatan lahan untuk lahan energi (lahan bekas tambang, lahan terlantar, dan lahan hutan energi)	Kementerian Agraria dan Tata Ruang	Perpres terkait alih fungsi pemanfaatan lahan untuk lahan energi	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
4 Pemanfaatan sumber energi dari jenis bahan bakar nabati dilakukan dengan tetap menjaga ketahanan pangan	Penggunaan jenis tanaman di luar kebutuhan pangan untuk BBN	1 Memprioritaskan penggunaan bahan baku BBN dari sumber baru di luar produk tanaman pangan prioritas	Kementerian Pertanian	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2 Menyusun target penggunaan biofuel yang tidak mengganggu pemenuhan kebutuhan pangan	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019
5 Pemanfaatan energi terbarukan dari jenis biomassa dan sampah diarahkan untuk ketenagalistrikan dan transportasi	1 Pembangunan PLT Bioenergi	1 Membangun PLT Biomassa paling sedikit satu unit per provinsi di luar Pulau Jawa	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2019-2050
		2 Membangun Pembangkit Listrik Berbasis Sampah (PLTSa) paling sedikit 10 MW per provinsi	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3 Mempercepat pembangunan PLTSa di Provinsi DKI Jakarta, Kota Tangerang, Kota Bandung, Kota Semarang, Kota Surakarta, Kota Surabaya, dan Kota Makassar melalui pemanfaatan sampah yang menjadi urusan Pemerintah	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		4 Mengembangkan PLT Biomassa oleh pabrik kelapa sawit dan pengelola hutan energi dengan kewajiban pembelian produksi listrik oleh badan usaha penyedia tenaga listrik	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		5 Menggalakkan budi daya tanaman-tanaman biomassa non-pangan	Kementerian Pertanian, Kementerian Lingkungan Hidup dan Kehutanan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		6 Mengembangkan pembangkit listrik biogas dari *Palm Oil Mill Effluent* (POME) oleh setiap pabrik kelapa sawit dengan kewajiban pembelian produksi listrik oleh badan usaha penyedia tenaga listrik	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	2 Pembangunan infrastruktur biogas	1 Menyusun peta jalan pengembangan biogas per provinsi untuk mencapai target produksi biogas di tahun 2025 sebesar 47,4 mmscfd untuk keperluan bahan bakar sektor rumah tangga	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2019
		2 Membangun *digester* biogas di setiap provinsi sesuai dengan target peta jalan (*roadmap*)	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga, RUED	2016-2025
6 Pemanfaatan minyak bumi hanya untuk transportasi dan komersial, yang memang tidak dan/atau belum bisa digantikan dengan energi atau sumber energi lainnya	Pembatasan BBM secara bertahap kecuali untuk sektor transportasi dan komersial	Melakukan pembatasan pemanfaatan BBM secara bertahap kecuali untuk sektor transportasi dan komersial	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait pembatasan penggunaan BBM untuk sektor tertentu	2016-2025

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
7 Pemanfaatan sumber energi gas untuk industri, ketenagalistrikan, rumah tangga, dan transportasi, diutamakan untuk pemanfaatan yang memiliki nilai tambah paling tinggi	Optimalisasi penggunaan gas untuk industri, ketenagalistrikan, rumah tangga, dan transportasi yang memiliki nilai tambah paling tinggi	1	Meningkatkan kapasitas pembangkit listrik berbahan bakar gas hingga mencapai sebesar 36 GW di tahun 2025 dan sebesar 114 GW pada tahun 2050	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2	Memprioritaskan pasokan gas dalam negeri sebagai bahan baku industri strategis yang memiliki nilai tambah tinggi bagi perekonomian nasional	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		3	Menyusun peta jalan penggunaan gas pada moda transportasi	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2016-2019
		4	Menyusun paket kebijakan pemanfaatan gas pada transportasi umum kota/perkotaan bagi produsen mobil maupun pengusaha angkutan umum	Kementerian Perhubungan, Kementerian Keuangan	Permen Keuangan terkait paket kebijakan pemanfaatan gas pada transportasi umum kota/ perkotaan	2016-2019

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		5	Membangun dan meningkatkan kapasitas industri Petrokimia Hulu berbahan baku gas untuk menyerap produksi gas dalam negeri	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2050
		6	Khusus untuk Teluk Bintuni segera dibangun industri petrokimia hulu untuk menyerap produksi gas Tangguh	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2025
		7	Meningkatkan pengadaan dan pemanfaatan bus menggunakan mesin BBG (*dedicated engine)* untuk angkutan umum	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2016-2025
		8	Mewajibkan kendaraan Pemerintah Pusat dan Pemerintah Daerah menggunakan bahan bakar gas bagi daerah yang sudah memiliki infrastruktur gas	Kementerian Perhubungan, Pemerintah Daerah	Permen Perhubungan terkait pemanfaatan bahan bakar sektor transportasi	2016-2050

	STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
8	Pemanfaatan sumber energi batubara untuk ketenagalistrikan dan industri	Penyediaan pasokan batubara untuk pembangkit listrik dan industri	1	Menyediakan batubara sebagai energi primer pembangkit listrik sekitar 148 juta ton atau sekitar 54,3 GW pada tahun 2025 dan sekitar 319 juta ton atau sekitar 161,5 GW pada tahun 2050	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait *Domestic Market Obligation* (DMO) Batubara	2016-2050
			2	Meningkatkan pemanfaatan batubara untuk sektor industri dengan target mencapai 55,2 juta ton pada tahun 2025 dan 115 juta ton pada tahun 2050	Kementerian Perindustrian	Inpres terkait pemanfaatan batubara untuk sektor industri	2016-2050
9	Pemanfaatan sumber energi baru berbentuk cair, yaitu batubara tercairkan dan hidrogen, untuk transportasi	Pengembangan pencairan batubara (*coal liquefaction*) dan hidrogen	1	Menyusun peta jalan dan kebijakan pengembangan sumber energi batubara berbentuk cair untuk transportasi sampai dengan tahun 2050	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait pemanfaatan batubara tercairkan	2016-2019
			2	Mengembangkan teknologi produksi dan penggunaan bahan bakar sintetis dan hidrogen untuk transportasi	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		3 Mempercepat pengembangan batubara tercairkan sebagai bahan bakar cair	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		4 Menyusun peraturan untuk mobil berbahan bakar sintetis dan hidrogen untuk angkutan umum dan kendaraan pribadi	Kementerian Perhubungan	Permen Perhubungan terkait penggunaan bahan bakar sintetis dan hidrogen	2016-2019
		6 Membangun industri kendaraan bermotor berbahan bakar hidrogen (*fuel cell*)	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2025-2050
10 Pemanfaatan sumber energi baru berbentuk padat dan gas untuk ketenagalistrikan	Pembangunanan pembangkit listrik berbahan bakar CBM	Membangun pembangkit listrik berbahan bakar gas dengan memanfaatkan gas dari CBM	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2019-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
11 Pemanfaatan sumber energi gerakan dan perbedaan suhu lapisan laut didorong dengan membangun prototipe sebagai langkah awal yang tersambung dengan jaringan listrik	Pengembangan potensi pemanfaatan sumber energi arus, gelombang, dan perbedaan suhu lapisan laut	1	Memetakan potensi energi tenaga arus, gelombang, dan perbedaan suhu lapisan laut	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2	Membangun pembangkit listrik tenaga arus, gelombang, dan perbedaan suhu lapisan laut	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2019-2050
		3	Menetapkan kebijakan terkait kegiatan usaha dan harga pembangkit listrik tenaga arus, gelombang, dan perbedaan suhu lapisan laut	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait kegiatan usaha dan harga listrik dari pembangkit listrik tenaga arus, gelombang, dan perbedaan suhu lapisan laut	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
12 Peningkatan pemanfaatan sumber energi sinar matahari melalui penggunaan sel surya pada transportasi, industri, gedung komersial dan rumah tangga	1 Pemanfaatan energi sinar matahari untuk industri dan gedung komersial	1 Memfasilitasi pemanfaatan produk sel surya sebagai sumber energi di sektor industri	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2019-2025
		2 Memberlakukan kewajiban pemanfaatan sel surya minimum sebesar 25% dari luas atap bangunan kompleks industri dan bangunan komersial, penerangan jalan umum serta bangunan fasilitas umum lainnya melalui Izin Mendirikan Bangunan (IMB)	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Perpres terkait pemanfaatan sel surya	2019-2050
	2 Pemanfaatan sel surya untuk bangunan rumah tangga	Memberlakukan kewajiban pemanfaatan sel surya minimum sebesar 25% dari luas atap bangunan rumah mewah, kompleks perumahan, apartemen melalui IMB	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2019-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	3 Pemanfaatan sel surya untuk bangunan pemerintah	Memberlakukan kewajiban pemanfaatan sel surya minimum sebesar 30% dari luas atap untuk seluruh bangunan Pemerintah Pusat dan Pemerintah Daerah	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2019-2050
	4 Pemanfaatan sel surya untuk transportasi	Mendorong pemanfaatan sel surya untuk transportasi	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2025-2050
13 Pemaksimalan dan kewajiban pemanfaatan sumber energi sinar matahari dilakukan dengan syarat seluruh komponen dan sistem pembangkit energi matahari dari hulu sampai hilir diproduksi di dalam negeri secara bertahap	Peningkatan Tingkat Komponen Dalam Negeri (TKDN) produksi komponen sel surya	1 Menyusun daftar TKDN produk industri komponen sel surya	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2019
		2 Menyusun dan menerapkan SNI sistem, teknologi dan produk sel surya	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
Kebijakan Utama-4: Cadangan Energi Nasional					
1 Cadangan strategis yang diatur dan dialokasikan oleh pemerintah untuk menjamin ketahanan energi jangka panjang serta hanya dapat diusahakan sesuai waktu yang telah ditetapkan atau sewaktu-waktu diperlukan untuk kepentingan nasional	Penetapan kebijakan cadangan strategis energi	1 Menetapkan jenis, jumlah, lokasi, dan mekanisme pengelolaan cadangan strategis energi	Kementerian Energi dan Sumber Daya Mineral	Perpres terkait cadangan strategis energi	2016-2019
		2 Menetapkan Wilayah Pencadangan Negara (WPN) batubara sesuai dengan amanat UU Nomor 4 Tahun 2009 tentang Pertambangan Mineral dan Batubara	Kementerian Energi dan Sumber Daya Mineral	PP terkait WPN batubara	2016-2019
2 Cadangan Penyangga Energi (CPE) wajib disediakan oleh Pemerintah	Penyediaan CPE	Menetapkan jenis, jumlah, waktu, dan lokasi serta pengelolaan CPE	Dewan Energi Nasional dan Kementerian Energi dan Sumber Daya Mineral	Perpres terkait CPE	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
3 Cadangan operasional yang wajib disediakan oleh badan usaha dan industri energi untuk menjamin kontinuitas pasokan energi	1 Penetapan jenis dan volume cadangan operasional BBM	1 Menyelesaikan penetapan jenis dan volume cadangan operasional BBM nasional untuk keperluan minimal 30 hari konsumsi	Kementerian Energi dan Sumber Daya Mineral	Kepmen ESDM terkait penetapan jenis dan jumlah cadangan BBM nasional	2016-2019
		2 Menentukan alokasi cadangan operasional BBM yang wajib dipenuhi oleh badan usaha	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019
	2 Percepatan pembangunan infrastruktur penyimpanan BBM	Memfasilitasi pembangunan infrastruktur penyimpanan BBM di beberapa daerah strategis	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
Kebijakan Pendukung-1: Konservasi energi, konservasi sumber daya energi, dan diversifikasi energi					
1 Konservasi energi dilakukan baik dari sisi hulu sampai hilir, meliputi pengelolaan sumber daya energi dan seluruh tahapan eksplorasi, produksi, transportasi, distribusi, serta pemanfaatan energi dan sumber energi	1 Pelaksanaan kebijakan konservasi energi	1 Menerapkan secara konsisten PP Nomor 70 Tahun 2009 tentang Konservasi Energi	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2 Menggunakan teknologi pembangkit listrik yang lebih efisien	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3 Menerapkan peremajaan suku cadang dan komponen (*retrofitting*) pada pembangkit	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		4 Menerapkan manajemen energi pada pembangkit	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		5 Mengurangi rugi-rugi (*losses*) pada transmisi dan distribusi listrik	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		6 Melakukan pengaturan pemakaian energi yang ramah lingkungan dan efisien pada kawasan pengguna energi terintegrasi	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2019-2050

	STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
2	Konservasi sumber daya energi dilaksanakan dengan pendekatan lintas sektor, paling sedikit melalui penyesuaian dengan tata ruang nasional dan daya dukung lingkungan hidup	Penyediaan energi mengutamakan sumber daya energi yang lebih lestari	1	Memelihara dan merehabilitasi daerah tangkapan air di wilayah panas bumi dan sumber energi air	Kementerian Lingkungan Hidup dan Kehutanan, Pemerintah Daerah	Peraturan perundang-undangan terkait	2016-2050
			2	Memberikan insentif fiskal dan non fiskal bagi pemanfaatan sumber daya energi dan sumber energi setempat	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
3	Produsen dan konsumen energi wajib melakukan konservasi energi dan efisiensi pengelolaan sumber daya energi untuk menjamin ketersediaan energi dalam jangka panjang	1 Pengembangan konservasi dan efisiensi energi di sektor industri	1	Menerapkan sistem pengelolaan energi dan optimalisasinya di industri secara bertahap dimulai dari industri lahap energi, industri besar, industri prioritas, dan Industri Kecil Menengah (IKM)	Kementerian Perindustrian, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2019
			2	Merencanakan kebutuhan dan efisiensi energi sektor industri	Kementerian Perindustrian	Permen Perindustrian terkait perencanaan kebutuhan dan efisiensi energi sektor industri	2016-2019

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)	PERIODE (Kegiatan)
	2 Penetapan target konsumsi bahan bakar di sektor transportasi dilakukan secara terukur dan bertahap untuk peningkatan efisiensi	1	Menyusun peta jalan pengembangan moda transportasi umum dan pribadi berdasarkan rencana diversifikasi energi sektor transportasi	Kementerian Perhubungan	Permen Perhubungan terkait peta jalan pengembangan moda transportasi	2016-2019	2016-2050
		2	Melakukan penghematan penggunaan BBM untuk sektor transportasi sehingga kebutuhan BBM untuk sektor transportasi menjadi sebesar 75,3 juta kl per tahun mulai tahun 2025	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2016-2050	2016-2025
		3	Mempercepat pengembangan transportasi massal dan kendaraan pribadi pengguna gas dengan target mencapai 282,1 mmscfd sampai dengan tahun 2025	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2016-2025	2016-2050
		4	Mempercepat penggunaan listrik untuk transportasi massal dan kendaraan pribadi mencapai 2,3 TWh sampai dengan tahun 2025	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2016-2025	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		5 Membangun industri moda transportasi listrik dan *hybrid* dari hulu sampai ke hilir	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2050
		6 Meningkatkan pemanfaatan biofuel sebagai campuran untuk bahan bakar transportasi dengan target mencapai 13,9 juta kl sampai dengan tahun 2025	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
4 Konservasi energi di sektor industri dilakukan dengan mempertimbangkan daya saing	1 Peningkatan efisiensi penggunaan energi dan mendorong inovasi serta pemanfaatan teknologi yang lebih efisien	1 Melakukan restrukturisasi permesinan industri dan pemberian fasilitas insentif (fiskal dan non fiskal bagi industri yang melaksanakan efisiensi energi)	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2 Menerbitkan standar industri hijau yang berasaskan efisiensi penggunaan bahan baku, energi, dan air, serta minimalisasi limbah	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2019

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		3	Mengembangkan standar keekonomian bahan bakar (*fuel-economy standard*) untuk kendaraan bermotor khususnya kendaraan pribadi sebelum tahun 2020	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2020
		4	Menyusun standar intensitas energi untuk masing-masing jenis industri	Kementerian Perindustrian	Permen Perindustrian terkait standar industri hijau	2016-2019
	2 Penerapan sistem manajemen energi	1	Menerapkan mandatori manajemen energi pada pengguna energi paling sedikit 6.000 TOE per tahun	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2	Menerapkan SNI ISO 50001	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3	Melaksanakan audit energi berkala	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
5 Pemerintah Pusat dan/atau Pemerintah Daerah sesuai dengan kewenangannya menetapkan pedoman dan penerapan kebijakan konservasi energi khususnya di bidang hemat energi	1 Penerapan standardisasi dan labelisasi semua peralatan pengguna energi	1 Menyusun pedoman tingkat efisiensi energi sistem termal dan penggerak untuk setiap jenis pembangkit listrik	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait tingkat efisiensi pembangkit listrik	2016-2019
		2 Menyusun standar peralatan hemat energi	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3 Menerapkan standar peralatan hemat energi di masing-masing kementerian dan lembaga	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		4 Memperkuat laboratorium uji peralatan hemat energi di masing-masing kementerian dan lembaga	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2025
		5 Menyusun standar terkait rancang bangun gedung hemat energi	Kementerian Pekerjaan Umum dan Perumahan Rakyat, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2019

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		6	Menyusun peraturan untuk penerapan desain rumah sesuai dengan standar energi efisien	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait *eco-building*	2016-2019
		7	Memperluas penerapan Standar Kinerja Energi Minimum (*Minimum Energy Performance Standard*/MEPS) dan labelisasi pada peralatan pemanfaat energi di masing-masing kementerian dan lembaga	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait MEPS dan/atau labelisasi	2016-2019
	2 Penerapan manajemen energi termasuk audit energi bagi pengguna energi	1	Menyusun peraturan Manajemen sisi pengguna (*Demand Side Management*/DSM) antara penyedia listrik dan pengguna listrik	Kementerian Energi dan Sumber Daya Mineral, Kementerian Perindustrian	Permen ESDM terkait DSM	2016-2019
		2	Menerapkan manajemen dan audit energi sesuai standar internasional untuk sektor industri, transportasi, dan komersial	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	3 Penggunaan teknologi pembangkit listrik dan peralatan konversi energi yang efisien	1	Menyusun rancangan SNI peralatan pembangkit listrik dan konversi energi lainnya di masing-masing kementerian dan lembaga terkait	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2019
		2	Menyusun peraturan pemanfaatan teknologi peralatan produksi hemat energi	Kementerian Perindustrian	Permen Perindustrian terkait pemanfaatan peralatan produksi hemat energi	2016-2019
		3	Menerapkan SNI atas peralatan pemanfaat energi di sektor rumah tangga dan komersial	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
	4 Sosialisasi budaya hemat energi		Melakukan sosialisasi dan edukasi hemat energi melalui media elektronik dan media sosial untuk meningkatkan kesadaran pelaku usaha dan masyarakat terhadap hemat energi	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	5 Peningkatan iklim usaha bagi berkembangnya usaha jasa energi sebagai investor dan penyedia energi secara hemat	Mengembangkan kebijakan Usaha Jasa Konservasi Energi (*Energy Service Company*/ESCO) untuk implementasi proyek efisiensi energi	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait ESCO	2016-2019
	6 Percepatan penerapan dan/atau pengalihan ke sistem transportasi massal, baik transportasi perkotaan maupun antar kota yang efisien	1 Mengembangkan sistem angkutan umum massal perkotaan, termasuk jaringan kereta api ke bandara dan pelabuhan (kereta api dan bus) sehingga pangsa (*share*) angkutan umum meningkat menjadi 30% dari total moda transportasi pada 2025	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2019-2025
		2 Mengembangkan angkutan bus cepat bebas hambatan (*Bus Rapid Transit*/BRT) sebanyak 10.000 bus di 50 wilayah perkotaan	Kementerian Perhubungan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		3	Meremajakan armada angkutan umum untuk meningkatkan efisiensi penggunaan energi	Kementerian Perhubungan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		4	Membangun sistem perkeretaapian Trans Jawa, Trans Sumatera, Trans Kalimantan, Trans Sulawesi, Trans Papua, dan kereta api yang sudah tidak aktif serta menambah kapasitas sistem	Kementerian Perhubungan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		5	Mengembangkan angkutan kereta api cepat terpadu (*Mass Rapid Transit*/MRT), kereta api ringan *(Light Rail Transit*/LRT), dan Trem di 13 wilayah perkotaan serta kereta api bandara	Kementerian Perhubungan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		6	Menyusun rencana pengembangan LRT sampai dengan tahun 2050	Kementerian Perhubungan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		7 Mengembangkan manajemen transportasi dengan membangun sistem transportasi cerdas (*Intelligent Transport System*/ITS) di 24 kota dan sistem pengendalian lalu lintas (*Area Traffic Control System*/ATCS) di 50 lokasi serta pembatasan angkutan barang masuk kota	Kementerian Perhubungan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
		8 Menerapkan manajemen parkir kendaraan termasuk zona parkir dengan tarif tinggi khusus di kota besar	Kementerian Perhubungan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
		9 Menerapkan pembangunan wilayah terpadu dengan jalur transportasi (*Transit Oriented Development*/TOD)	Kementerian Perhubungan, Pemerintah Daerah	Permen Perhubungan terkait TOD	2016-2025

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		10	Mengoptimalkan pergerakan pesawat di bandara dan jalur penerbangan, serta menerapkan bandara ramah lingkungan (*Eco Airport*) di 15 bandara	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2016-2025
		11	Membangun sistem tol laut (angkutan laut utama reguler untuk barang) dengan menyediakan 150 kapal	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2016-2050
	7 Percepatan penerapan jalan berbayar (*Electronic Road Pricing*/ERP) untuk mengurangi kemacetan yang ditimbulkan oleh kendaraan pribadi	1	Menyusun kebijakan dan penerapan ERP pada jalan-jalan utama kota/perkotaan	Kementerian Perhubungan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2019
		2	Menyusun kebijakan dan penerapan biaya preservasi jalan yang dananya dipungut melalui mekanisme pendapatan pemerintah	Kementerian Perhubungan, Kementerian Keuangan	Rencana Strategis Kementerian/ Lembaga	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
6 Pemerintah Pusat dan/atau Pemerintah Daerah sesuai dengan kewenangannya wajib melaksanakan diversifikasi energi untuk meningkatkan konservasi sumber daya energi dan ketahanan energi nasional dan/atau daerah	1 Percepatan penyediaan dan pemanfaatan berbagai jenis sumber energi baru dan sumber energi terbarukan	1 Menyusun peraturan percepatan pembangunan EBT	Kementerian Energi dan Sumber Daya Mineral	Perpres terkait percepatan pembangunan EBT	2016-2019
		2 Mengembangkan kebijakan harga energi yang kondusif dari usaha EBT	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait harga energi EBT	2016-2025
		3 Menyusun peta jalan pemanfaatan EBT untuk industri	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2019
	2 Percepatan pelaksanaan substitusi BBM dengan gas di sektor rumah tangga dan transportasi	1 Menyusun kebijakan untuk percepatan substitusi BBM dengan gas sektor transportasi	Kementerian Energi dan Sumber Daya Mineral, Kementerian Perhubungan, Pemerintah Daerah	Inpres terkait kewajiban penggunaan BBG sektor transportasi	2016-2019
		2 Meningkatkan secara bertahap jumlah kendaraan yang menggunakan mesin BBG (*dedicated engine*) sebanyak 2 juta unit di 15 kota sampai dengan tahun 2025	Kementerian Perhubungan, Kementerian Perindustrian, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		3 Mengalokasikan anggaran intensifikasi penggunaan BBG dalam APBN dan APBD	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		4 Menyusun kebijakan insentif fiskal untuk produksi mobil/motor BBG (*dedicated engine*) bagi pabrikan sesuai ketentuan peraturan perundang-undangan	Kementerian Keuangan, Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2019
		5 Membangun secara bertahap SPBG sebanyak 632 unit dengan total kapasitas 282 mmscfd di 15 kota sampai dengan tahun 2025, dan meningkat menjadi 2.888 unit dengan total kapasitas 1.291 mmscfd pada tahun 2050 dalam rangka percepatan pelaksanaan subtitusi BBM dengan gas di sektor transportasi	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		6	Mencantumkan kebutuhan lahan SPBG dalam RTRW Nasional/Daerah	Kementerian Agraria dan Tata Ruang, Pemerintah Daerah	Permen Agraria dan Tata Ruang terkait penyusunan RTRW	2016-2019
		7	Membangun jaringan gas kota bagi 4,7 juta sambungan rumah tangga pada tahun 2025	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
		8	Mengadakan *digester* biogas dengan target 1,7 juta rumah tangga pada tahun 2025	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
		9	Membangun fasilitas pengolahan *Dimethyl Ether*/DME (sebagai campuran LPG) dengan rencana produksi sekitar 1 juta ton pada tahun 2025	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		10	Mengembangkan tabung khusus (*absorbed natural gas*/ANG) dengan rencana pengembangan sebesar 0,1 juta ton pada tahun 2025	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	3 Percepatan pemanfaatan tenaga listrik untuk penggerak kendaraan bermotor	1	Menyusun peraturan terkait percepatan pemanfaatan tenaga listrik untuk penggerak kendaraan bermotor	Kementerian Perindustrian	Permen Perindustrian terkait pengembangan usaha kendaraan bermotor listrik	2016-2019
		2	Mengembangkan kendaraan bermotor bertenaga mesin hibrida (*hybrid engine*)	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2019-2025
		3	Mengembangkan kendaraan bertenaga listrik/*hybrid* pada tahun 2025 sebesar 2.200 unit untuk roda 4 dan 2,1 juta unit untuk kendaraan roda 2	Kementerian Perhubungan, Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2019-2025
		4	Meningkatkan secara bertahap jumlah mobil listrik untuk angkutan umum menjadi 10% dari jumlah total populasi mobil angkutan umum di kota/ perkotaan pada 2025	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2019-2025

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		5	Menyusun kebijakan insentif fiskal untuk produksi mobil/motor listrik bagi pabrikan sesuai ketentuan peraturan perundang-undangan	Kementerian Keuangan, Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2019
		6	Membangun secara bertahap sistem dan Stasiun Pengisian Listrik Umum (SPLU) untuk kendaraan bermotor listrik menjadi sebanyak 1.000 unit pada tahun 2025	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
	4 Peningkatan pemanfaatan batubara kualitas rendah untuk Pembangkit Listrik Tenaga Uap (PLTU) Mulut Tambang, batubara tergaskan (*gasified coal*), dan batubara tercairkan (*liquified coal*)	1	Menyusun peraturan terkait peningkatan pemanfaatan batubara kualitas rendah untuk PLTU Mulut Tambang, batubara tergaskan (*gasified coal*), dan batubara tercairkan (*liquified coal*)	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait pemanfaatan batubara kualitas rendah untuk PLTU Mulut Tambang, batubara tergaskan (*gasified coal*), dan batubara tercairkan (*liquified coal*)	2016-2019

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		2	Meningkatkan kapasitas Pembangkit Listrik Tenaga Gasifikasi Batubara (PLTGB) sampai 2025 sebesar 44 MW	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		3	Menyusun kerangka peraturan pembelian harga listrik dari tenaga gasifikasi batubara	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait kebijakan harga pembelian listrik dari tenaga gasifikasi batubara	2016-2019
		4	Menyusun rencana pengembangan industri komponen/peralatan instalasi PLTGB	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2019
		5	Mendorong perluasan usaha yang terintegrasi antara PLTU Mulut Tambang dan industri	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019
		6	Menjamin pasokan batubara untuk PLTU mulut tambang dialokasikan untuk jangka waktu sesuai dengan kontrak	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		7	Mengembangkan skema usaha baru untuk PLTU Mulut Tambang yang lebih kompetitif	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait PLTU Mulut Tambang	2016-2019
		8	Mengembangkan teknologi pembangkit listrik berbahan bakar batubara tercairkan/tergaskan dan penerapannya	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2025
		9	Mengembangkan penerapan konversi batubara pada industri petrokimia untuk menghasilkan produk olefin dan amonia	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2050
		10	Mengembangkan industri gasifikasi batubara sebagai bahan baku industri petrokimia dan industri pupuk	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2050
	5 Peningkatan pemanfaatan batubara kualitas menengah dan tinggi untuk pembangkit listrik dalam negeri		Mengoptimalkan pemanfaatan batubara kualitas menengah dan tinggi untuk pembangkit listrik dalam negeri	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
Kebijakan Pendukung-2: Lingkungan Hidup dan Keselamatan					
1 Pengelolaan energi nasional diselaraskan dengan arah pembangunan nasional berkelanjutan, pelestarian sumber daya alam, konservasi sumber daya energi, dan pengendalian pencemaran lingkungan hidup	Pengendalian emisi gas rumah kaca (GRK) dari sektor energi	1 Melaksanakan konservasi energi di sisi suplai energi	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait konservasi energi	2016-2050
		2 Reklamasi lahan pasca tambang batubara	Kementerian Energi dan Sumber Daya Mineral, Kementerian Lingkungan Hidup dan Kehutanan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3 Melaksanakan program audit dan manajemen energi	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		4 Mewajibkan pemanfaatan teknologi energi batubara yang ramah lingkungan (*Clean Coal Technology*/CCT) dan efisiensi tinggi (*Ultra Super Critical*/USC) secara bertahap	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		5 Melaksanakan Perpres Nomor 61 Tahun 2011 tentang RAN-GRK secara konsisten	Kementerian Lingkungan Hidup dan Kehutanan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
2 Kegiatan pengelolaan energi nasional wajib memperhatikan faktor kesehatan, keselamatan kerja, dan dampak sosial dengan tetap mempertahankan fungsi lingkungan hidup	Peningkatan penerapan standar dan keselamatan di bidang kegiatan usaha penyediaan dan pemanfaatan energi	1 Meningkatkan kegiatan pembinaan dan pengawasan teknis usaha energi	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2 Mengembangkan standar keselamatan, sistem, dan komponen di bidang ketenagalistrikan, migas serta EBT yang harmonis dengan standar internasional	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2025
		3 Meningkatkan kualitas layanan penerbitan Sertifikat Laik Operasi (SLO) dalam pengusahaan energi nasional	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
3 Penyediaan energi dan pemanfaatan energi yang berwawasan lingkungan	1 Pencegahan, penanggulangan, dan pemulihan dampak lingkungan hidup	Mengintegrasikan kebijakan lingkungan mencakup perencanaan, pemanfaatan, pengendalian, pemulihan, pengawasan, dan penegakan hukum	Kementerian Lingkungan Hidup dan Kehutanan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
	2 Pengurangan dan penggunaan kembali produksi limbah, serta mengekstrak unsur yang masih bisa dimanfaatkan	1 Mendorong peningkatan penggunaan teknologi energi yang ramah lingkungan berdasarkan prinsip 3R (*reuse, reduce, and recycle*)	Kementerian Lingkungan Hidup dan Kehutanan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2 Memanfaatkan limbah produk energi secara berkelanjutan (*fly ash, bottom ash*)	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3 Memanfaatkan gas buang untuk listrik dan proses termal di industri (*co-generation*)	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	3 Peningkatan koordinasi dan layanan perizinan dalam kawasan hutan	1	Memfasilitasi proses layanan penerbitan izin pemanfaatan kawasan hutan (pinjam pakai, kerja sama, pemanfaatan jasa lingkungan, atau pelepasan kawasan hutan) untuk pengusahaan tenaga air, panas bumi, migas, dan batubara termasuk sarana dan prasarana, dan instalasi pembangkit, transmisi dan distribusi listrik serta teknologi energi baru dan terbarukan	Kementerian Lingkungan Hidup dan Kehutanan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016 - 2025
		2	Moratorium pemberian Izin Usaha Pertambangan (IUP) dan Izin Usaha Pertambangan Khusus (IUPK) batubara di hutan alam primer dan lahan gambut yang berada di hutan konservasi, hutan lindung, hutan produksi, dan area penggunaan lain	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah		2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
4 Setiap pengusahaan instalasi nuklir wajib memperhatikan keselamatan dan risiko kecelakaan serta menanggung seluruh ganti rugi kepada pihak ketiga yang mengalami kerugian akibat kecelakaan nuklir	Penguatan kapasitas nasional di bidang keselamatan penggunaan tenaga nuklir	1 Menerapkan standar internasional keselamatan PLTN	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2 Menyusun pra studi kelayakan (kajian akademik) untuk memutuskan perencanaan pembangunan PLTN	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019
		3 Melaksanakan secara konsisten Perpres Nomor 74 Tahun 2012 tentang Pertanggungjawaban Kerugian Nuklir	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
Kebijakan Pendukung-3: Harga, Subsidi dan Insentif Energi					
1 Harga energi ditetapkan berdasarkan nilai keekonomian berkeadilan	Penyesuaian harga energi berdasarkan nilai keekonomian yang berkeadilan	1 Regionalisasi penetapan tarif dasar listrik, BBM, dan gas berdasarkan biaya produksi, lingkungan, konservasi, dan keuntungan	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait penyesuaian harga energi	2019-2050
		2 Menetapkan harga energi untuk pengalihan subsidi fosil ke subsidi EBT	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3 Menentukan harga energi dengan pertimbangan keterjangkauan (*affordability*) kemampuan masyarakat	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
2 Pemerintah mengatur harga energi terbarukan	1 Penyesuaian perhitungan harga energi terbarukan yang bersaing dengan sumber energi minyak bumi yang berlaku di suatu wilayah tanpa memasukkan subsidi BBM	1 Menerapkan dan menyempurnakan *feed-in tariff* dari pembangkit EBT kepada badan usaha ketenagalistrikan yang berlaku selama harga listrik EBT lebih tinggi dari harga listrik dari sumber energi primer lainnya	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait insentif harga EBT	2016-2050
		2 Mengalokasikan subsidi untuk menerapkan *feed-in tariff* dari pembangkit EBT	Kementerian Energi dan Sumber Daya Mineral, Kementerian Keuangan	UU terkait APBN	2016-2050
		3 Menyusun kebijakan penerapan cukai BBM atau dis-insentif fiskal lainnya	Kementerian Energi dan Sumber Daya Mineral, Kementerian Keuangan	Permen Keuangan terkait cukai BBM	2017-2019
		4 Menyusun peta jalan penerapan kebijakan pajak karbon atas konsumsi energi fosil	Kementerian Energi dan Sumber Daya Mineral, Kementerian Keuangan	Rencana Strategis Kementerian/ Lembaga	2016-2019

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		5	Mewajibkan badan usaha yang ditetapkan oleh Pemerintah untuk membeli tenaga listrik bersumber EBT	Kementerian Energi dan Sumber Daya Mineral	Perpres terkait kewajiban membeli tenaga listrik dari EBT	2016-2050
		6	Meningkatkan implementasi peraturan perundang-undangan mengenai pembelian tenaga listrik dari Pembangkit Listrik Tenaga Air (PLTA) dengan kapasitas sampai dengan 10 MW oleh PT PLN (Persero).	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
	2 Perhitungan harga energi yang rasional untuk penyediaan energi terbarukan dari sumber setempat dalam rangka pengamanan pasokan energi di wilayah terpencil/perbatasan NKRI	1	Membangun unit pembangkit PLTS/hybrid, PLT Bioenergi, PLTB di daerah terpencil, pulau terluar dan perbatasan NKRI	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2	Menyusun peraturan tersendiri peluang investasi energi terbarukan dari sumber setempat khusus di daerah terpencil/perbatasan NKRI	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Permen ESDM terkait kemudahan investasi EBT di daerah terpencil/ perbatasan NKRI	2016-2019

	STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
3	Pemerintah mengatur harga batubara dalam negeri sampai terbentuknya pasar yang efisien	Pengendalian harga batubara dalam negeri	1	Meningkatkan pengawasan perdagangan batubara dalam negeri	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
			2	Melanjutkan kebijakan DMO batubara untuk kebutuhan nasional	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait penentuan alokasi batubara keperluan dalam negeri	2016-2050
			3	Memberlakukan bea keluar batubara disaat harga internasional tinggi	Kementerian Energi dan Sumber Daya Mineral, dan Kementerian Keuangan	Permen Keuangan terkait bea keluar/pajak ekspor batubara	2025-2050
4	Pemerintah mewujudkan pasar tenaga listrik (*electricity pricing policy*)	1 Penyempurnaan pengelolaan energi panas bumi (pembagian risiko) dan penerapan *feed-in tariff* dalam penetapan harga jual EBT	1	Menyusun peraturan pembagian risiko antara pemegang izin usaha tenaga listrik dan pengembang PLTP	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait pengelolaan dan pembaharuan harga jual listrik PLTP	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		2 Menetapkan *feed-in tariff* PLT Bayu, PLTS, PLT Bioenergi dan PLT arus laut serta dari PLTA/PLTMH	Kementerian Energi dan Sumber Daya Mineral	Kepmen ESDM terkait harga jual listrik pembangkit EBT	2016-2019
		3 Menetapkan harga patokan BBN termasuk untuk pembangkit listrik	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait pengelolaan BBN	2016-2019
	2 Pemerintah mengatur pasar energi terbarukan, termasuk kuota minimum tenaga listrik, bahan bakar cair, dan gas yang bersumber dari EBT	Mewajibkan badan usaha penyedia tenaga listrik dan non tenaga listrik untuk mengalokasikan sumber energinya dari EBT secara bertahap	Kementerian Energi dan Sumber Daya Mineral	PP/Perpres terkait kuota minimum tenaga listrik dan non tenaga listrik	2016-2050
	3 Penetapan tarif listrik secara progresif	Menerapkan tarif dasar listrik progresif kepada masing-masing konsumen dengan perhitungan yang berbeda	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	4 Pengaturan harga energi primer (batubara, gas, air, panas bumi) untuk pembangkit listrik	1	Mengevaluasi kebijakan harga pembelian listrik dari batubara, gas, air, dan panas bumi	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019
		2	Menyusun peraturan harga energi primer untuk pembangkit listrik	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait harga energi primer pembangkit listrik	2016-2019
	5 Restrukturisasi harga listrik industri dikaitkan dengan tingkat intensitas energi	1	Merumuskan pedoman harga listrik untuk industri berdasarkan tingkat intensitas energi	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait penyesuaian harga listrik industri	2016-2019
		2	Menyusun metodologi atau petunjuk baku mengenai perhitungan intensitas energi industri	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019

	STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
5	Pemerintah Pusat dan Pemerintah Daerah menyediakan subsidi yang dilakukan secara tepat sasaran untuk golongan masyarakat tidak mampu yang diberikan bilamana: a) Penerapan keekonomian berkeadilan tidak dapat dilaksanakan; dan/atau b) Harga energi terbarukan lebih mahal daripada harga energi dari BBM yang tidak disubsidi	Pemberian subsidi energi tepat sasaran	1	Menyusun kebijakan terkait pemberian subsidi energi bagi masyarakat yang tidak mampu serta mengembangkan skema baru pemberian subsidi energi kepada masyarakat, seperti antara lain penerapan distribusi tertutup, penerapan tarif/harga progresif, regionalisasi harga energi, dan sebagainya	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Permen ESDM terkait petunjuk pelaksanaan pemberian subsidi energi oleh Pemerintah Daerah	2016-2019
			2	Menyusun pedoman pemberian subsidi energi oleh Pemerintah Daerah yang anggarannya dialokasikan dalam APBD	Kementerian Dalam Negeri	Peraturan terkait pedoman pemberian subsidi energi oleh Pemerintah Daerah	2016-2019
			3	Memberikan insentif fiskal untuk mendukung produksi dan pemanfaatan BBN	Kementerian Keuangan	Permen Keuangan terkait alokasi insentif BBN	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		4 Menyusun kebijakan regionalisasi subsidi energi dari Pemerintah	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2019
6 Pengurangan subsidi BBM dan listrik secara bertahap sampai kemampuan daya beli masyarakat tercapai	Pengurangan subsidi BBM dan listrik secara bertahap	1 Menyesuaikan alokasi subsidi BBM dan listrik secara bertahap dalam APBN	Kementerian Keuangan, Kementerian Energi dan Sumber Daya Mineral	UU terkait APBN	2016-2025
		2 Menyesuaikan harga BBM dan tarif listrik sesuai keekonomiannya dengan memperhatikan kemampuan daya beli masyarakat	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait harga BBM dan tarif dasar listrik	2016-2025
7 Pemerintah Pusat dan Pemerintah Daerah memberikan insentif fiskal dan nonfiskal untuk mendorong program diversifikasi sumber energi dan pengembangan energi terbarukan	1 Pemberian insentif non fiskal EBT	1 Memberikan kemudahan pelayanan perizinan di daerah	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2 Memberikan fasilitasi kerja sama antara produsen EBT dengan *off-taker*	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	2 Pemberian insentif fiskal bagi produsen dan konsumen yang menggunakan non-BBM dan energi terbarukan di sektor transportasi	1	Memberikan insentif fiskal kendaraan berbahan bakar gas, bahan bakar sintetis, dan hidrogen, sesuai ketentuan perundang-undangan perpajakan dan kepabeanan yang berlaku	Kementerian Keuangan, Kementerian Perindustrian, Kementerian Perhubungan	Permen Keuangan terkait insentif kepada konsumen kendaraan berbahan bakar EBT	2016-2050
		2	Menyusun kebijakan insentif bagi produk angkutan umum bertenaga listrik, sesuai ketentuan perundang-undangan perpajakan dan kepabeanan yang berlaku	Kementerian Keuangan, Kementerian Perhubungan	Permen Keuangan terkait insentif kepada kendaraan angkutan umum bertenaga listrik	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
8 Pemerintah Pusat dan Pemerintah Daerah menyediakan insentif bagi pengembangan, pengusahaan, dan pemanfaatan energi terbarukan terutama untuk skala kecil dan berlokasi di daerah terpencil sampai nilai keekonomiannya kompetitif dengan energi konvensional	Pemberian insentif bagi pengembangan usaha energi terbarukan	1 Memfasilitasi pemberian insentif tambahan kepada Badan Usaha/ BUMN yang ditugasi oleh Pemerintah di daerah *frontier area* atau WK Panas Bumi yang tidak menarik	Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2 Memfasilitasi pemberian insentif tambahan kepada Badan Usaha/BUMN yang ditugasi oleh Pemerintah untuk membangun unit pembangkit PLTS/*hybrid* di pulau terluar	Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional	Rencana Strategis Kementerian/ Lembaga	2016-2050

	STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
9	Pemerintah memberikan insentif kepada produsen dan konsumen energi yang melaksanakan kewajiban konservasi energi dan efisiensi energi serta memberikan disinsentif kepada yang tidak melaksanakan kewajiban konservasi energi dan efisiensi energi	Pemberian fasilitas insentif (fiskal dan non fiskal) bagi industri yang melaksanakan energi efisiensi	1	Memberikan penghargaan (finansial atau *rating*) terhadap industri yang berhasil melakukan penghematan energi dan menurunkan konsumsi energi per unit produksi (intensitas energi)	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
			2	Memberikan insentif fiskal untuk penggunaan teknologi efisiensi energi, sesuai ketentuan perundang-undangan perpajakan dan kepabeanan yang berlaku	Kementerian Keuangan, Kementerian Energi dan Sumber Daya Mineral	Permen Keuangan terkait insentif fiskal teknologi efisiensi energi	2016-2050
			3	Memberlakukan disinsentif harga terhadap penggunaan BBM pada sektor tertentu (industri dan pembangkit) yang tidak efisien	Kementerian Energi dan Sumber Daya Mineral	Permen ESDM terkait disinsentif harga pada sektor industri/ pengguna tertentu	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
10 Pemerintah memberikan insentif bagi lembaga swasta atau perorangan yang mengembangkan teknologi inti pada bidang EBT	Pemberian insentif dan fasilitas investasi bagi lembaga swasta atau perorangan yang mengembangkan teknologi inti pada bidang EBT	1	Memberikan insentif dan fasilitas investasi berupa penerapan jaminan resiko atas pemanfaatan hasil penelitian teknologi energi nasional kepada perguruan tinggi, perorangan, dan lembaga penelitian yang berhasil mengembangkan teknologi inti pada bidang EBT	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2	Memberikan penghargaan bagi lembaga swasta atau perorangan yang telah berhasil mengembangkan teknologi inti dan inovasi untuk mendorong usaha EBT	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
Kebijakan Pendukung-4: Infrastruktur, Akses untuk Masyarakat, dan Industri Energi					
1 Pengembangan dan penguatan infrastruktur energi serta akses untuk masyarakat terhadap energi dilaksanakan oleh Pemerintah Pusat dan/atau Pemerintah Daerah	1 Peningkatan kemampuan industri dalam negeri dalam penyediaan infrastruktur energi	1 Menyusun kebijakan yang memprioritaskan penggunaan peralatan dan jasa produksi nasional, khusus untuk EBT harus diupayakan secara bertahap bisa mencapai 50% pada tahun 2025 dan 100% selambat-lambatnya pada tahun 2050	Kementerian Perindustrian	Permen Perindustrian terkait Peningkatan Penggunaan Produk Dalam Negeri (P3DN) untuk industri energi nasional	2016-2019
		2 Audit kepatuhan pelaksanaan P3DN kepada badan usaha energi	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3 Mendorong pembentukan konsorsium perusahaan industri, perbankan, *Engineering Procurement Construction* (EPC) dalam negeri dalam membangun proyek ketenagalistrikan berkapasitas di bawah 200 MW	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	2 Pengembangan infrastruktur pendukung industri batubara yang meliputi transportasi, *stockpiling*, dan *blending* untuk mewujudkan pasar yang efisien dan dapat mensuplai kebutuhan dalam negeri secara terus-menerus	1 Menyusun *master plan* rencana pembangunan pelabuhan terpadu batubara	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2016-2019
		2 Memberikan fasilitasi pembangunan pelabuhan (terminal) bongkar muat dan area *stockpiling* batubara, serta kemudahan pelayanan	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2019-2050
	3 Percepatan penyediaan infrastruktur pendukung produksi minyak dan gas, pengilangan bahan bakar, transportasi dan distribusi energi, sistem transmisi, dan distribusi energi	1 Mempercepat pembangunan perluasan jaringan jalur kereta api untuk percepatan distribusi bahan bakar	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2 Memberikan kesempatan bersama atas penggunaan fasilitas infrastruktur perhubungan untuk menjaga distribusi bahan bakar nasional	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		3	Meningkatkan kapasitas dan layanan bongkar muat pelabuhan yang efisien untuk percepatan distribusi energi	Kementerian Perhubungan	Rencana Strategis Kementerian/ Lembaga	2016-2050
		4	Menyusun peraturan yang memprioritaskan distribusi bahan bakar nasional dalam penggunaan infrastruktur perhubungan	Kementerian Perhubungan	Permen Perhubungan terkait prioritas distribusi bahan bakar	2016-2019
	4 Percepatan penyediaan infrastruktur pendukung EBT	1	Memperluas jaringan transmisi dan distribusi ketenagalistrikan	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2	Menugaskan lembaga pembiayaan infrastruktur nasional untuk membiayai proyek pembangunan EBT	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	5 Pemberian akses untuk masyarakat dalam memperoleh informasi mengenai energi secara transparan dan kemudahan dalam mendapatkan energi	1	Memperluas informasi kebijakan dan pembangunan bidang energi berbasis teknologi informasi dan media sosial	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2	Memberikan kesadaran pemanfaatan energi yang produktif dan efisien kepada masyarakat	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
		3	Membentuk brigade energi untuk memberi penyuluhan energi kepada masyarakat di berbagai daerah	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2019
		4	Mengembangkan Sistem Informasi Industri Nasional (SIINAS) yang antara lain memuat kebutuhan energi per wilayah industri	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	6 Pemberian kemudahan akses masyarakat memperoleh energi terhadap pengembangan dan penguatan infrastruktur energi	1	Membangun infrastruktur migas dan jaringan ketenagalistrikan	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2	Membangun infrastruktur BBM/BBG untuk sektor transportasi serta jaringan gas kota untuk rumah tangga dan komersial	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga, Rencana Pembangunan Jangka Menengah Daerah	2016-2025
		3	Memperluas jaringan listrik masuk desa	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2020

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
2 Pemerintah mendorong dan memperkuat berkembangnya industri energi dalam rangka mempercepat tercapainya sasaran penyediaan energi dan pemanfaatan energi, penguatan perekonomian nasional, dan penyerapan lapangan kerja	1 Peningkatan kemampuan industri energi dan jasa energi dalam negeri	Memfasilitasi (skema *public, private partnership*) pembangunan industri manufaktur penunjang industri energi dan jasa energi dalam negeri	Kementerian Perindustrian, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
	2 Peningkatan pengembangan industri peralatan produksi dan pemanfaat energi terbarukan dalam negeri	1 Memfasilitasi pembangunan industri peralatan penunjang produksi dan pemanfaat energi terbarukan	Kementerian Perindustrian, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2 Meningkatkan penggunaan peralatan listrik untuk keperluan rumah tangga	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
	3 Peningkatan kemampuan dalam negeri untuk mendukung kegiatan eksplorasi panas bumi dan industri pendukung ketenagalistrikan	Memfasilitasi pembangunan industri peralatan eksplorasi panas bumi dan industri pendukung ketenagalistrikan	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	4 Pengembangan industri sistem dan komponen peralatan instalasi pembangkit listrik tenaga sinar matahari dan pembangkit listrik tenaga gerakan dan perbedaan suhu lapisan laut	Memfasilitasi pembangunan industri sistem dan komponen peralatan instalasi pembangkit listrik tenaga surya, tenaga gerakan dan perbedaan suhu lapisan laut	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2019-2050
	5 Peningkatan TKDN dalam industri energi nasional	Melakukan verifikasi dan sertifikasi TKDN Industri dalam rangka mendukung Pembangunan Infrastruktur Ketenagalistrikan 35.000 MW untuk PLTU	Kementerian Perindustrian	Rencana Strategis Kementerian/ Lembaga	2016-2019

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
Kebijakan Pendukung-5: Penelitian, Pengembangan dan Penerapan Teknologi Energi					
1 Kegiatan penelitian, pengembangan, dan penerapan teknologi Energi diarahkan untuk mendukung Industri Energi nasional	Pendanaan kegiatan penelitian, pengembangan, dan penerapan teknologi energi berasal dari Pemerintah Pusat dan Pemerintah Daerah serta badan usaha	1 Memprioritaskan anggaran Pemerintah Pusat dan Pemerintah Daerah untuk penelitian dan pengembangan di bidang energi	Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2 Memberi penugasan kepada badan usaha energi untuk menyediakan anggaran penelitian dan pengembangan teknologi energi nasional	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
2 Pemerintah Pusat dan/atau Pemerintah Daerah mendorong terciptanya iklim pemanfaatan dan keberpihakan terhadap hasil penelitian, pengembangan, dan penerapan teknologi energi nasional	Peningkatan penggunaan hasil penelitian, pengembangan, dan penerapan teknologi energi nasional	1 Merumuskan dan memprioritaskan jenis riset bidang energi yang dibutuhkan untuk kepentingan industri dan masyarakat	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2 Mengoptimalkan pemanfaatan hasil penelitian untuk penerapan teknologi secara komersial	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3 Memperkuat kerja sama antar lembaga penelitian dan pengembangan (perguruan tinggi, industri, dan Pemerintah), dan konsumen	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050
		4 Melakukan audit teknologi impor untuk meningkatkan daya saing industri nasional	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Perpres terkait audit teknologi impor	2016-2050
3 Pemerintah Pusat dan/atau Pemerintah Daerah melakukan penguatan bidang penelitian, pengembangan, dan penerapan energi	1 Peningkatan penelitian dan pengembangan serta penguasaan dan penerapan teknologi energi	1 Memprioritaskan kegiatan penelitian dan pengembangan serta penerapan teknologi bersih *(clean technology)* di bidang energi	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		2 Melakukan penguasaan dan alih teknologi asing (*reverse engineering*) bidang energi terutama pengembangan EBT	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3 Memperkuat penelitian, pengembangan dan penerapan sistem dan komponen industri energi terutama untuk pemanfaatan EBT	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050
		4 Mengembangkan teknologi dan inovasi peralatan/permesinan/ sarana transportasi untuk pemanfaatan biofuel	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050
		5 Mengembangkan purwarupa kendaraan (berbahan bakar sintetis, dan hidrogen), bertenaga matahari dan bertenaga listrik/hibrida, hingga siap komersial	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		6 Membuat purwarupa pembangkit listrik yang berasal dari EBT hingga siap komersial	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2025
		7 Mengembangkan purwarupa PLTU dengan TKDN 100% sampai dengan kapasitas 200 MW hingga siap komersial	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2025
		8 Menyiapkan peta jalan peningkatan penguasaan dan pemanfaatan teknologi PLTGB dalam negeri	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2019
		9 Menyiapkan penguasaan teknologi PLTN	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
	2 Penelitian dan pengembangan pemanfaatan jenis tanaman beserta hasil ikutannya di luar kebutuhan pangan untuk BBN	1	Meningkatkan kegiatan penelitian bahan baku BBN dari sumber baru di luar dari jenis tanaman pangan	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2	Mempercepat penelitian, pengembangan, dan penerapan teknologi untuk beberapa jenis tanaman seperti jerami padi, bioenergi yang berbasis kelautan dan sorgum serta jenis tanaman bahan baku di luar jenis tanaman pangan	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3	Mempercepat komersialisasi purwarupa pemanfaatan bioenergi	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
	3 Peningkatan kemampuan sumber daya manusia dalam penguasaan teknologi serta keselamatan bidang energi	1	Meningkatkan jumlah dan kualitas Inspektur Ketenagalistrikan, Inspektur Migas, dan Inspektur Tambang serta Manajer dan Auditor energi	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		2	Menyelenggarakan pelatihan dan bimbingan teknis di bidang energi dan bekerjasama secara internasional	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3	Membentuk program studi EBT serta konversi dan konservasi energi di perguruan tinggi tertentu	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2025
		4	Meningkatkan jumlah dan kualitas tenaga teknik di bidang energi	Kementerian Riset, Teknologi dan Pendidikan Tinggi, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
	4 Penguatan pembiayaan penguasaan teknologi energi	1	Meningkatkan pendanaan penelitian dan pengembangan *pilot project* sampai mencapai komersial untuk penguasaan teknologi energi tertentu	Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2	Menerapkan premi pengurasan energi fosil untuk alokasi pembiayaan penelitian dan pengembangan bidang energi terutama EBT sampai tahap komersial	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
Kebijakan Pendukung-6: Kelembagaan dan Pendanaan					
1 Pemerintah Pusat dan atau Pemerintah Daerah melakukan penguatan kelembagaan untuk memastikan tercapainya tujuan dan sasaran penyediaan energi dan pemanfaatan energi	1 Penyempurnaan sistem kelembagaan dan layanan birokrasi Pemerintah Pusat dan Pemerintah Daerah dan peningkatan koordinasi antar lembaga di bidang energi guna mempercepat pengambilan keputusan, proses perizinan, dan pembangunan infrastruktur energi	1 Menyederhanakan perizinan yang semula 89 perizinan menjadi 10 perizinan	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2019
		2 Memperkuat kapasitas kelembagaan di tingkat provinsi/kabupaten/kota yang akan bertanggung jawab terhadap perencanaan, pengembangan, dan pengelolaan energi	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
		3 Meningkatkan kualitas pelayanan publik Pemerintah Daerah yang mendukung percepatan penerbitan/ penyederhanaan izin dan pembangunan infrastruktur energi di daerah	Kementerian Dalam Negeri, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		4	Memperkuat kapasitas organisasi di tingkat provinsi, kabupaten/kota yang akan bertanggung jawab terhadap perencanaan, pengembangan, dan pengelolaan energi	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
		5	Memfasilitasi kerja satuan kerja yang bertugas memantau dan mengkoordinasikan penyelesaian masalah birokrasi dan/atau tumpang tindih kewenangan di daerah	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025
	2 Peningkatan kemampuan sumber daya manusia di bidang energi di daerah dalam pengelolaan energi	1	Menyelenggarakan pendidikan, pelatihan, dan penyuluhan bidang energi	Kementerian Riset, Teknologi dan Pendidikan Tinggi, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		2 Menyelenggarakan pendidikan formal bidang energi	Kementerian Riset, Teknologi dan Pendidikan Tinggi	Rencana Strategis Kementerian/ Lembaga	2016-2025
	3 Regionalisasi penyediaan energi listrik untuk memperkecil disparitas penyediaan energi listrik di luar pulau Jawa	1 Membentuk wilayah usaha baru ketenagalistrikan tersendiri di luar Jawa, Madura, dan Bali	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		2 Mengatur harga jual tenaga listrik secara regional berdasarkan tingkat keekonomian berkeadilan	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025
		3 Membangun jaringan interkoneksi ketenagalistrikan di setiap wilayah usaha di luar Jawa, Madura, dan Bali	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2025

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
2 Penyusunan sasaran pertumbuhan penyediaan energi dengan memperhatikan sasaran pertumbuhan ekonomi	Pengalokasian dana untuk pengembangan dan penguatan infrastruktur energi yang memadai	1 Mendorong peningkatan anggaran Pemerintah untuk pembangunan infrastruktur energi dan komponen pendukung energi	Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional	Rencana Strategis Kementerian/ Lembaga	2016-2050
		2 Mendorong peningkatan anggaran Pemerintah Daerah untuk pembangunan infrastruktur ketenagalistrikan terutama bersumber dari EBT	Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM	KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
3 Pemerintah dan/atau Pemerintah Daerah mendorong penguatan pendanaan untuk menjamin ketersediaan energi, pemerataan infrastruktur energi, pemerataan akses masyarakat terhadap energi, pengembangan industri energi nasional, dan pencapaian sasaran penyediaan energi serta pemanfaatan energi	1 Penerapan premi pengurasan Energi fosil untuk pengembangan Energi	1 Menyusun kebijakan dan peraturan terkait premi pengurasan energi fosil dan Dana Ketahanan Energi (DKE)	Kementerian Energi dan Sumber Daya Mineral	PP terkait PNBP Kementerian Energi dan Sumber Daya Mineral dan PP terkait DKE	2016-2019
		2 Menyelenggarakan kegiatan eksplorasi migas, pengembangan EBT, dan peningkatan kemampuan sumber daya manusia dengan dana bersumber dari premi pengurasan energi fosil	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
	2 Penyediaan alokasi anggaran khusus oleh Pemerintah Pusat dan/atau Pemerintah Daerah untuk mempercepat pemerataan akses listrik dan energi	1 Menganggarkan pembangunan infrastruktur EBT secara berkelanjutan untuk desa-desa yang tidak akan terlistriki dalam jangka panjang	Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		2	Menganggarkan perluasan jaringan infrastruktur energi untuk peningkatan rasio elektrifikasi dan konversi minyak tanah ke LPG	Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan Nasional, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3	Menyediakan subsidi energi yang bersumber APBN dan APBD sesuai dengan ketentuan perundang-undangan yang berlaku	Kementerian Keuangan, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050
		4	Memberikan subsidi atas selisih biaya energi dari EBT dengan biaya pokok produksi dari pembeli yang menanggung resiko (*off-taker*) EBT	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050
4 Pemerintah mendorong Badan Usaha dan perbankan untuk turut mendanai pembangunan infrastruktur dan pemanfaatan energi	Peningkatan peran swasta dan pendanaan perbankan nasional dalam mendanai pembangunan infrastruktur dan pemanfaatan energi	1	Memberi kesempatan berusaha dan peran yang lebih luas kepada swasta untuk berinvestasi dalam infrastruktur dan pemanfaatan energi	Kementerian Energi dan Sumber Daya Mineral, Pemerintah Daerah	Rencana Strategis Kementerian/ Lembaga	2016-2050

STRATEGI	PROGRAM		KEGIATAN	KELEMBAGAAN (Koordinator)	INSTRUMEN	PERIODE (Kegiatan)
		2	Mengembangkan penjaminan proyek infrastruktur energi yang strategis	Kementerian Keuangan	Rencana Strategis Kementerian/ Lembaga	2016-2050
		3	Meningkatkan peran lembaga keuangan bank dan non-bank nasional untuk mengembangkan pendanaan yang sesuai dengan karakter proyek energi	Kementerian Energi dan Sumber Daya Mineral	Rencana Strategis Kementerian/ Lembaga	2016-2050

PRESIDEN REPUBLIK INDONESIA,

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RANCANG BANGUN KOMPONEN UTAMA PLTS OFF-GRID UNTUK MENUNJANG OPERASI INCINERATOR SIPESAT®

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Abstract

To increase reliability of SIPESAT® Incinerator, off-grid solar powerplant was installed. The aim of this paper is to designing the requirement of the main equipment for the solar powerplant. 270 w, 3 autonomies days were used as the main parameter. GHI gathered from NASA's data, VRLA battery type with MPPT inverter type was chosen to design the solar powerplant system. based on calculation results, the solar powerplant system need two solar panels 150watt each, and two VRLA battery 24V 200 Ah each,

Keywords : *solar powerplant, SIPESAT®, Incinerator, Off-grid*

Abstrak

Untuk meningkatkan kehandalan mesin incinerator milik SIPESAT® dilakukan pemasangan PLTS dengan system Off-Grid. Tujuan dari penelitian ini adalah untuk mendesign kebutuhan alat utama pada PLTS. Adapun Parameter yang ditentukan adalah kebutuhan daya incinerator sebesar 270 Watt dengan hari otonomi selama 3 hari. Untuk data GHI menggunakan data NASA. Tipe baterai terpilih adalah tipe VRLA, dan jenis MPPT inverter digunakan untuk system PLTS ini. setelah dilakukan perhitungan dibutuhkan 2 buah panel surya berdaya 150w dengan 2 baterai VRLA berkapasitas 24V 200 Ah untuk memenuhi kebutuhan daya incinerator milik SIPESAT®.

Kata kunci : *PLTS, SIPESAT®, Incinerator, Off-grid*

Pendahuluan

Latar Belakang

SIPESAT®merupakan Perusahaan yang bergerak di bidang Pengelolahan sampah. Saat ini SIPESAT® memiliki modular incinerator untuk membakar sampah secara pyrolysis. Dalam modular tersebut terdapat fan dan blower. Hingga saat ini Fan dan blower pada modular incinerator milik SIPESAT® masih menggunakan listrik dari PLN.

Untuk meningkatkan kehandalan mesin incenerator maka direncanakan untuk membuat listrik mandiri menggunakan tenaga surya. Listrik yang dihasilkan dari panel surya akan dimanfaatkan untuk menggerakan fan dan blower yang terdapat dalam mesin incinerator tersebut.

Tujuan dari penelitian ini adalah untuk merancang komponen utama system kelistrikan menggunakan system PLTS secara offgrid pada mesin incinerator milik SIPESAT® agar dapat beroperasi mandiri tanpa memerlukan listrik dari PLN. Komponen utama yang akan ditentukan adalah jenis, jumlah, serta susunan panel surya, baterai, dan inverter PLTS.

Dasar Teori

Kebutuhan daya bangkitan diketahui menggunakan persamaan berikut:

$$P_{hari} = t \times P_{alat}$$

P_{hari} = kebutuhan daya per hari (watt)

P_{alat} = kebutuhan daya pada alat (watt)

t = Waktu (jam)

Luasan area pada PLTS dapat ditentukan berdasarkan intensitas radiasi pada lokasi yang ditentukan, serta suhu maksimum pada lokasi pemasangan. Adapun persamaan untuk menentukan luas minimum area

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pemasangan PLTS dapat dihitung memggunakan persamaan berikut [1]:

$$\text{PV area} = \frac{P_{hari}}{Gmin \times TCF \times \eta PV \times \eta out}$$

P_{hari} = kebutuhan daya per hari (watt)
PV_{area} = Luas untuk Panel PV (m^2)
G_{min} = GHI minimum
TCF = Thermal correction Factor
ηPV = effisiensi solar panel
ηout = effisiensi system

***Global Horizontal Irradiance* (GHI)** atau radiasi matahari yang diukur pada permukaan horizontal, umunya diukur menggunakan Solarimeter, Pyranometer, atau radiometer. Bilamana, pyranometer tidak tersedia maka radiasi matahari dapat dihitung berdasarkan sinar matahari tercerah [2]. Terdapat dua sumber terpercaya dalam menyediakan data radiasi matahari global yaitu Website NASA [3] dan TUTIEMPO [4]. Pada data NASA data radiasi matahari diambil berdasarkan obeservasi menggunakan satelit, sedangkan data TUTIEMPO menggunakan data pengukuran darat. NASA menggunakan data rata-rata bulanan, sedangkan pada TUTIEMPO berbasiskan data perhari. Pada penelitian saat ini data menggunakan data NASA karena kelengkapan data dari tahun sebelumnya [2].

***Temperature Correction Factor* (TCF)** Merupakan factor koreksi yang diperhitungkan untuk mengetahui performa panel surya. Perlu diketahui bahwa tiap kenaikan 1°C dari suhu oprasi panel surya. Maka panel surya tersebut akan mengalami penuruan efisiensi sebesar 0,5% [1]. Oleh karenaya, TCF perlu untuk dihitung, berdasarkan persamaan berikut [1]:

$$P_{\Delta T} = 0{,}5\% \times P_{Mpp} \times \Delta T$$

$$P_{T_{op}} = P_{Mpp} - P_{\Delta T}$$

$$TCF = \frac{P_{\Delta T}}{P_{Mpp}}$$

$P_{\Delta T}$
$= Daya\ maksium\ dihasilkan\ pada\ saat\ temperature\ mengalami\ kenaikan\ \Delta T\ (watt)$
P_{Mpp}
$= Daya\ pada\ kondisi\ maksium\ power\ point\ (watt)$
ΔT
$= Perbedaan\ temperature\ pada\ kondisi\ standar\ panel\ dengan\ kondisi\ operasi\ (°C)$
$P_{T_{op}}$
$= Daya\ maksium\ yang\ dihasilkan\ pada\ temperature\ operasi\ (watt)$

Panel Surya, Secara garis besar terdapat berbagai macam teknologi panel surya. Baik panel surya yang terbuat dari kristalin maupun dari Thin film. Perusahaan independent NREL telah memplotkan perkembangan effisiensi panel surya sesuai pada Gambar 2 [5]

Berdasarkan Gambar 2, teknologi solar panel dibagi menjadi 4 teknologi besar yaitu sel surya berbasis multi junction, sel surya berbasis crystalline silica, sel surya berbasis teknologi thin film, dan sel surya berbasis teknologi PV terbaru (emerging PV). Hingga sekitaran tahun 2016 teknologi berbasis multi junction memiliki effisiensi tertinggi yaitu 46%, untuk teknologi berbasis Kristal silika, konsentrator Kristal tunggal perusahaan Amonix memiliki effisiensi tertinggi sebesar 27,6%. Sedangkan monocrystaline non-concentrator tertinggi dimiliki oleh Sun-Power sebesar 25%, dan polycrytaline silica oleh panasonik sebesar 25,6%. Dari Teknologi thin film, CIGS konsentrator memiliki effisiensi sebesar 23,3%. Dan dari teknologi terbaru emerging PV, CZTSSe memiliki effisiensi tertinggi di kelasnya dengan effisiensi 12,6%.

Dari data pada **Gambar 3**, diketahui teknologi yang sudah dipakai secara luas dan komersial di dunia adalah teknologi kristal silika, baik berupa poly-cristaline/multi-cristaline dan mono-cristaline. Aplikasi panel surya teknologi kristalin sudah banyak digunakan di berbagai belahan bumi, sementara untuk teknologi thin-film masih dalam skala laboratorium maupun skala percontohan. Sampai sekarang, teknologi muti-junction masih menjadi teknologi sel surya yang terbaik dan banyak dipakai untuk program angkasa luar karena tahan terhadap radiasi dan panas, namun material dan teknologi fabrikasi untuk produksi massal masih terkendala. Panel surya yang digunakan harus mempunyai spesifikasi

tertentu sesuai dengan sistem PLTS yang direncanakan. Parameter teknis panel mencakup hal-hal sebagai berikut:

- Jenis modul adalah Mono/Polycrystasiunlline Silicon.
- Output Modul Surya (Peak Power Output) per unit (ex: 150 Wp), karakteristik hasil tegangan tes Produsen harus terbaca pada modul (Manufacture, Serial Number, Peak Watt Rating, Peak Current, Peak Voltage, Open Circuit Voltage dan Short Circuit Current).
- Efisiensi modul surya minimum 16%.
- Koneksi antar modul surya menggunakan koneksi plug-insocket.
- Keluaran array modul surya langsung ke String Inverter bergantung pada spesifikasi jumlah input String Inverter

Inverter, berfungsi mengubah arus searah (DC) menjadi arus bolak-balik (AC). Listrik yang dibangkitkan oleh modul (panel) surya merupakan listrik arus searah (DC – direct current), sedangkan yang digunakan untuk kebutuhan manusia sehari-hari adalah listrik arus bolak balik (AC – alternating current). Agar sistem PLTS dapat bekerja paralel dengan jaringan sistem kelistrikan yang ada, diperlukan perangkat inverter.

Saat ini inverter telah dilengkapi dengan SCC/BCC yaitu solar charge controller/baterai charge controller. Fungsi alat ini untuk memlindungi baterai dari over charge dari panel surya atau over dischager [7]. Inverter yang digunakan harus mempunyai spesifikasi tertentu sesuai dengan sistem PLTS yang direncanakan. Parameter teknis inverter mencakup hal-hal sebagai berikut:

- Harus mampu memproduksi gelombang sinus murni
- Mempunyai effisiensi ≥ 95 %
- Total Harmonic Distortion (THD) ≤ 5%
- Mempunyai sistem proteksi terhadap over current, over load, short circuits, over suhu, over/under voltage, reverse polarity
- Indicator (LCD display): power output, inverter voltage & current, inverter frequency

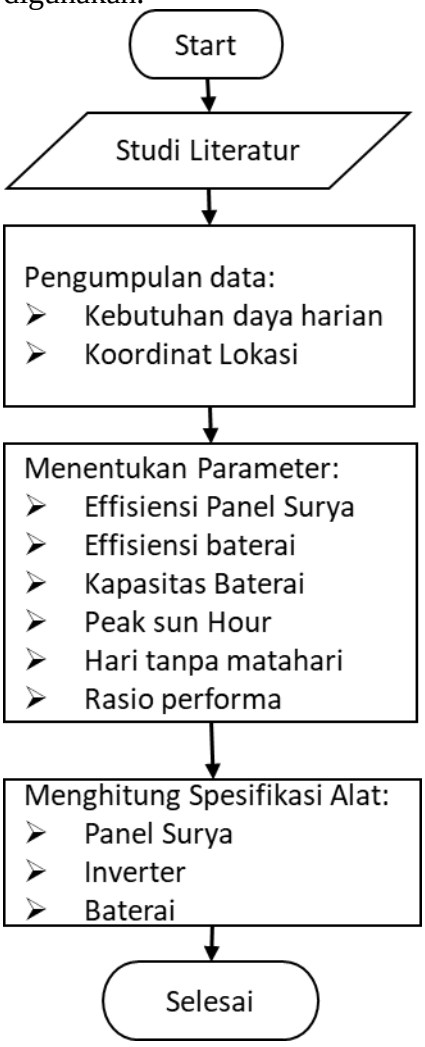
Baterai merupakan alat penyimpan energy listrik. Baterai dibutuhkan terutama pada rangkaian off-grid. Dalam perancangan kebutuhan baterai terdapat beberapa factor yang harus diperhatikan seperti Dod (depth of discharge), jumlah siklus, effisiensi baterai, discharge rate dan suhu. depth of discharge merupakan presentasi keluaran energy dari baterai, semakin tinggi nilai Dod semakin pendek umur baterai [7]. Umur baterai juga dilihat dari jumlah siklus. Satu siklus baterai dihitung dari satu kali keluaran dan satu kali pengisian. Semakin banyak jumlah siklus perhari maka umur baterai akan semakin pendek. Sebagai contoh bila dalam satu hari dilakukan satu siklus baterai sedangkan baterai tersebut memiliki 2000 cycle, maka umur baterai adlah 2000 dibagi 365 hari yaitu sekitar 5 tahun, namun apabila dalam sehari dilakukan 3kali siklus maka umur baterai menjadi 2000 dibagi dengan 3/365 hari yaitu 1,8 tahun. Karena baterai juga memiliki internal resisten maka terdapat rugi-rugi didalam baterai. Umumnya dalam 1 siklus effisiensi baterai sekitar 75%.. effisiensi round trip merupakan efisiensi dalam 1 siklus. Untuk suhu, baterai dapat berkerja maksimal pada suhu tinggi, namun hal tersebut dapat mempersingkat umur baterai, suhu ideal baterai adalah 20-25oC [7]. Discharge Rate pada baterai disimbolkan dengan Cxx, Cxx mengartikan arus yang dapat dikeluarkan dalam xx jam. Sebagai contoh pada baterai 1000 ah dengan C20 mengartikan bahwa baterai tersebut dapat mengeluarkan arus 1000 Ah dalam 20 jam. Atau perjamnya 1000Ah/20jam = 50 A. apabila dalam pemakiannya perjamnya baterai harus berkerja diatas kapasitasnya misal 100 A .hal tersebut akan mempersingkat waktu pakai baterai, dapat dilihat secara perhitungan berikut 1000Ah/100A= 10 hours. Jadi dapat dilihat bila arus yang dikeluarkan perjamnya sebesar 100 A maka waktu pakai baterai akan berkurang setengahnya yaitu hanya 10 jam. Untuk baterai pada system off-grid harus mempertimbangkan factor sebagai berikut [7] :

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- Memiliki system ventilasi/ katup pengatur VRLA (Valve Regulated Lead Acid)
- Baterai berjenis deep cycle
- Kapasitas baterai minimal 1800 Ah pada C20 discharge
- Jumlah Cycle baterai minimal adalah 2000 Cycle pada Dod 80%,C20
- Kapasitas baterai yang didesain dapat bertahan untuk 3 hari otonomi
- Dod maksimal 80%
- Dod harian pada off-grid sebesar 50%
- Mampu berkerja pada suhu 45oC

Metode Penelitian

Pada bagian ini akan dijelaskan mengenai tahapan penelitian yang digambarkan pada Gambar 3. Tahap pertama dilakukan study litertature terkait rancang bangun PLTS khususnya pada off-grid. Tahap selanjutnya adalah pengumpulan data. Data kebutuhan listrik dan lokasi pemasangan didapatkan memalui survey alat langsung dan interview. Setelah mengumpulkan data, tahap perancangan selanjutnya adalah menentukan parameter. Tahapa ini diperlukan sebagai batasan dalam mendesign. Adapun parameter yang di tentukan sepeerti jenis baterai, jenis panel surya,serta jenis inverter yang digunakan.



Gambar 1. Flowchart tahap penelitian

Hasil dan Pembahasan

Berdasarkan hasil interview dan survey lokasi, daya yang dibutuhkan untuk menghidupkan blower dan fan masing-masing sebesar 180watt dan 90watt. Estimasi Waktu pemakaian per hari saat ini 2 jam. Ditambah dengan 1 jam untuk factor keamanan,sehingga total waktu adalah 3 jam, dan untuk daya yang dibutuhkan sebesar 270 watt, didapatkan dari penjumlahan daya 180 dan 90 watt yang berasal dari blower dan fan.Sehingga kebutuhan daya selama satu hari adalah pengkalian 3 jam dengan 270w

$$P_{hari} = t \times P_{alat}$$
$$P_{hari} = 810 \text{ Wh.}$$

Intensitas Matahari dan Suhu Maksimum. Berdasarkan koordinat lokasi. Data GHI atau intensitas radiasi matahari dan suhu maksimum matahari dapat diketahui dengan memasukan data latitude dan longtidtude lokasi ke dalam web NASA [3]. Data intensitas radiasi dan suhu maksimum yang diambil dari data NASA dari tahun 1990-2019 dapat dilihat pada Tabel 1.

Data Insolasi Matahari (kWh/m^2/Hari) diambil pada kondisi all-sky yaitu data radiasi matahari yang jatuh secara horizontal pada permukaan bumi, diambil pada kondisi berawan selama duapuluh sembilan tahun 1990-2019.

Dari data Tabel 1, diambil nilai tahunan minimum sebesar 4.48 kWh/m^2/Hari. Tujuan dari pengambilan nilai minimum ini adalah agar PLTS dapat tetap berkerja secara optimal pada saat radiasi berada dititik minimumnya. sedangkan untuk suhu, diambil data tertinggi untuk mendapatkan factor koreksi suhu [1]. Dari data NASA yang dapat dilihat pada **Tabel 2**, didapatkan suhu tertinggi selama duapuluh Sembilan tahun adalah 32,92^{o}C.

Penentuan Parameter

Dalam mendesain PLTS terutama secara off-grid ada beberapa parameter yang harus ditetapkan seperti Durasi Pengoperasian, Hari Tanpa Matahari, Dod (deep of discharge) dan Peak Sun Hour. Durasi Pengoperasian merupakan lamanya waktu fan dan blower digunakan selama sehari. Berdasarkan hasil interview diketahui bahwa alat berkerja selama 2 jam ditiap harinya, namun karena mempertimbangkan faktor kenyamanan dan keamanan maka ditentukan waktu pengoperasian alat diestimasi selama 3 jam tiap harinya.

Untuk mendesign kebutuhan baterai maka terlebih dahulu ditentukan kemungkinan hari tanpa matahari/otonimi. Dalam rancangan ini ditentukan 3 hari tanpa matahari. Hal ini bertujuann agar alat fan dan blower dapat tetap menyala meskipun tidak terdapat matahari atau dalam tiga hari mendung maupun hujan.

Selain hari tanpa matahari,salah satu factor yang ditentukan adalah Dod (deep of discharge). Dod merupakan parameter yang menunjukan besarnya keluaran energy dari baterai yang ditunjukan dalam bentuk presentase dari nominal kapasitas baterai. Semakin besar angka Dod maka semakin besar energy yang dikeluarga dari baterai tersebut. Hal ini akan berpengaruh pada keawetan umur baterai. Semakin tinggi Dod maka umur baterai semakin pendek. Oleh karena itu umunya dalam PLTS, Dod didesain sebesar 25% - 30%. Apabila Dod ditentukan sebesar 25%-35% umur baterai dapat diperkirakan sampai 5 tahun. Baterai dengan DoD 50% akan memiliki umur lebih panjang dua kali. Jika DoD 10%, maka umurnya akan bertambah 5 kali dari DoD 50%. Konsekuensinya adalah tingginya biaya baterai [7].Untuk mencapai keseimbangan antra keawetan dan keekonomisan harga maka ditentukan Dod dalam system PLTS kali ini sebesar 50%.

Parameter penting lainnya yaitu Peak Sun Hour, merupakan Waktu optimal pengisian daya oleh matahari kepada system PLTS. diIndonesia waktu optimal pengisian matahri dalama sehari hanya selama 4 jam [7].tipe batrai ditentukan dengan baterai yang memiliki tegangan 24V 200 AH jenis VRLA, sedangkan untuk jumlah dan susunan baterai akan diketahui melalui perhitungan disubab selanjutnya. Dalam menentukan kebutuhan baterai sangat erat kaitanya dengan jenis inverter yang dipilih. Dalam hal ini jenis inverter terpilih adalah inverter dengan tipe MPPT effisiensi inverter 95% dengan tegangan output inverter 220 VAC

Selain baterai parameter lain yang ditentukan adalah jenis, effisiensi, dan spesifikasi panel yang akan digunakan. Penentuan panel dilakukan diawal guna mempermudah penentuan jumlah keperluan panel dan komponen lainnya. Dalam rancangan kali ini didesain menggunakan panel surya tipe polycrystalin dengan daya Pmpp 150 Watt,

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dan effisiensi 16% , memiliki Vmp 17,6 V dengan Imp 8,55 A.

Menghitung Kebutuhan Alat Utama dan Susunannya

Setelah mengetahui kebutuhan daya, energy yang di peroleh dari matahari, dan menentukan parameter, langkah berikutnya adalah menentukan kebutuhan dan susunan alat berdasarkan parameter yang telah ditentukan, dan sumber energy yang ada.

Perhitungan Luas Area .

Panel surya akan mengalami penurunan performa apabila dioperasikan pada suhu tinggi [8].oleh karena itu perlu dilakukan koreksi daya keluaran berdasarkan suhu. Solar panel pada kondisi standar yaitu pada 25^{o}C akan mengalami penurunan performa apabila dipasangkan pada kondisi suhu maksimum 32,92^{o}C. dari data tersebut diketahui selisih suhu standar dengan suhu maksimum sebesar 7,92^{o}C. dengan daya maksimum *power point* (P_{MPP}) Panel diketahui sebesar 150 watt,dan penurunan effisiensi panel sebesar 0,5%. maka daya yang hilang pada suhu maksimum dapat dihitung dengan persamaan berikut [1].

$$P_{\Delta T} = 0{,}5\% \times P_{Mpp} \times \Delta T$$

= 5,94 W

Dari perhitungan diatas diketahui, bahwa pada suhu maksimum panel akan kehilangan daya sebesar 5,94 watt, sehingga daya yang keluar pada suhu operasi yaitu selisih dari daya maksimum *power point* (P_{MPP}) Panel dengan daya daya yang hilang pada suhu maksimum, yaitu 144,06 Watt, sesuai perhitungan dibawah ini.

$$P_{T_{op}} = P_{Mpp} - P_{\Delta T}$$

= 144,06 W

Untuk mengetahui berapa persen factor koreksi daya keluaran panel yang disebabkan oleh suhu operasi dapat dilakukan perhitungan sebagai berikut.

$$TCF = \frac{P_{T_{op}}}{P_{Mpp}} \times 100\%$$

TCF = 96%

Dari persamaan di atas diketahui, nilai TCF didapatkan dengan membagi daya keluaran pda temperature operasi yaitu 144,06 watt dengan daya maksimum panel yaitu 150, dikalikan 100% maka didapatkan nilai TCF adalah 96%.

Dengan Nilai TCF sebesar 96%, dengan mengasumsikan effisiensi system PLTS sebesar 95%, serta kebutuhan daya perhari sebesar 0,81 kWh, dan Global horizontal irradiance minimal tahunan yang didapatkan dari data nasa sebesar 4,48 $\frac{\frac{kWh}{m2}}{day}$ dan effisiensi panel 16%, maka kebutuhan luas aktif dari PV dapat dihitung menggunakan persamaan berikut [1] :

$$\text{PV area} = \frac{P_{hari}}{Gmin \times TCF \times \eta PV \times \eta out}$$

PV Area = 1,24 m^2

Dari perhitungan diatas didapatkan bahwa luasan aktif area minimal sebesar 1,24 m^2

Perhitungan Kebutuhan Panel

Nilai TCF digunakan juga untuk menentukan kebutuhan solar panel. Diketahui kebuthan daya harian adalah sebesar 810 Wh/hari, dan pada penentuan parameter telah ditentukan panel dengan daya bangkitan maksimum (P_{mpp})150 Wp,dengan PSH selama 4 jam maka jumlah solar panel yang dibutuhkan dapat dicari mengguanakan perhitungan berikut :

$$P_{\max ideal} = P_{mpp\ Panel} \times PSH$$
$$P_{\max ideal} = 600\ wh$$

600 Wh merupakan daya keluaran pada kondisi ideal yang diukur pada suhu 25^{0}C. oleh karenanya nilai tersebut harus dikoreksi dengan factor suhu (TCF) . sehingga daya bangkitan dengan memperhitungkan factor suhu operasi dapat dihitung sebagai berikut :

$$P_{Wp_{tem}} = P_{\max ideal} \times TCF$$
$$P_{Wp_{tem}} = 600\ wh \times 96\%$$
$$P_{Wp_{tem}} = 576\ wh$$

Untuk mengetahui berapa banyak panel yang diperlukan untuk membangkitkan 810 Wp per hari dapat dilakukan dengan membagi Kebuthan daya harian yaitu 810 Wh dengan $P_{Wp_{tem}}$ 576 Wh

$$Jumlah\ Panel = \frac{Kebuthan\ daya\ harian}{P_{Wp_{tem}}}$$

$$Jumlah\ Panel = 1{,}4 Buah$$

Dari hasil perhitungan didapatkan nilai 1,4 buah panel Dibulatkan menjadi 2 panel. Jadi untuk memenuhi kebutuhan daya 810 kWh/hari dibutuhkan dua buah solar panel dimana, tiap satu panel memiliki daya sebesar 150watt. Sehingga total daya bangkitan menggunakan 2 panel menjadi 300 Wp.

Penyusunan Seri parallel Panel surya

Untuk mengetahui susunan seri atau parallel suatu solar panel harus terlebih dahulu dipahami konsep pada saat panel surya disusun secara seri yaitu kutub positif dipertemukan dengan kutup negative panel lainnya, maka hal tersebut akan menaikan nilai tegangan dan nilai arus tetap. Sedangkan, saat panel disusun parallel dimana kutub positif bertemu dengan kutub positif panel lainnya, akan menaikan nilai arus dengan nilai tegangan tetap [7].

Selain itu, untuk mendapatkan jenis susunan panel perlu diketahui tegangan system baterai yang dipilih, dalam hal ini tegangan yang dipilih adalah 24 V dan V panel 17,6 V. maka jumlah panel disusun seri sebanyak:

$$jumlah\ panel\ seri = \frac{V_{\ baterai}}{V_{\ panel}}$$

$$jumlah\ panel\ seri\ = 1{,}36$$

Dibulatkan menjadi 2 buah disusun secara seri. Dan jumlah panel disusun parallel dapat dihitung sebagai berikut :

$$jumlah\ panel\ paralel = \frac{\text{jumlah panel disusun seri}}{\text{jumlah panel yang dibutuhkan}}$$

Jumlah panel disusun seri sebanyak 2 buah, dan jumlah panel yang dibutuhkan sebanyak 2. Sehingga didapatkan jumlah panel disusun parallel sebanyak 1 buah

Dengan tegangan panel perbuah sebesar 17,6 V dan jumlah seri 2 panel maka dapat dicek tegangan string sebesar 35,2 V

$$V_{panel_{seri}} = V_{panel} \times jumlah\ panel\ seri$$

$$V_{panel_{seri}} = 35{,}2\ V$$

Diketahui dari perhitungan untuk tegangan string panel sebesar (V_{string}) 35,2V dan arus tetap 8,55 A maka daya yang dibangkitkan dapat dihitung dengan mengkalikan tegangan dan arus string sebagai berikut :

$$P = I_{string} \times V_{string}$$

$$P = 300{,}96\ W$$

Nilai bangkitan sebesar 300,96 watt mendekati 300 watt. Sehingga sesuai dengan daya bangkitan yang diperlukan.

Menentukan Kapasitas Baterai

Besar kapasitas baterai yang dibutuhkan dapa dihitung melalui persamaan berikut [1]:

$$C_{baterai} = \frac{Hari\ tanpa\ matahari \times Kebutuhan\ daya}{tegangan\ sistem \times DOD \times \eta}$$

$C_{baterai}$ = 145,33 Ah

Dengan hari tanpa matahari selama 3 hari, dengan daya yang dibutuhkan perhari 810 w, dan tegangan system sebesar 35,2 V dan DOD baterai 50% serta effisiensi baterai 95% maka didapatkan capasitas baterai yang dibutuhkan sebesar 145,33 Ah

Karena telah ditentukan baterai yang dipilih memiliki spesifikasi 24V 200 Ah maka susunan baterai dapat diketahui sebagai berikut

$$N_{\text{baterai seri}} = \frac{V_{string}}{V_{Baterai}}$$

Dengan nilai tegangan string sebesar 35,2 V dan tegangan baterai terpilih sebesar 24 V maka jumlah baterai yang disusun seri sebesar 1,47 dibulatkan menjadi 2 buah.

Untuk baterai yang disusun parallel dapat dicari dengan membagi kapasitas baterai 145,33 Ah dengan kapasitas baterai terpilih yaitu 200 Ah

$$N_{\text{baterai Paralel}} = \frac{C_{baterai}}{C_{Ah\ terpilih}}$$

$N_{\text{baterai Paralel}}$ = 0,7

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Sehingga baterai disusun seri dibulatkan sebanyak 1 buah. Perlu diketahui bahwa saat baterai disusun secara parallel maka akan meningkatkan tegangan dan arus tetap, namun saat baterai disusun seri akan menaikan arus dan tegangan tetap, Kebalikan dari konsep seri parallel pada panel surya. Dan baterai disusun seri adalah 1. Sehingga output baterai 48V 200 Ah.

Menentukan Kapasitas Inverter

Inverter yang sudah dilengkapi SCC secara internal maka SCC external dapat ditiadakan. Jenis inverter yang dipilih saat ini adalah MPPT karena dapat mengambil energi maksimal dari solar panel.kapasitas inverter yang dibutuhkan dapat dilihat berdasarkan persamaan berikut [7]

$$C_{inverter} = factor\ safety \times beban\ puncak$$

Factor safety ditentukan sebesar 125% dengan beban puncak sebesar 270 W didapatkan $C_{inverter}$ sebesar 351 w

Dimana tegangan system baterai atau Vdc sebesar 48V yang juga diseting menjadi tegangan pada inverter

$$I_{inverter} = \frac{C_{inverter}}{V_{inverter}}$$

$$I_{inverter} = 7{,}03\ A$$

KESIMPULAN

Untuk memenuhi kebutuhan *fan* dan *blower* dibutuhkan dua buah solar panel polikristalin berdaya 150Wp. yang disusun secara seri.Yang dilengkapi dengan Inverter bertipe MPPT yang telah dilengkapi dengan SCC dengan kapasitas minimum 351 watt dan harus mampu dilewati arus sebesar 7,03A. system PLTS bersifat *off-grid* atau *stand alone* yang harus dilengkapi dengan baterai bertipe VRLA berjumlah 2 buah yang disusun secara seri sehingga *output* baterai sebesar 48V 200AH.

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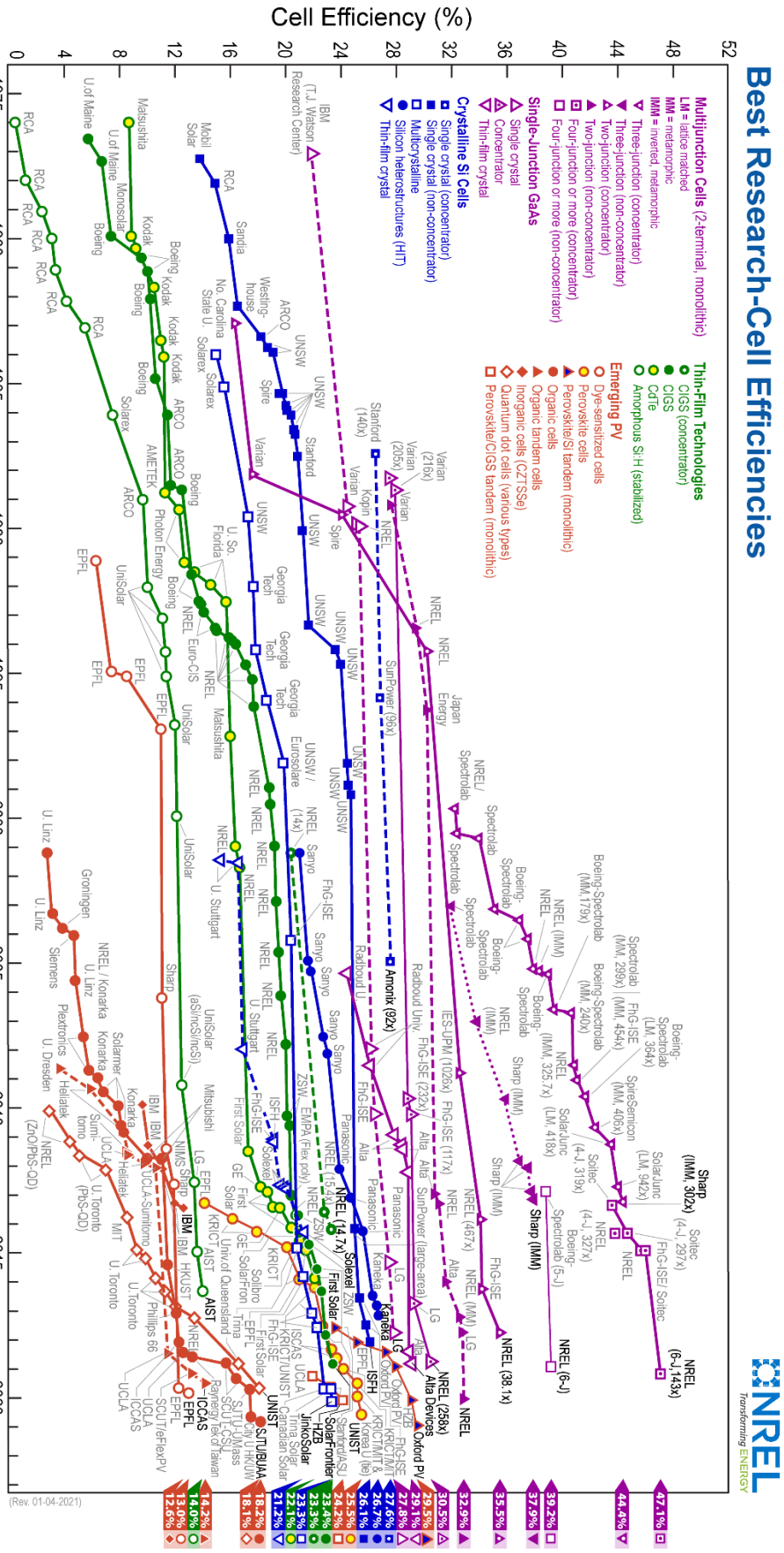
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Gambar 2. Timeline kenaikan Effisiensi Solar Panel

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Gambar 3. Grafik Kematangan Teknologi Panel

Tabel 1. GHI Cawang-Jakarta 1990-2019 pada all sky condition [3]

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
1990	3.77	4.73	4.49	5.11	4.71	4.65	4.76	4.8	5.53	5.69	5.64	4.42	4.85
1991	4.24	3.65	5	4.71	4.93	4.97	5.06	5.67	5.92	5.77	4.9	4.54	4.95
1992	4.85	4.84	5.12	5	4.78	4.87	4.83	4.62	4.88	4.19	4.54	4.43	4.74
1993	4.19	4.53	5.05	4.69	4.71	4.57	5.01	5	5.63	5.84	4.55	4.01	4.82
1994	3.66	4.02	4.58	4.43	4.86	4.79	5.27	5.53	5.79	5.75	5.1	4.77	4.89
1995	3.91	4.44	4.71	5.05	4.76	4.26	4.59	5.42	5.42	4.87	3.88	3.78	4.59
1996	4.04	4.31	4.74	4.71	4.72	4.49	4.72	5.16	5.28	4.48	4.67	3.8	4.59
1997	4.32	4.23	5.54	4.58	4.7	5.1	5.15	5.58	6.13	5.98	5.35	4.99	5.14
1998	4.84	4.64	5.04	4.51	4.55	3.96	4.16	4.83	5.41	4.29	4.02	4.19	4.54
1999	3.82	3.99	4.66	4.67	4.37	4.7	4.93	5.38	5.78	5.11	4.49	4	4.66
2000	4.04	4.34	4.25	4.77	4.5	4.25	4.71	5.14	5.81	4.99	4.05	5.05	4.66
2001	4.42	3.78	4.3	4.9	4.58	4.56	4.73	5.3	5.34	4.26	3.97	5.08	4.61
2002	4.44	3.86	4.89	4.61	4.48	4.57	4.55	5.3	5.98	6.01	4.85	4.3	4.83
2003	5.03	3.72	4.61	4.72	4.78	4.67	5.24	5.35	5.31	4.71	4.81	3.95	4.75
2004	4.53	3.67	4.9	5.11	4.35	4.54	4.68	5.57	5.46	5.74	4.52	4.16	4.77
2005	4.61	4.27	4.33	4.61	4.73	4.4	4.85	5.26	5.09	4.79	4.88	3.92	4.65
2006	4.1	4.52	4.31	4.37	4.69	4.53	4.91	5.79	6.35	6.2	5.66	4.42	4.99
2007	5	4.21	4.16	4.37	4.48	4.44	4.76	5.67	6.02	5.5	5.22	3.79	4.81
2008	5.13	3.87	4.69	4.67	4.98	4.74	5.36	4.95	5.67	5.21	4.23	4.43	4.83
2009	4.32	4.24	5.37	4.85	4.46	4.65	5.19	5.62	5.95	5.52	4.75	4.93	4.99
2010	4.38	5.05	4.87	5.39	4.09	3.89	4.21	4.79	4.6	4.71	4.55	4.16	4.55
2011	4.32	4.72	4.52	4.69	4.4	4.74	4.92	5.69	5.92	5.27	4.77	4.78	4.89
2012	4.2	5.3	5.06	4.87	4.54	4.81	5.1	5.66	6.01	5.48	4.63	4.71	5.03
2013	3.67	5	5.27	4.48	4.08	4.18	3.88	5.5	5.4	5.43	4.93	4.46	4.69
2014	3.97	4.45	4.96	4.98	4.48	4.2	4.39	5.39	6.02	5.63	4.89	4.38	4.81
2015	4.33	4.69	4.72	4.5	4.83	4.85	5.05	5.59	5.89	6.03	5.07	4.63	5.02
2016	4.94	4.13	4.8	4.82	4.04	4.24	4.59	4.88	4.75	4.01	4.25	4.28	4.48
2017	4.51	3.76	4.82	4.79	4.4	4.13	4.62	5.25	5.33	5.05	4.6	4.22	4.61
2018	4.09	4.8	5.15	4.82	4.64	4.51	5.21	5.36	5.42	5.43	4.55	4.62	4.87
2019	4.55	5.23	4.59	4.89	4.75	4.95	5.16	5.51	5.92	6.07	5.81	4.7	5.14
Rata-rata	**4.34**	**4.37**	**4.78**	**4.76**	**4.58**	**4.54**	**4.82**	**5.32**	**5.60**	**5.27**	**4.74**	**4.40**	**4.79**
Maksimum	**5.13**	**5.30**	**5.54**	**5.39**	**4.98**	**5.10**	**5.36**	**5.79**	**6.35**	**6.20**	**5.81**	**5.08**	**5.14**
Minimum	**3.66**	**3.65**	**4.16**	**4.37**	**4.04**	**3.89**	**3.88**	**4.62**	**4.60**	**4.01**	**3.88**	**3.78**	**4.48**

Tabel 2. Suhu Maksimum di Cawang-Jakarta dari tahun 1990-2019 [3].

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
1990	27.68	28.51	28.7	29.94	29.91	29.07	29.06	29.41	30.7	31.76	30.92	28.69	29.53
1991	28.15	27.72	28.66	28.45	29.3	29.22	29.01	30.1	31.84	32.27	29.38	28.92	29.43
1992	28.27	27.91	29.11	28.57	28.79	29.19	28.87	28.58	29.05	28.67	28.38	27.92	28.61
1993	27.19	27.62	28.45	28.02	28.83	28.59	28.79	28.79	29.81	30.6	29.92	28.68	28.78
1994	27.45	27.54	27.79	28.47	28.63	28.56	28.39	29.39	30.97	31.73	30.89	29.16	29.09
1995	27.67	27.48	28.35	28.59	28.98	28.63	28.28	29.46	29.8	29.57	28.88	28.17	28.66
1996	26.81	26.81	28.11	28.93	29.41	28.74	29.26	29.13	30.04	29.58	29.03	28.13	28.67
1997	26.94	27.2	28.97	28.35	29.1	29.21	28.69	29.4	31.47	32.92	31.79	29.86	29.5
1998	30.31	29.08	28.96	29.29	29.65	28.6	28.44	29.33	29.67	28.64	28.45	28.44	29.07
1999	27.58	27.32	28.22	28.93	28.64	28.66	28.53	29.33	30.97	29.96	28.95	28.42	28.8
2000	27.45	27.57	28.04	28.66	28.79	28.79	29.17	29.65	31.36	30.39	29.17	30.27	29.11
2001	28.13	28.15	28.14	28.91	29.38	28.55	28.66	29.37	30.46	29.6	28.67	29.36	28.95
2002	27.97	27.05	28.72	28.65	29.34	29.09	28.71	29.21	30.16	31.99	30.68	29.59	29.28
2003	30.46	27.97	28.77	29.79	29.79	29.89	30.12	30.71	31.02	30.98	29.92	28.6	29.85
2004	28.26	27.61	28.21	29.37	29.24	28.85	28.6	29.29	30.27	31.27	30.33	28.52	29.15
2005	28.1	28.28	27.98	28.96	29.37	28.87	28.73	29.25	29.92	29.84	29.56	28.6	28.96
2006	27.84	28.2	27.9	28.56	28.64	28.75	28.89	29.25	30.87	32.55	31.69	29.55	29.39
2007	30.05	28.04	28.07	28.67	28.89	28.77	28.84	29.2	30.43	30.7	29.94	28.5	29.18
2008	28.83	26.79	27.99	28.39	28.93	28.75	28.88	29.2	30.51	30.5	29.17	28.47	28.88
2009	27.89	27.35	28.5	28.91	28.96	28.89	29.04	29.68	31.06	30.55	29.93	29.38	29.19
2010	28.08	29.06	28.83	29.89	29.45	28.4	28.36	28.52	28.78	28.39	28.35	27.38	28.62
2011	26.91	27.64	27.85	28.6	28.69	28.82	28.7	29.23	30.15	30.14	29.32	29.21	28.78
2012	28.32	28.61	28.6	28.69	29.44	29.09	29.1	30.22	31.53	30.71	29.66	28.99	29.41
2013	27.6	28.22	29.22	28.73	28.79	28.79	28.28	29.2	30.22	30.39	29.51	28.52	28.96
2014	27.14	27.28	28.46	29.21	29.56	29.15	28.93	29.27	30.23	30.75	29.99	28.66	29.06
2015	27.76	27.67	28.28	28.65	29.4	29.31	29.1	29.79	31.38	32.84	31.1	29.54	29.58
2016	29.8	28.77	29.21	29.44	29.47	29.21	28.92	29.46	29.18	28.41	28.32	28.48	29.06
2017	27.92	27.64	28.48	28.58	29.46	28.71	28.96	29.47	30.36	29.82	29.49	28.64	28.97
2018	28.12	27.75	28.98	29.35	29.7	29.29	29.35	29.77	30.75	31.39	29.65	29.38	29.47
2019	28.59	29.23	29.11	29.64	29.72	29.44	29.21	29.67	31.42	32.58	31.72	30.18	30.04
Rata-rata	**28.11**	**27.87**	**28.49**	**28.91**	**29.21**	**28.93**	**28.86**	**29.41**	**30.48**	**30.65**	**29.76**	**28.87**	**29.13**
Maksimum	**30.46**	**29.23**	**29.22**	**29.94**	**29.91**	**29.89**	**30.12**	**30.71**	**31.84**	**32.92**	**31.79**	**30.27**	**30.04**
Minimum	**26.81**	**26.79**	**27.79**	**28.02**	**28.63**	**28.40**	**28.28**	**28.52**	**28.78**	**28.39**	**28.32**	**27.38**	**28.61**

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Integration of Electric Vehicles and Renewable Energy in Indonesia's Electrical Grid

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Abstract: As the global transition toward sustainable energy gains momentum, integrating electric vehicles (EVs), energy storage, and renewable energy sources has become a pivotal strategy. This paper analyses the interplay between EVs, energy storage, and renewable energy integration with Indonesia's grid as a test case. A comprehensive energy system modeling approach using PLEXOS is presented, using historical data on electricity generation, hourly demand, and renewable energy, and multiple scenarios of charging patterns and EV adoption. Through a series of scenarios, we evaluate the impact of different charging strategies and EV penetration levels on generation capacity, battery storage requirements, total system cost, renewable energy penetration, and emissions reduction. The findings reveal that optimized charging patterns and higher EV adoption rates, compared to no EVs adoption, led to substantial improvements in renewable energy utilization (+4%), emissions reduction (−12.8%), and overall system cost (−9%). While EVs contribute to reduced emissions compared to conventional vehicles, non-optimized charging behavior may lead to higher total emissions when compared to scenarios without EVs. The research also found the potential of vehicle to grid (V2G) to reduce the need for battery storage compared to zero EV (−84%), to reduce emissions significantly (−23.7%), and boost penetration of renewable energy (+10%). This research offers valuable insights for policymakers, energy planners, and stakeholders seeking to leverage the synergies between EVs and renewable energy integration to pursue a sustainable energy future for Indonesia.

Keywords: electric vehicles; renewable energy integration; energy storage; energy modeling; net zero emissions; sustainable transportation; Indonesia

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1. Introduction

The global energy landscape is amid a significant transformation, driven by the pressing need to combat climate change and achieve sustainable development goals [1]. One of the main issues in this transformation is the widespread adoption of EVs, which promise to reduce greenhouse gas emissions and enhance the resilience of energy systems [2]. EVs are poised to play a pivotal role in the convergence of the transportation and energy sectors, facilitating the integration of renewable energy sources with sustainable mobility options [3]. As countries worldwide work toward meeting their emission reduction targets and transitioning to cleaner energy systems, understanding the dynamics of EV integration becomes crucial.

In the case of Indonesia, a nation marked by rapid urbanization and surging energy demand, the transportation sector emerges as a significant contributor to emissions [4]. It contributes 27% of the total carbon emissions from energy [5]. Recognizing this, Indonesia has embarked on an ambitious EV program aimed at promoting sustainable transportation and reducing its carbon footprint [5]. Indonesia has set an ambitious goal of achieving net zero emissions by 2060 [6]. This objective aligns with the country's dual focus on advancing renewable energy sources and promoting the electrification of vehicles. This paper aims to harmonize these two pivotal targets by exploring the integration of renewable energy and EVs.

Indonesia has made notable strides in its commitment to combat climate change and reduce carbon emissions. Initially, the country pledged to reduce emissions by 29% (unconditionally) and 41% (conditionally) by 2030 when it submitted its National Determined Contribution (NDC) under the Paris Climate Agreement in 2016. However, in its more recent Enhanced NDC submission in September 2022, Indonesia has set even more ambitious targets, aiming for a reduction of 31.89% (unconditional) and 43.2% (conditional) by 2030 [7]. To realize these ambitious goals, Indonesia, under the leadership of the Ministry of Energy and Mineral Resources (MEMR), is actively crafting a Net Zero Emission Roadmap for the Energy Sector. This roadmap outlines clear objectives, including a target of reaching 422 million metric tons of CO_2 equivalent emissions by 2050 and reducing total energy sector emissions to 129 million metric tons of CO_2 equivalent by 2060 [6–8].

The strategy primarily centers on enhancing the utilization of renewable energy across various end-use sectors. Under this plan, energy sector emissions are anticipated to peak in 2030 at 680 million metric tons of CO_2 equivalent. Ultimately, the roadmap envisions a transition to a power sector with zero emissions by 2060, with any remaining emissions originating from end-use sectors, specifically industry and transportation. Indonesia's robust commitment and strategic initiatives represent significant progress in addressing climate change and advancing toward a sustainable, low-carbon future [6].

This article serves as a case study examining the effects of EVs on Indonesia's grid system to support the integration of renewable energy in the year 2050 toward net zero emissions in 2060. It seeks to gauge the economic and environmental advantages arising from different scenarios involving EV demand, charging behavior, and their participation in V2G systems. The study employs a least-cost optimization approach as its methodology, using commercial energy modeling software. To accomplish this, a power dispatch and expansion model yearly from 2023–2050 is employed to conduct a quantitative assessment of the impact of EVs as both energy consumers and storage units, with the primary goal of reducing the overall costs and carbon emissions of the power system. Simultaneously, it aims to enhance the utilization of renewable energy sources. This research takes into consideration various critical factors, including the current fleet of electricity generators and the characteristics of the power generation mix, hourly electricity demand, existing transmission constraints, the hourly pattern of renewable energy resources in each province, investments and operations related to battery storage, and the widespread adoption of EVs. Through extensive simulation, this study computes the economic and environmental benefits associated with EVs. Consequently, it provides a data-driven foundation for the Indonesian government and other stakeholders to formulate strategies aimed at achieving a cleaner and more sustainable utilization of the energy system.

The remaining structure of the paper is as follows: Section 2 conducts a literature review on EVs and their impact on the energy system. Section 3 outlines our research methodology, detailing data gathering and analysis approaches. In Section 4, we present our research findings and engage in a thorough discussion of these results. Finally, in Section 5, we provide the key conclusions drawn from our study, offering a comprehensive overview of our research outcomes.

2. Literature Review

The recent surge in EV adoption on a global scale underscores the significant role of transportation electrification in shaping a new era of mobility. According to the International Energy Agency (IEA), the global EV stock surpassed 30 million units in 2022, with exponential sales growth exceeding 10 million in 2022 [9]. This remarkable growth is attributed to advancements in battery technology, supportive policy frameworks, and growing environmental awareness [10]. This transition is altering the transportation sector landscape, diversifying energy sources, and accelerating the shift away from fossil fuels.

In the foreseeable future, the path of EV development heralds a transformative era, marked by a fundamental shift in how we propel vehicles. Governments around the world are strongly dedicated to promoting sustainable transportation, and this dedication is evident in their plans to gradually eliminate internal combustion engine vehicles. For instance, the United Kingdom and France have announced their intentions to halt the sale of new gasoline and diesel vehicles by 2030 [11,12]. Such resolute commitments drive a substantial transformation within the automotive industry, leading to significant investments in cutting-edge EV technologies [12]. This transition is not confined to the automotive sector alone; it has a far-reaching impact on the entire energy landscape, signifying a profound recalibration of our energy systems [13].

Indonesia plays a pivotal role in the global context, embedding itself in the narrative of sustainable mobility and renewable energy integration. Indonesia's Ministry of Energy and Mineral Resources (MEMR) has laid out an ambitious strategy, positioning EV integration as a linchpin of the nation's energy agenda [8]. This strategy transcends transportation electrification, embodying a comprehensive commitment to sustainable development: Indonesia's initiative bridges vehicular electrification and renewable energy propagation, embodying a holistic approach to national progress. The global electric car market has witnessed unprecedented growth, with sales topping 10 million in 2022 and accounting for 14% of all new car sales, reflecting a worldwide pivot toward sustainable transportation. Within this global context, Indonesia has emerged as a notable player in the electric vehicle (EV) sector, showcasing remarkable growth from a relatively modest base. In 2022, the nation saw its EV sales triple compared to the previous year, with electric cars making up about 1.5% of the country's total car sales. In 2023, the government plans to offer subsidies for the sale of 200,000 electric two-wheelers and 36,000 electric cars, aiming for these to constitute 4% and 5% of sales shares, respectively. These subsidies are expected to lower the cost of electric two-wheelers by 25–50%, enhancing their competitiveness against traditional internal combustion engine (ICE) vehicles [9]. Indonesia aims to produce 1 million electric cars and 1 million electric motorbikes per year in 2035 [14]. A more optimistic report by IRENA [6] suggested that for Indonesia the number of electric cars could be 58 million in 2050.

The proliferation of lithium-ion batteries is at the heart of this transformation, catalyzing an era of electrification. Driven by the wave of EV adoption, the cost of lithium-ion batteries has witnessed a decline, making EVs both environmentally appealing and economically viable [15]. This technological shift shapes the trajectory of EV expansion while fostering a symbiotic relationship between the transportation and energy sectors. This symbiosis redefines energy generation and consumption, driven by the interplay between EVs, renewable energy, and storage systems.

The notable impacts of EVs can be summarized as below:

1. They transform the dispersed emissions arising from conventional gasoline vehicles, which are challenging to manage, into centralized emissions from power plants, which can be more effectively controlled. These emissions can then be addressed using ultra-low emission technologies within power plants, thereby reducing pollution levels [16].
2. As the proportion of renewable energy generation within the power grid rises, the widespread adoption of EVs potentially reduces carbon emissions within the transportation sector [17,18].
3. EVs can serve as valuable assets in enhancing the reliability and sustainability of, and reducing the cost of electricity [19,20].
4. EVs may be able to enhance the flexibility of the power system through V2G technology, aiding the integration of intermittent renewable energy sources. This V2G approach encompasses controlling charging from, and/or discharging to the grid so as to coordinate EV charging with grid load fluctuations and utilizing EV batteries to bolster the energy storage capacity of the power system [21–23].

The modes for connecting EVs to the power grid can be classified into three types [23]: uncontrolled charging vehicle (grid to vehicle), unidirectional optimized charging, and bidirectional optimized charging (vehicle to grid) [22]. In the uncoordinated charging case, EV owners charge their vehicles based on individual needs and preferences. The optimized charging option employs incentives or regulations to guide EVs in synchrony with grid operations, reducing peak-hour charging and optimizing power utilization during off-peak periods. Bidirectional V2G harnesses EV batteries as substantial energy storage units dispersed throughout the power system, absorbing and storing fluctuating renewable energy and supplying it back to the grid during peak power demand hours [22].

Several researchers have delved into the study of various aspects of EV penetration, EV charging demand, and the use of EVs as a form of energy storage. Some of these studies have focused on simulating optimal charging strategies [24–26] and assessing the impact of different levels of EV penetration [27]. They have explored how EVs influence renewable energy integration [27–30], emissions [31,32], and cost analysis [33,34]. Additionally, there is ongoing research on V2G strategies and their effects on energy systems and energy storage requirements [35–37]. Notably, researchers have investigated the potential of EVs to support renewable energy adoption using electricity systems in various contexts, including simulation data [38], microgrids [24,25,39,40], urban areas [41], regional systems in Europe [27,42], and the US [35]. However, it is important to note that there has been limited research conducted on this topic within the context of Indonesia's energy system.

The previously mentioned existing studies in this field have focused on specific factors, such as EV charging behavior, EV demand, renewable energy integration, or emissions. Moreover, there has been limited research that considers the broader impact of EVs on a country's energy storage planning. Furthermore, many of these studies rely on simulation data or data from regions with different electrical systems compared to Indonesia. What sets this study apart is its comprehensive approach. It aims to quantify the impact of electric vehicle penetration and charging behavior on various aspects, including cost, investment in battery energy storage, renewable energy integration, and emissions. Importantly, this research utilizes real data from Indonesia's electrical system and renewable energy sources. The goal is to provide a detailed exploration of this critical area, with a specific focus on the Indonesian context.

3. Methodology

3.1. The Electricity System

The Indonesian electricity system in this model uses 17 nodes representing each province in the Java–Bali and Sumatra Electrical System, with 10 nodes in Sumatra and 7 in Java–Bali (Figure 1). Those two systems are the two biggest electrical systems in Indonesia, which account for 87% of the total demand in Indonesia. These nodes serve as connection locations for generators, power lines, energy storage, and consumers within the PLEXOS framework. In this study, we incorporate projections for integrating EVs from 2030–2050 into the electrical systems of Java–Bali and Sumatra.

This model operates from 2023 to 2050, using an annual step through the 'Long-Term (LT)' cost-minimization module as highlighted in Equation (1) [42,43]. This LT module determines the required investments related to power generation and energy storage, which can either function independently or in a connected manner. The LT module operates a 1-year step size on two weeks sampled per year with hourly resolution. The model internally computes the required new power generation and storage capacity, using a scenario-based approach that accounts for current data for generators, transmission lines, future installation projections, and the unique features of electrical system [44]. The hourly load is represented by historical data from the Java–Bali system in 2018 [45], with 10 years of hourly data for renewable energy resources from Renewable Ninja [46,47]. The model has some constraints, such as a minimum renewable energy requirement based on the targets of Indonesia, the ramping operation parameters of the generators, and transmission power flow constraints.

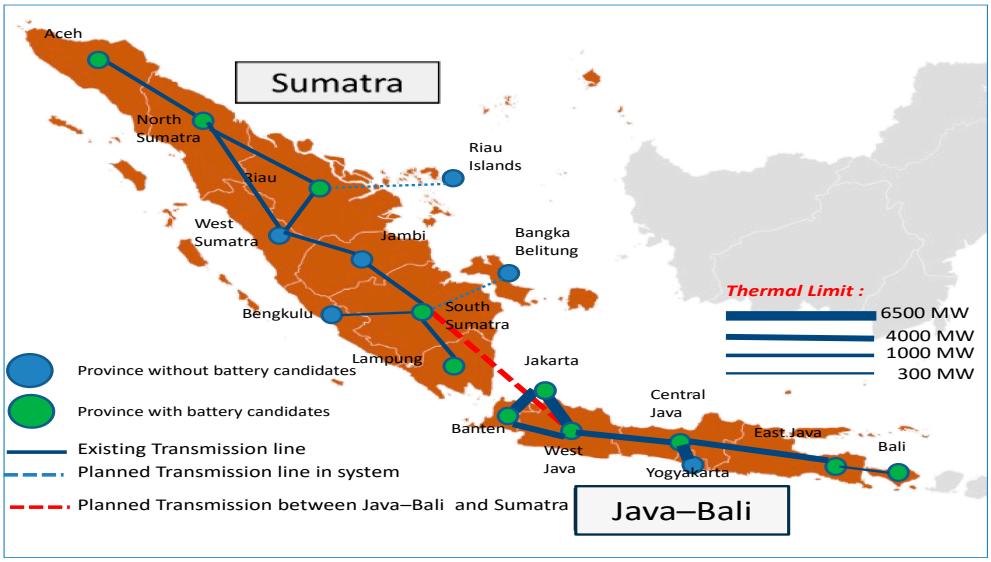


Figure 1. Nodes of Java–Bali and Sumatra and scenarios in model.

The weekly base load profile of this model is derived from the 2018 Java–Bali evaluation report [45] and is subsequently expanded each year in alignment with the Indonesian business-as-usual prediction of a 4.9% annual energy increase [44]. This profile is adopted as the basis of a zero electric vehicle (EV) charging scenario, targeting a shift to 100% renewable energy by 2060. Targeting renewable energy indirectly reduces the emissions from fossil fuels, as each type of fossil fuel is associated with a specific emission factor. Figure 2 illustrates the weekly base load profile without the inclusion of EV charging demands.

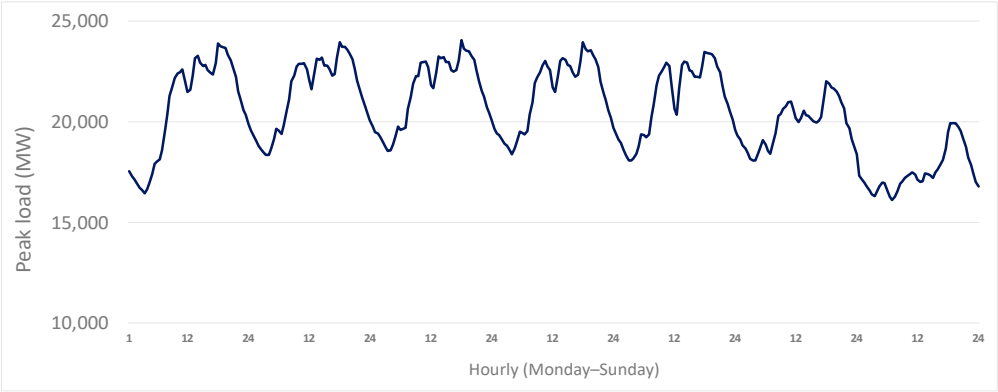


Figure 2. Hourly load profile in a typical week without EV charging influence (zero EV).

3.2. Modeling Approach

The study employs the PLEXOS simulation tool, widely recognized for its capacity to model complex energy systems and optimize cost-efficient solutions. PLEXOS is utilized to simulate Indonesia's intricate electricity system, offering a comprehensive assessment of various parameters that shape energy dynamics. These parameters include hourly demand profiles, solar photovoltaic (PV) generation profiles, power generation characteristics, battery investments, ramping rates, fuel costs, and EV charging patterns. Using the long-term (LT) expansion cost optimization model, the objective function [48] is to minimize the net present value of the system's cost over the period of model. This LT module tailored the required investments and operation for generation, energy storage [42], and optimal charging and discharging EV. Additionally, the LT made use of sample hourly profile two weeks per year and the outcomes were then extrapolated to represent the entire year based on that sample. The overarching methodology of the model is depicted in Figure 3, providing a visual guide to the approach taken in this study.

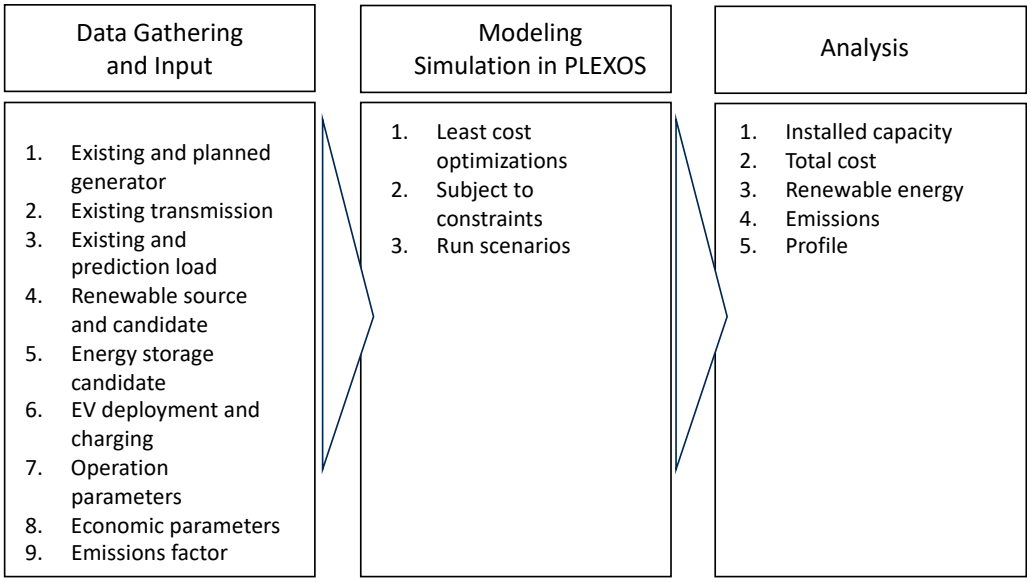


Figure 3. The general structure of the study.

The formula [42,49] of the model is to minimize:

$$\begin{aligned} &\sum_y \sum_{g,b} DF_y * \left(\left(BuildCost_g * GenBuild_{(g,y)} \right) \right. \\ &\qquad \left. + \left(BuildCost_b * BattBuild_{(b,y)} \right) \right) \\ &+ \sum DF_y (* \left[FOMCharge_g * 1000 * PMAX_g \left(Units_g + \sum_{i \le y} GenBuild_{g,i} \right) \right] \\ &\qquad + [FOMCharge_b * 1000 \\ &\qquad * BMAX_b \left(Units_b + \sum_{i \le y} BattBuild_{b,i} \right) \Big]) + \sum (t) DF_{t \in y} \\ &\qquad * L_t * \left[VoLL \times USE_t + \sum_g \left(SRMC_g \times GenLoad_{g,t} \right) \right] \end{aligned} \quad (1)$$

where: '*y*' is the total horizon of simulation; '*g*' is the generator; '*b*' is battery storage; "*DF*" is the discount factor [$DF = 1/(1 + D)^y$] where '*D*' is annual discount rate; '*BuildCost*' is the overnight build cost; '*GenBuild*' the number of generator units built in the year '*i*' for generator '*g*'; '*BattBuild*' is the number of batteries built in the year '*i*' for battery '*b*'; '*FOMCharge*' is the Fixed operations and maintenance charge of generator '*g*' or battery '*b*'; '*PMAX*' is the Maximum generating capacity of each generator '*g*'; '*BMAX*' is the Maximum generating capacity of each battery '*b*'; '*Units*' is the number of installed generating units of generator '*g*' or battery '*b*'; '*GenBuild*' is the number of built generating units of generator '*g*'; '*Lt*' is Duration of dispatch period *t*; '*VoLL*' is the Value of lost load; '*USE*' is unserved energy; '*SRMC*' is short-run marginal cost generator = Heat Rate * Fuel Cost + Variable Operation and Maintenance Charge; '*GenLoad*' is the dispatch level of generating unit 'g in period '*t*'.

Subject to:

1. Energy Balance

$$\sum_{(g)} GenLoad_{(g,y)} + USE_t = Demand_t \; \forall_t$$
$$Demand = Native\ Demand + Electric\ Vehicle\ Demand$$

2. Feasible energy dispatch

$$GenLoad_{(g,t)} \le \mathrm{PMAX}\left(\mathrm{Units}_g + \sum_{i \le y} GenBuild_{g,i} \right)$$

3. Feasible build

$$\sum_{i \leq y} GenBuild_{g,i} \leq MaxUnitsBuilt_{g,y}$$

4. Renewable energy target

$$\sum_{i \leq y} GenLoadRenewable_{g,i} \geq \sum Renewable\ Energy\ Target(\%) * Demand_i$$

3.3. General Parameters in the Model

In this model, the existing power plants and transmission lines of Indonesia's electrical system are represented in the model's initialization [44]. The existing power generation data are detailed in Table A1 in Appendix A. Given that the current power generation fleet is relatively new, and our simulation relatively short, we have not taken into account forced retirement of power plants. However, the model chooses whether or not to utilize the existing power plants in the optimal solution. Power plants not used in the later periods of the model would be described as stranded assets.

The power generation options for the model to add to the system include open cycle gas turbines (OCGT), combined cycle gas turbines (CCGT), biomass, geothermal, solar, hydro, and wind energy. Table A5 in Appendix A outlines the maximum generation capacities for renewable energy sources. Since Indonesia has a target to achieve 100% renewable energy in 2060, we assume there is no new-build coal generation except those plants which have already been planned [46]. There are no official plans for expanding transmission infrastructure, but in our model, the power transfer capacity between regions is set to increase by 25% every five years in line with demand growth to avoid constraints that would be likely to be addressed through network planning and capacity expansion.

Data for renewable energy resources are sourced from Renewable Ninja for 2011–2020. The settings used for solar generation are equator-facing fixed-axis PV panels with a 10-degree tilt. Wind data were only chosen from three provinces in Java–Bali and Sumatra as the data source (Aceh, Banten, and West Java), because of the limitations on wind resource in Indonesia.

Energy storage candidates are located in 10 provinces, as depicted in Figure 1, and comprise lithium-ion batteries with 2 h, 4 h, and 10 h discharge durations. Most of the above data have also been used in our previous research on optimal energy storage configurations for Indonesia. Additional parameters for generators, energy storage, fuel, and renewable energy potential can be found in Tables A3–A5 in Appendix A, referencing various sources such as [8,44,50–58].

3.4. EV Modeling and Charging Stations

In this study, we employ a novel transport module from PLEXOS 9.2. There are still limited studies using this module in the research; the latest research uses storage as a representation of EVs [42]. This module provided two distinct methods for representing EVs. The simpler of these treats an EV as a static electrical load, which consumes a fixed amount of power, measured in kilowatts (kW), at predetermined times. This model is particularly useful for scenarios where EV charging has a predetermined hourly schedule and does not optimize (as shown in Figure 9a). On the other hand, a more complex model allows for representing EV demand in kilometers driven, incorporating additional parameters like efficiency (Wh/km) and battery capacity, as shown in Table 1. This approach can facilitate optimized charging that adjusts to the vehicle's optimal time to charge. To further refine the model, each EV is associated with a "home" charging station capable of delivering up to 10 kW of power.

The EV and charging station modules feature key parameters, including the maximum charging and discharging rates. These rates are crucial in determining the functionality of an EV, specifically whether it serves merely as a load or includes V2G capabilities. In scenarios with a predetermined charging period, all EVs are equipped with a charging

parameter, while none have the capability to discharge. For V2G scenarios, half of the EVs are allocated discharging parameters, and all vehicles have charging capabilities. Motorbikes, in contrast, have no discharging parameters and are solely equipped with the ability to charge. To ensure the model remains computationally efficient, it scales down the real world by representing 10,000 actual EVs or charging stations as a single unit within the simulation.

In the process of modeling electric vehicles (EVs), an essential factor considered is the emission reduction achieved through replacing internal combustion engine (ICE) vehicles with EVs. This is quantitatively represented by incorporating an 'emission distance coefficient'. This coefficient effectively measures the decrease in emissions for every kilometer driven or the equivalent energy consumed in kilowatt-hours (kWh) by an EV, as opposed to an ICE vehicle. Specifically, the 'emission distance coefficient' is defined as the amount of emissions that would have been produced by an ICE vehicle [59] for the same distance. By introducing this coefficient into the model, it becomes possible to account for the environmental benefits of adopting EVs, showcasing the reduction in emissions attributable to the substitution of ICE vehicles with their electric counterparts.

Table 1. The parameters of electric cars and motorbikes in the model.

Parameters	Unit	Electric Car	Motorbike
Efficiency	(Wh/km)	162 [60]	31 [61]
Demand	Km/day	32.8 [62]	32.8 [62]
Demand	kWh/day	5.3 [62]	1.0192 [62]
Battery Capacity	kWh	64 [60]	1 [61]
Emission Distance Coefficient	kg CO_2/km	−0.216 [59]	−0.0313 [59]

3.5. Deployment Scenarios

We have formulated three distinct EV deployment scenarios—base, middle, and high—considering the projected adoption of EVs. These scenarios encompass both cars and motorbikes, recognizing the dual nature of the transportation landscape in Indonesia. Our estimation for the total number of vehicles in 2050 is based on population projections from the Indonesian Central Bureau of Statistics (BPS) [63], which anticipates a population of 329 million and 84 million households by that time. We assume a ratio of one car per household and two motorbikes per household. The deployment of electric cars and motorbikes will be determined based on the percentage of the total vehicles within each scenario. The base method aligns with the roadmap set forth by the government of Indonesia [14]. In contrast, the medium and high methods represent situations where the penetration of EVs becomes a much more substantial portion of the total number of vehicles. The complete demand scenarios are shown in Table 2.

Table 2. The demand for EVs scenarios.

Demand	Number of Electric Cars	Number of Electric Motorbikes
Base	4.2 million (5% of the total)	47 million (28% of the total)
Medium	42 million (50% of the total)	84 million (50% of the total)
High	84 million (75% of the total)	168 million (75% of the total)

Charging patterns are segmented into fixed times, including early morning, daytime, and evening, as well as an optimized time designed to leverage flexibility to maximize the benefit of integrating EVs into the grid. These scenarios collectively capture the intricate interplay of EV charging dynamics and demand variability. The shape of the charging profiles is shown in Figure 9a in the results section.

3.6. Scenario Formulation

A total of 17 scenarios (shown in Table 3) are crafted by blending different charging times with varying EV deployment levels, V2G functionality, and additional cost for charging the EV. These scenarios encapsulate a wide spectrum of EV adoption trajectories, enabling a nuanced exploration of the challenges and opportunities associated with EV integration in Indonesia's energy system. The diverse scenarios provide a comprehensive view of the potential impacts of EV adoption on grid operations, renewable energy integration, and emissions reductions. The charging time consists of fixed and optimized times, as shown in Figure 9a. While the discharging as part of V2G functionality results from the optimal solution. For V2G scenarios, only 50% of the electric vehicles have V2G functionality.

Table 3. The scenario formulation.

Group	Name	Charging Time	V2G	Additional Cost for Charging Station (USD/MWh)	Demand EVs Scenarios		
					Base (1)	Medium (2)	High (3)
Charging Time	Early Morning (M)	1 AM–7 AM	-	-	M1	M2	M3
	Daytime (D)	10 AM–4 PM	-	-	D1	D2	D3
	Evening (E)	5 PM–10 PM	-	-	E1	E2	E3
	Optimized (O)	Optimized	-	-	O1	O2	O3
V2G Scenarios V2G Scenarios	Optimized + Vehicle to grid	Optimized	p	-	-	O2-V2G	O3-V2G
	Optimized + Vehicle to grid_10	Optimized	p	USD 10	-	-	O3-V2G_10
	Optimized + Vehicle to grid_25	Optimized	p	USD 25	-	-	O3-V2G_25
	Optimized + Vehicle to grid_50	Optimized	p	USD 50	-	-	O3-V2G_50

3.7. Treatment of Vehicle-to-Grid Charging Costs

In the current PLEXOS release, there are no parameters available to model battery degradation cost for V2G. We therefore simulate battery degradation by adding charging station charge cost for different numbers. Even though it does not directly represent the degradation of battery cost, it can show how the additional cost to make the charging station have V2G functionality can affect the capacity of generation, battery, emissions, and renewable energy. When the extra cost is more or less than USD 25/MWh, the optimal solution will choose to use the V2G rather than build additional stationary battery capacity. However, when the charge cost is USD 50/MWh, it will instead develop or use stationary battery energy storage.

3.8. The Main Contribution of the Paper

This paper introduces a new methodology employing detailed energy system modeling to analyze the dynamic interactions between EV demand, renewable energy sources (specifically solar PV), and critical power generation and battery system parameters. The main contributions of this paper are:

1. The study assesses the impact of EV integration on the optimal configuration and operation of the electricity grid. This assessment considers the penetration of renewable energy sources, the evolution of power generation, the deployment of battery systems, and the resulting emissions. The study delves into the intricate interdependencies between these factors, offering a comprehensive understanding of the potential ramifications of EV integration.

2. The adoption of an hourly energy flow analysis. By capturing the nuanced fluctuations in energy demand and supply on an hourly basis, the study offers a holistic perspective on the challenges and opportunities of EV integration. This temporal granularity allows for a more nuanced evaluation of EV impacts on energy systems, bridging the gap between real-world dynamics and modeling outcomes.
3. The utilization of real-world electricity generation data from Indonesia. This incorporation enhances the accuracy and applicability of the analysis, aligning the findings with the actual conditions of the country's energy landscape. By grounding the analysis in empirical data, the study offers insights that resonate with Indonesia's energy context and transition goals.
4. The study is the first of a comprehensive assessment of EVs' impact and contribution in Indonesia toward net zero emissions by considering the hourly variation in power generation, transmission power flow, demand and dispatch of renewable energy resources combined with battery investment in the provinces in Java–Bali and Sumatra.

The combination of these contributions underscores the comprehensive nature of this paper's exploration into the symbiotic relationship between EVs, renewable energy integration, and the dynamics of energy systems. By merging theoretical insights with real-world data, this study forms a foundation for strategic policy interventions, technological advancements, and informed decision-making that collectively drive sustainable energy transition in Indonesia and beyond.

4. Results and Discussion

The analysis reveals that optimized charging strategies increase renewable energy utilization, reduce emissions, and improve system efficiency. Integrating EVs with renewable energy sources reduces the need for conventional power generation during peak demand, enhancing overall grid sustainability. The analysis of the formulated scenarios reveals significant insights into the impacts of EV integration on Indonesia's energy system.

4.1. Generator Installed Capacity

Integrating EVs results in a higher demand for electricity and increased requirements for electricity generation capacity. The choice of power plant technology for expansion is contingent upon the timing of EV charging. When most charging occurs during the day, the optimal approach is to maximize solar power generation by strategically deploying PV systems. Conversely, during periods of elevated load in the middle of the night or early morning, a competition arises between constructing a thermal power plant, which offers rapid response and start-up capabilities, or investing in battery storage for storing excess energy generated from PV sources. It is noteworthy that for nighttime EV charging, the preference leans toward constructing open cycle gas turbine (OCGT) power plants rather than prioritizing battery storage infrastructure.

As shown in Figure 4, compared to the zero-EV scenario which has a total installed generation capacity of 467 GW, the installed generation capacity for daytime charging increases by 12%, for evening charging by 4%, and for early morning charging by 9%. When opting for optimized charging, the capacity requirement increases by 21% due to the increased adoption of lower-availability factor solar PV systems. The predominant technologies in these scenarios are PV systems, which dominate in optimized daytime and evening charging. Conversely, for fixed-time charging during the early morning, open cycle gas turbine (OCGT) technology is favored for capacity expansion.

Implementing V2G systems can enhance optimal PV capacity by as much as 33%, concurrently diminishing the necessity for expanding open cycle gas turbine (OCGT) and combined cycle gas turbine (CCGT) facilities. In the absence of supplementary costs, the optimal strategy involves increasing solar PV usage, with the excess energy stored in V2G batteries. However, when additional costs for V2G are considered, the installation of PV systems decreases compared to scenarios without such costs. This suggests that if V2G costs

are recognized, there is no urgent need to augment the number of PV installations, as the current PV capacity is sufficient to store energy in the already-established battery systems.

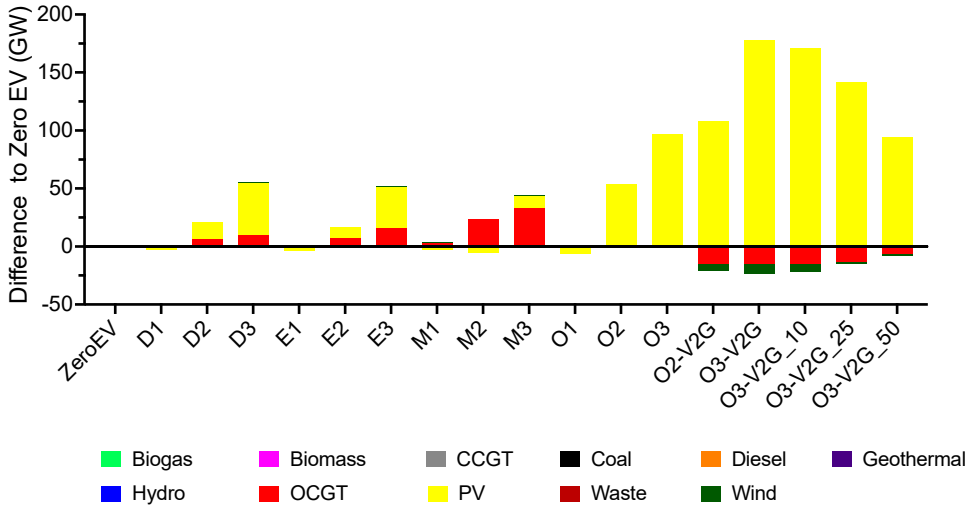


Figure 4. Comparison of generator installed capacity in 2050 for different scenarios to zero EV.

4.2. Battery-Installed Capacity

Specific charging behaviors have a direct impact on the optimal deployment pattern of batteries. Evening charging scenarios require larger battery capacities due to the surge in electricity demand during peak hours when solar PV generation is limited. In contrast, optimized charging scenarios demand comparatively smaller battery capacities, while daytime and early morning charging patterns exhibit similar battery requirements. This trend can be attributed to the effective utilization of excess solar PV energy during daytime charging. As depicted in Figure 5, a scenario with zero EVs necessitates a battery-installed capacity of 710 GWh by 2050.

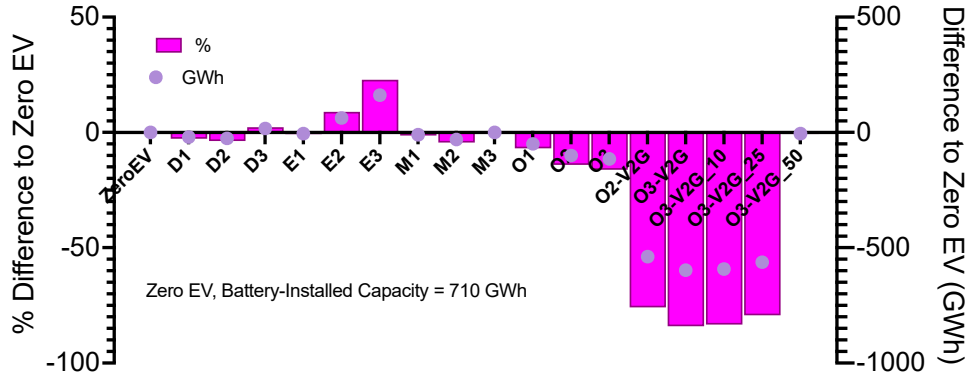


Figure 5. Comparison of battery-installed capacity in 2050 for different scenarios to zero EV.

Notably, the requirements are nearly identical for daytime charging (an increase of 2%) and early morning charging (a rise of 0.1%). However, there is a substantial increase of 22.8% in battery capacity needs in the evening charging scenario. In the optimized charging scenario, which primarily utilizes power directly from PV sources, the need for batteries is significantly reduced, resulting in a decrease in battery capacity by 16%.

Incorporating optimized charging and enhanced functionality could result in a significant decrease—up to 84%—in the required number of energy storage units. Energy can be efficiently stored in EV batteries and utilized as needed, a concept that is further explored in Section 4.8. Nonetheless, when factoring in additional vehicle charging costs, the optimal number of batteries increases. If the V2G charging cost reaches USD 50/MWh, the required number of batteries would be comparable to the scenario where no EVs are utilized for V2G.

4.3. Total Cost

Evaluating total system costs across different charging time scenarios demonstrates that optimal charging strategies result in the lowest prices. Following optimal charging, daytime charging emerges as the second most cost-effective approach. Conversely, early morning charging is associated with the highest total system costs due to the simultaneous rise in electricity generation demand and limited renewable generation during this period.

As depicted in Figure 6, by integrating V2G technology, the overall system costs can be reduced, provided the cost is below USD 25/MWh, compared to systems with optimized charging alone. The total system cost was reduced due to lower open cycle gas turbine (OCGT) requirements and a lesser need for energy storage construction. Despite the increased demand for photovoltaic (PV) installations, this configuration is ultimately more cost-efficient in comparison to the alternatives involving larger energy storage and OCGT setups. However, if V2G charging costs rise to USD 50/MWh, the total expenses surpass those of optimized charging systems without V2G capabilities. This indicates that V2G has the potential to lower total system costs if additional costs can be minimized effectively.

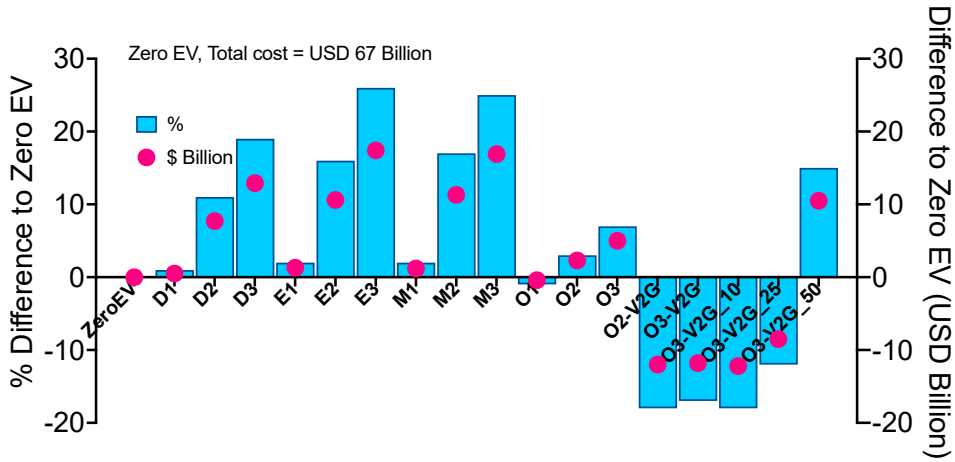


Figure 6. Comparison of total cost in 2050 for different scenarios to zero EV.

4.4. Renewable Energy Percentage

The integration of optimized charging strategies achieves a notable increase in the penetration of renewable energy sources. In contrast, non-optimized charging scenarios exhibit relatively lower renewable energy integration, particularly during evening and early morning charging periods. This observation underscores the potential of EVs to enhance renewable energy utilization.

As shown in Figure 7, in the case of zero EV penetration, a 67% renewable energy (RE) target can be achieved; however when the EV load is added with fixed-time charging it can lead to lower renewable energy uptake with an increase in the use of OCGT and coal to cover the increasing demand during the charging time (RE 64% for D3, and RE 63% for E3). The early morning charging scenario (M3) has the least renewable energy uptake (RE 60%), because it needs more OCGT to meet the load requirements. By using optimal charging, RE is increased to 71% to total supply and by combining the optimal charging with vehicle to grid, the penetration of RE can increase to 77%. V2G capabilities enhance the penetration of renewable energy by leveraging the increased storage to harness energy from PV sources. Even with V2G facility costs escalating to USD 50/MWh, V2G remains competitively priced in comparison to optimized charging systems that operate at zero cost.

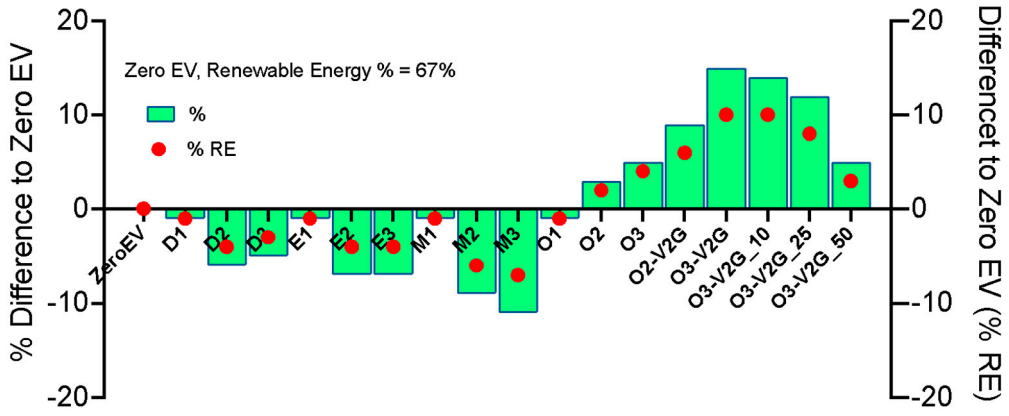


Figure 7. Comparison of renewable energy percentage in 2050 for different scenarios to zero EV.

4.5. Emission Comparison

While EVs contribute to reduced emissions compared to conventional vehicles, non-optimized charging behaviors may lead to higher emissions when compared to scenarios without EVs. Early morning charging scenarios exhibit the highest emissions, followed by evening and daytime charging, highlighting the significance of efficient charging strategies in minimizing emissions.

This analysis indicates that although EVs have the potential to reduce overall emissions, as suggested by the relatively negative value assigned to EV emissions in our calculations, this is not always the case. Inefficient charging times can necessitate the increased use of fossil fuel power plants, inadvertently increasing emissions beyond those in scenarios without EVs. However, the use of V2G functionality can mitigate total emissions by optimizing the use of PV energy stored in EV batteries. As depicted in Figure 8, it is noteworthy that when V2G incurs an additional cost of USD 50/MWh, the emissions equate to scenarios devoid of EVs.

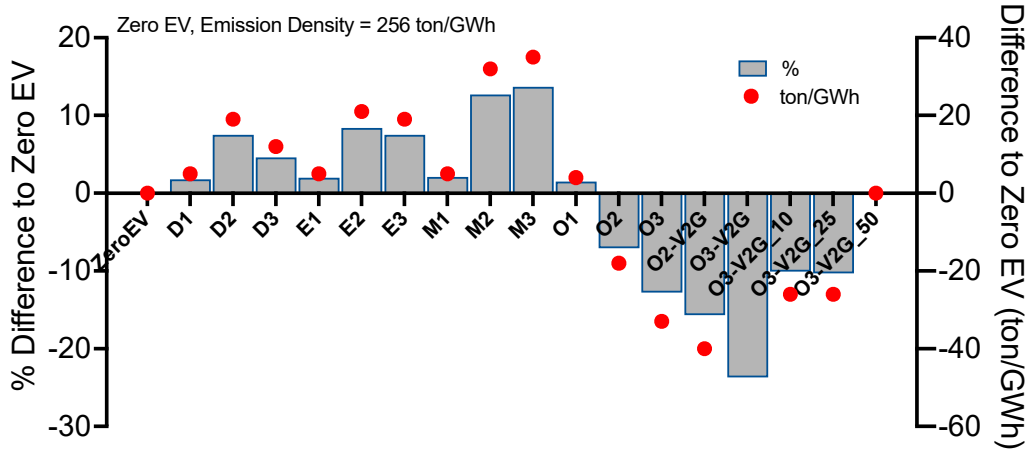


Figure 8. Comparison of emissions in 2050 for different scenarios to zero EV.

4.6. Vehicle to Grid

In both the O2-V2G and O3-V2G scenarios, total system costs are notably lower compared to scenarios O2 and O3. This cost reduction primarily stems from the choice to utilize the EV's battery instead of constructing separate energy storage systems. The calculated value, derived from the difference in total costs between the optimized scenario with and without V2G, considering a discount rate of 10% and a 15-year lifetime, suggests that the value of V2G per unit amounts to USD 1500. However, it is crucial to note that this calculation does not yet account for additional battery degradation resulting from V2G functionality.

Battery degradation rates can vary based on several variables such as battery chemistry, the number of cycles per day, state of charge, depth of discharge, and the specific functionality of the EV's battery, including its role as an ancillary service for tasks like peak shaving, as discussed in the literature [64,65]. Research conducted by [66] indicates that the extra battery degradation attributable to V2G functionality falls within the range of a 1–12% reduction in capacity, while another study indicates an incremental degradation rate of 0.155% per annum, attributable to daily discharge cycles in the studied context [65].

4.7. Comparison Charging Pattern

The comparison of charging scenarios reveals that optimized charging strategies yield the most favorable outcomes in terms of higher renewable energy penetration, reduced emissions, and lower total system costs. As shown in Figure 9, daytime charging presents an intermediary option, while evening charging emerges as the least economic charging strategy and the early morning charging is least favorable to reducing emissions and increasing penetration of renewable energy.

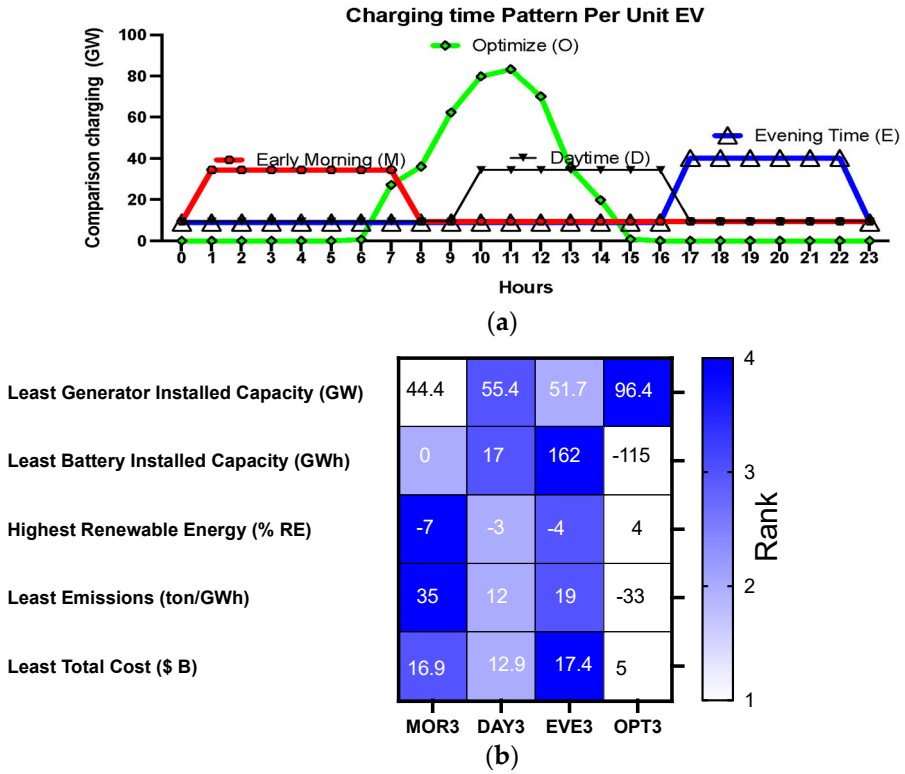
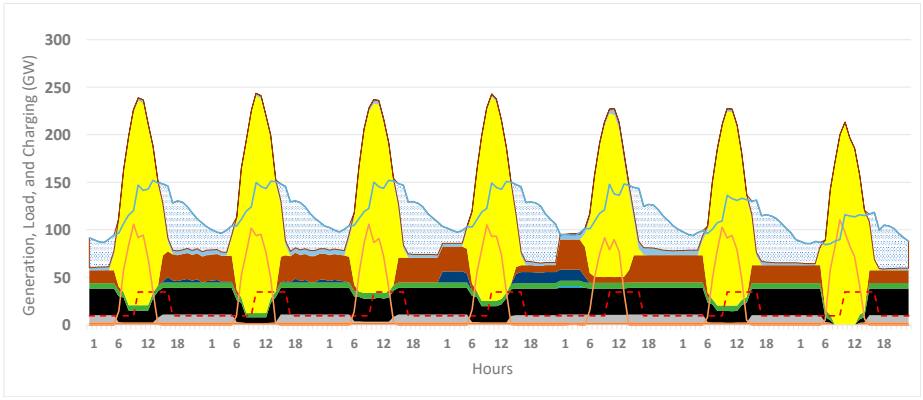


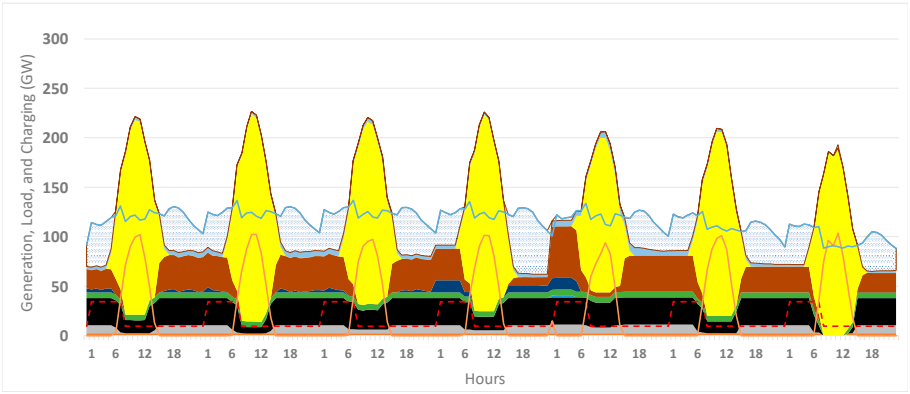
Figure 9. Charging Time Pattern and Scenario Comparison results. (**a**) Charging pattern. (**b**) Rank comparison of scenarios (Rank 1 is preferable).

4.8. Hourly Profile

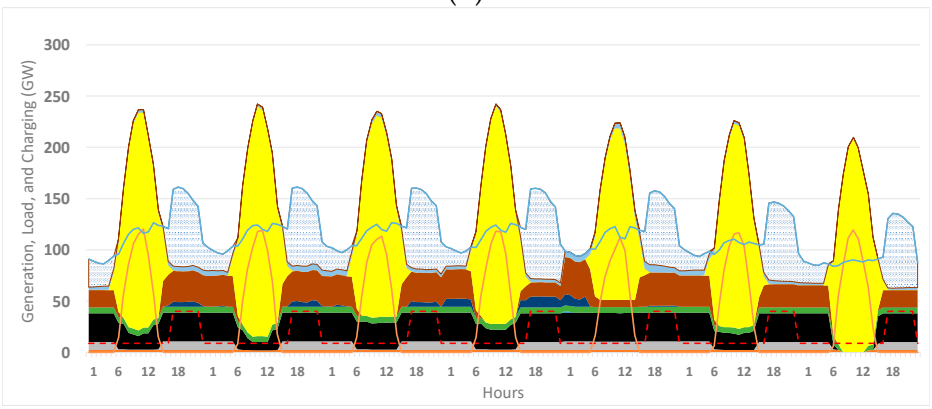
Figure 10 below shows the interaction of different technology power plants, energy storage, and charging EVs. PV systems are most productive during daylight hours, with excess energy being stored in batteries for later use, including charging EVs. Battery storage systems discharge energy during peak hours when PV generation is low. Although batteries are preferred, open cycle gas turbine (OCGT) power generation is used during peak periods to meet demand. Some days are entirely powered by renewable energy sources like wind and solar, eliminating the need for fossil fuels. The choice between fixed and optimized EV charging times has significant effects, with fixed schedules leading to evening demand peaks, while optimized charging increases demand during daytime hours, taking full advantage of PV generation.



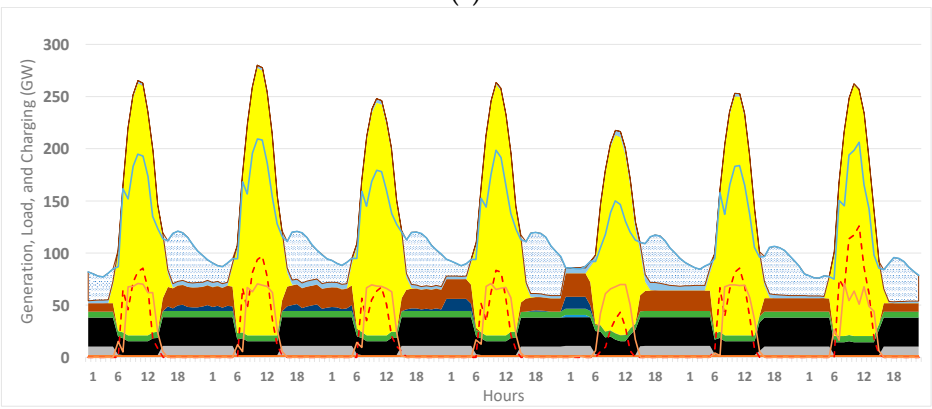
(**a**)



(**b**)



(**c**)



(**d**)

Figure 10. *Cont*.

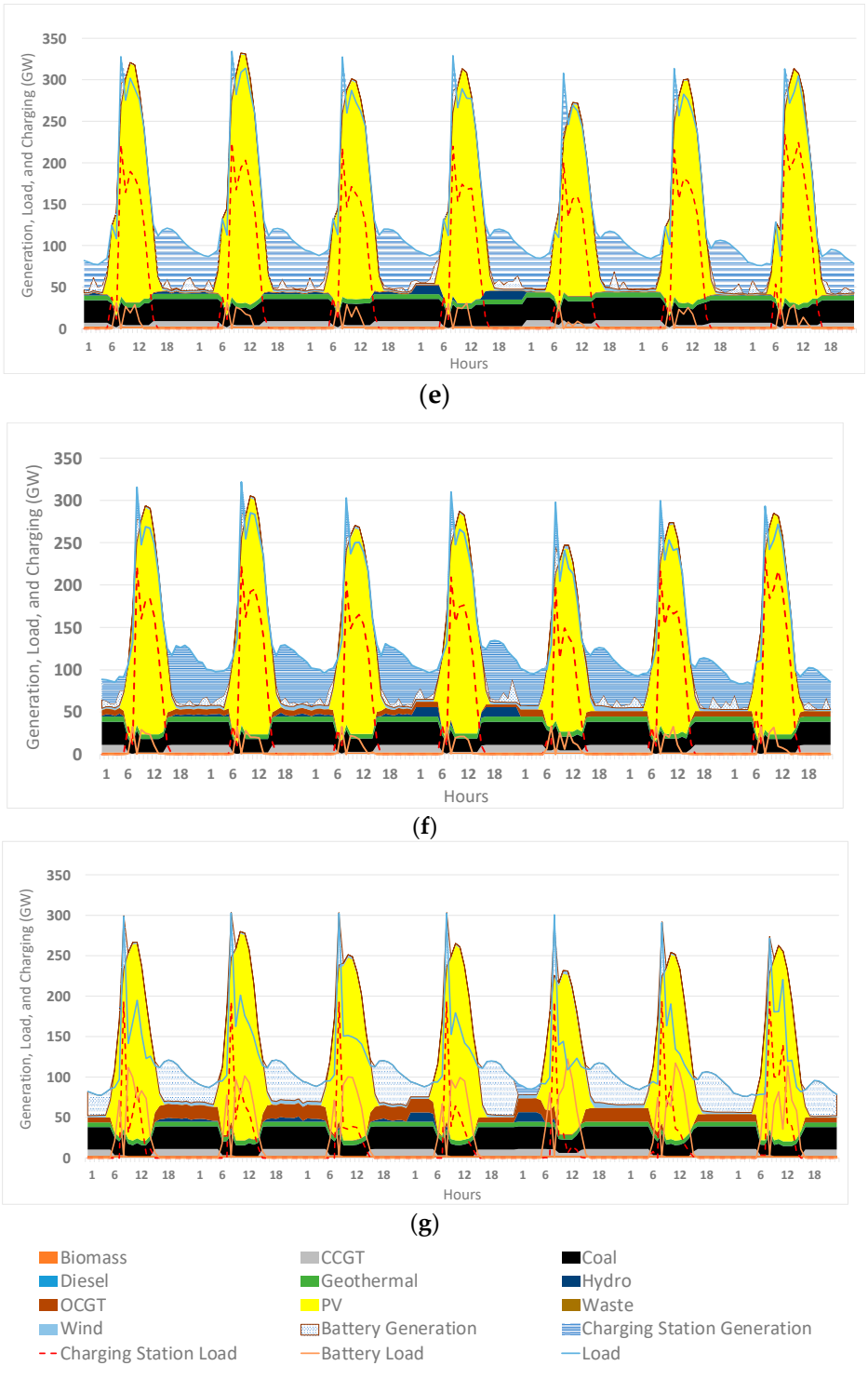


Figure 10. Typical weekly generation, load, charging EV, and charging energy storage in 2050. (**a**) Daytime (scenario D3). (**b**) Early Morning (scenario M3). (**c**) Evening (Scenario E3). (**d**) Optimized (Scenario O3) (**e**) Optimized with V2G functionality and zero charge cost (O3-V2G). (**f**) Optimized with V2G functionality and with charge cost (O3-V2G-25). (**g**) Optimized with V2G functionality and with charge cost (O3-V2G-50).

Figure 10 illustrates hourly results from a representative week in 2050, spanning 1–8 August 2050 (Monday to Sunday). These results depict power generation across various technologies, battery operations, and EV charging and discharging through V2G systems. The figures show that PV sources dominate power generation during daylight hours. In

contrast, fossil fuel generators, hydroelectric power, geothermal energy, and batteries primarily meet nighttime power requirements. Peak power demands are particularly noticeable during EV charging sessions. Specifically, daytime charging experiences its peak in the afternoon, whereas fixed-time charging has its highest need in the evening.

However, when charging times are optimized, this peak demand transitions to the daytime to harness more low-cost solar energy. Regarding the V2G feature, it is observed that when charging costs are nil, utilizing EVs as an energy resource is more favorable than establishing new energy storage systems. This preference remains even when a USD 25/MWh cost is introduced to the charging station. However, when this cost reaches USD 50/MWh, the inclination shifts toward dedicated energy storage solutions. A zero-cost V2G system bolsters the PV capacity, emphasizing the advantage of storing solar energy for later use, and more greatly relying on alternative power generation techniques.

Considering the additional expenses associated with battery discharging as energy storage, as mentioned in Section 3.7, it becomes economically viable to construct and employ large-scale energy storage systems for the majority of the time. Nevertheless, as depicted in Figure 10g, there are specific hours during which V2G technology remains beneficial. This indicates that, despite the added costs, the potential for utilizing V2G technology effectively remains.

With its vast reserves of nickel and other raw materials essential for lithium-ion battery production, Indonesia is poised to play a significant role in this burgeoning industry. Nickel is essential for cathode materials used in these batteries. The country's vast nickel reserves present a unique opportunity to become a significant supplier in the lithium-ion battery value chain, especially in the mining, refining, and manufacturing of materials [67]. As highlighted by the Indonesian government's policy to restrict the export of raw nickel and promote in-country processing, Indonesia aims to add value to its nickel resources and foster a domestic battery manufacturing industry [51]. Indonesia has taken proactive steps to establish a lithium-ion battery manufacturing industry. The government has initiated plans to build battery-grade nickel smelters to support this effort. As of 2022, several projects are in progress, and collaborations with international battery manufacturers have been established [68]. As countries worldwide transition to EVs to reduce carbon emissions and combat air pollution, Indonesia can become a significant player in supplying batteries for EV manufacturers.

5. Conclusions

Our study's findings highlight the substantial benefits of optimally charging EVs in conjunction with the availability of renewable energy. Such strategic charging can significantly enhance the use of renewable energy sources, decrease reliance on fossil fuel power generation, and thereby reduce carbon emissions from the energy system. The implementation of V2G technologies amplifies these benefits, enabling a marked reduction in the dependency on traditional power generation and storage systems.

The demand for generator capacity is closely linked to the timing of EV charging. Optimized daytime charging strategies particularly require notable increases in solar PV and total capacity. V2G technology offers a promising solution, with the potential to increase PV capacity by up to 33%, thereby mitigating the need to expand gas turbine facilities. Regarding battery storage, optimized charging strategies considerably lessen the necessity for large battery systems, presenting a cost-effective method to manage the surging electricity demands due to EVs. These strategies also lead to a significant reduction in total system costs and play a pivotal role in curbing emissions.

Our analysis reveals a significant difference between optimal and fixed charging times for EVs, carrying important implications for emissions and the integration of renewable energy into the grid. Non-optimal charging typically coincides with peak energy demand, which in turn leads to increased reliance on fossil-fueled power plants and, consequently, higher emissions. A misalignment between charging times and peak renewable energy generation, notably solar and wind, means renewables are underutilized despite their availability, as our results show, thereby hampering efforts to decarbonize the energy grid.

To address this misalignment, incentivizing off-peak charging through time-of-use tariffs and providing real-time information to consumers could better align EV charging behaviors with periods of high renewable generation and low demand. Furthermore, developing smart charging infrastructures capable of responding to grid signals and charging during optimal times is crucial.

Beyond the challenge of non-optimal charging times, the introduction of V2G technology adds complexity in terms of cost and potential benefits. Adopting V2G technology entails higher initial expenses due to the need for compatible vehicles and charging stations equipped with bidirectional charging capabilities and advanced communication systems. Despite these costs, the benefits of V2G are significant. By allowing EVs to return energy to the grid, they act as mobile energy storage units, which can be particularly beneficial during peak demand periods or when intermittent renewable sources are not generating energy.

The long-term financial benefits from V2G, such as grid stabilization and potential income for EV owners through energy sales back to the grid, could counterbalance the upfront costs. Moreover, by diminishing the need for additional grid storage and peak power plants, V2G could contribute to lowering overall system costs, potentially leading to reduced energy prices for consumers. A detailed cost–benefit analysis is essential to determine the economic viability of V2G technologies. Incentives and subsidies for early adopters, along with research into cost reduction strategies, could accelerate the adoption of V2G. Policy frameworks also need to be established to ensure that the full advantages of V2G are realized and equitably distributed among all energy ecosystem stakeholders.

The integration of V2G not only bolsters the use of renewable energy but also offers a potential reduction in total system costs, especially if the additional costs can remain below USD 25/MWh. Our findings suggest that even with added costs of USD 50/MWh to account for battery degradation, V2G systems still provide a competitive edge over non-optimized charging strategies. From an environmental standpoint, applying efficient EV charging and discharging through V2G systems can considerably lower emissions, potentially equalizing emission levels to those of scenarios without EVs, even when additional costs are taken into account. In comparing different charging scenarios, optimized charging patterns emerge as the most favorable, enhancing renewable energy penetration, reducing emissions, and decreasing total system costs. The least favorable outcomes are linked to evening and early morning charging strategies.

In conclusion, for Indonesia to realize an efficient, cost-effective, and sustainable energy system, the adoption of optimized charging strategies, particularly those incorporating V2G technologies, is essential. These strategies support greater integration of renewable energy, optimized battery usage, substantial cost savings, and significant emission reductions, aligning with global sustainability targets and the advancement of renewable energy technologies.

Nonetheless, our study did not consider the potential additional costs to the electrical distribution system that could stem from increased peak demand, particularly during optimal EV charging. This oversight could affect the overall assessment of the cost-effectiveness of different charging strategies and their related infrastructure requirements. A potential solution could be to distribute some of the solar PV and battery capacity into consumers' premises and the distribution system to closely match EV charging with the local energy and network capacity. Future research should aim to conduct a comprehensive analysis of the financial implications of increased peak demand on the local distribution and feeder networks, particularly during optimal charging periods, to provide a more complete understanding of the true costs associated with various EV charging scenarios.

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Appendix A

Table A1. Existing capacity of the power plants in the Java–Bali and Sumatra region (RUPTL) [44].

No	Province	Net Capacity of Power Plant (MW)											
		Biogas	Bio Mass	CCGT	Coal	Diesel	Fuel Oil	Geo Thermal	Hydro	OCGT	Solar	Wind	Grand Total
1	Aceh				140	141			20	447			749
2	Bali				375	605							980
3	Bangka Belitung	3	16		40	288				50			397
4	Banten			236	7543					424			8203
5	Bengkulu				115	11			120				246
6	Central Java and Yogyakarta			810	5995	114		45	495				7458
7	East Java			4083	5074	16			209				9382
8	Jakarta			2419		101	368			2497	6		5391
9	Jambi		29		12	23				165			230
10	Lampung				173	25		107	115	-			419
11	North Sumatra		2	272	475	179		414	463	397			2202
12	Riau				234	129			114	27			504
13	Riau Islands		1		133	168				576	1		880
14	South Sumatra			66	1130	91		55	13	374	2		1731
15	West Java			322	2809	10		1145	2010	1968			14,265
16	West Sumatra				180	24		85	101	49			440
Grand Total		**3**	**48**	**8208**	**24,428**	**1924**	**368**	**1852**	**3661**	**6974**	**9**	**-**	**53,475**

Table A2. Renewable energy potential capacity in Java–Bali and Sumatra region (MW) [8,44].

No	Potential (MW)					
	Province	Bio	Solar	Wind	Geothermal	Hydro
1	Aceh	293.5	86,000	894	245	1.75
2	Bangka Belitung	55.75	117,000	1787	26.5	0
3	Bengkulu	161.25	36,000	1513	145	27
4	Jambi	460	289,000	37	105.5	111.75
5	Lampung	373	136,000	1137	0.25	88
6	North Sumatra	728	309,000	356	108.5	1.25
7	Riau	1048.75	15,000	22	10.25	972.75
8	Riau Islands	4	116,000	922	0	0
9	South Sumatra	533.25	104,000	301	229.5	887.5
10	West Sumatra	239.5	13,000	428	200.25	0.25
11	Bali	48	23,000	1019	23	3.75
12	Central Java	558.25	141,000	5213	129.25	464.25
13	Banten	116.25	190,000	1753	65.25	18
14	East Java	855.25	28,000	7907	90.5	416.75
15	Jakarta	31.75	189,000	4	0	0
16	West Java	638.5	38,000	7036	539.75	877
17	Yogyakarta	56	21,000	1079	0	0
Total		6201	1,851,000	31,408	1918.5	3870

Table A3. Generation parameters in the Model [52–54].

Technology	Fuel	Minimum Stable Level (%)	Heat Rate (GJ/MWh)	Variable O&M (USD/MWh)	Start-Up costs (USD/MWe/start-up)	Min Up Time	Min Down Time	Fixed O&M (USD/kW/year)	Maintenance Rate (%)	Forced Outage (%)	Mean Time to Repair (hrs)	Economic Life (year)	Ramping Rate Up/Down (% of Max Capacity per minute)
Subcritical coal (<150 MW)	Coal	50	13.33	0.13	110	48	48	45.3	12%	7	24	30	1.0%
Diesel	Diesel	30	8.79	6.4	54	1	1	8.0	6%	3	24	25	25%
Geothermal	Geothermal	46	N/A	0.25	N/A	48	48	50.0	8%	10	24	30	3%
OCGT	Gas	20	10.017	2.3	24	1	1	23.2	6%	2	24	25	20%
CCGT	Gas	45%	7.068	2.3	80	4	4	23.5	10%	5	24	25	20%
Biomass	Biomass	30	12.596	3	110	48	48	47.6	12%	7	24	25	10%
Waste	Biogas	30	12.596	24.1	110	48	48	243.7	6%	1	24	25	10%
Biogas	Biogas	30	12.596	0.11	110	1	1	97.0	10%	5	24	25	20%
Hydro Large (>100 MW)	Hydro	0	N/A	0.65	N/A	N/A	N/A	37.7	12%	4	24	50	50%
Hydro Medium (10–100)	Hydro	0	N/A	0.5	N/A	N/A	N/A	41.9	12%	4	24	50	50%
Hydro Mini (<10 MW)	Hydro	0	N/A	0.5	N/A	N/A	N/A	53.0	12%	4	24	50	50%
Super Critical coal (150–650 MW)	Coal	40	9.3	0.12	50	48	48	41.2	13%	7	24	30	1%
Ultra Super Critical (650 MW)	Coal	30	8.548	0.11	50	48	48	56.6	13%	7	24	30	1%
PV	Solar	N/A	N/A	0	N/A	N/A	N/A	14.4	0.3%	2.5	24	25	N/A
Wind	Wind	N/A	N/A	0	N/A	N/A	N/A	60.0	0.3%	2.5	24	25	N/A

Table A4. Fuel parameters in the Model [5,69].

Coal		**Gas**		**Diesel**	
Attributes	**Value**	**Attributes**	**Value**	**Attributes**	**Value**
Kg/ton	907	USD/MMBTU	7	USD/L	0.46
Kcal/kg	4200	Kcal/MSCF	252,000	Kcal/L	9070
Kcal/kJ	4184	Kcal/kJ	4.184	Kcal/kJ	4.184
USD/ton	50	MMBTU to MSCF	0.9756		
Price (USD/GJ)	3.14	Price (USD/GJ)	6.81	Price (USD/GJ)	12.12
CO2 Production rate ($KgCO_2Eq/GJ$)	99.718	CO_2 Production rate ($KgCO_2Eq/GJ$)	57.6	CO_2 Production rate ($KgCO_2Eq/GJ$)	74.067

Table A5. Battery parameters in the Model [52,57,70,71].

Operation Parameters	**Li-Ion**			
	Unit	**2 h**	**4 h**	**10 h**
Power Capacity	MW	100	100	100
Energy Capacity	MWh	200	400	1000
Ramp Up Rate Up/Down	MW/Min	10,000	10,000	10,000
Charge Efficiency	%	92	93	94
Discharge Efficiency	%	92	93	94
Max SOC	%	100	100	100
Min Soc	%	25	25	25
Max Cycles		5000	5500	6000
Depth of Discharge	%	75	75	75
Battery Degradation	%/annum	2%	2%	2%
Economic Life	Years	15	15	15
Maintenance Rate	%	1%	1%	1%
Forced Outage Rate	%	0.50%	0.50%	0.50%
Cost Parameters				
Fixed O&M Including Extended Warranty USD	USD/kW	4	6.75	15
Variable O&M	USD/MWh	0	0	0

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A System Dynamics Model for Rooftop Solar PV System Development in Indonesia

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ABSTRACT: Despite of Indonesia's vast solar energy potential according to the Indonesian Ministry of Energy and Mineral Resources, Indonesia's total installed capacity of rooftop solar photovoltaic (PV) is very far from Indonesia's target of 3.6 GW in 2025. Indonesia once applied net metering scheme for rooftop solar PV policy and was expected to be able to boost rooftop solar PV growth. A system dynamics approach is used in the research to develop an assessment model to evaluate the policies' impact on residential rooftop solar PV system growth. A Causal Loop Diagram was established then transformed into Stock and Flow Diagram (SFD) using software Vensim PLE 10.1.3, which was used to simulate several policies' scenarios related to residential rooftop solar PV adoption and CO_2 emissions reduction. Ten scenarios were simulated in this study involving three groups of intervention: initial net metering tariff, reduction on initial solar PV cost, upper limit of ROI, and combination of initial net metering tariff and initial solar PV cost reduction. The simulations revealed that combination of increasing net metering tariff to 80% & initial cost reduction 30% has the highest potential solar PV installations, the highest CO2 emissions reduction, and the lowest accumulation cost of net metering in 2030. This study can be used as reference by the policy makers in Indonesia to formulate the optimum policy to boost rooftop solar PV growth as the simulations shows that residential rooftop solar PV with the right intervention can meet the government's target of rooftop solar PV in 2030.

KEYWORDS: Emission Reduction, Net Metering, System Dynamics, Solar PV.

I. INTRODUCTION

The Indonesia economic development combined with the population growth exceeding 275 million people [1] has strived to growing domestic energy demand. Indonesia annual population growth rate relatively steady at 1.25% between year of 2010-2020 but show a slight decline to 1.17% between year of 2020-2022 most possible cause by Covid-19 pandemic. In the energy supply perspective, population growth shapes the world's energy system and act as basic drivers of energy demand [2]. A study by (Dat et al., 2020) [3] revealed that using the history of energy consumption can predict Indonesia economic growth. Based on data from International Energy Agency (IEA), Indonesia energy mix in year of 2021 is predominantly fossil fuels (coal, oil, and natural gas). Coal is predominantly used in power plant for electricity generation while oil is predominantly used in transportation sector.

Electricity is taking into account 16% of share in Indonesia final energy consumption. As of 2021, Indonesia electricity consumption has increased 169% become 1.04 MWh/ Capita compare to year of 2000. Indonesia electrical consumption is dominated by Industrial sector (36.2%), Residential (41%) and commercial and public services (21.9%), meanwhile transportation sector is accounted for only 0.1%. Household electricity is mainly used for heating, cooling, lighting, cooking, and home appliances. There are several options to fulfill the electricity consumption, but mostly still fossil fuel based which make our dependency to the fossil fuel is still high. As energy demand for electricity generation has increased, coal has stepped in to fill the gap. Coal supplied 62% of Indonesia's on-grid power generation equal 181 TWh per year [4]. In share of Indonesia's total emission, power sector today contributes around 40% emission. Per unit of energy consumed, the country's energy sector now emits one-third more CO2 than it did in 2000. Total emissions from the energy sector have grown faster than energy demand, which has increased more than doubled in the past two decades. In 2021, emissions from the energy sector will be around 600 million tons of carbon dioxide (Mt CO_2), making Indonesia the ninth largest emitter in the world. However, per capita energy CO_2 emissions are only 2 tons, half the global average [5] although the trend in year of 20021 increased 71% compared to year of 2000.

The objective of this study is to identify all variables and parameters related to residential rooftop Photovoltaic (PV) system Indonesia to develop an assessment model to evaluate the policies' impact on promoting residential rooftop solar PV system. The variables and parameters specified will be modelled into a system dynamics model. The model will be a baseline for the proposed best scenario to address the business issue related to residential PV system development in Indonesia. The scope of this research is

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limited to rooftop solar PV system in residential area (households) in Indonesia, specifically PLN on-grid customers. History of residential PV system installation from year of 2018 to 2021 and future projection for the year of 2022 to 2030 will be the concerned time frame of the research. Specific policies related to renewable energy development particularly in solar PV system which is MEMR regulation no. 49/ 2018. Some limitations may occur due to data availability and quality, assumptions made in the modelling may result uncertainties in the findings, and last but not least that resource constraint like budget, time and data limitations may impact the depth and breadth of this research.

A. Paris Agreement

The Paris Agreement is an international agreement on climate change. It was adopted by 196 Parties at the United Nations Climate Change Conference (COP21) in Paris, France, on December 12, 2015. It is to maintain "global average temperature rise to well below 2°C above pre-industrial levels" and continue efforts to "limit temperature rise to 1.5°C above pre-industrial levels". To meet Paris agreement target, greenhouse gas emissions must peak by 2025 at the latest and fall by 43% by 2030 to limit global warming to 1.5°C. In COP21, all parties submitted their National Determined Contribution (NDC) to outline their target and actions to achieve global net zero emission by 2060. Each country submitted their plan to phase-out fossil fuel and shift to renewable energy. Indonesia announced its ambitious objective to reach net zero emissions by 2060 during the UN Climate Change conference (COP26) in Glasgow, 2021.

Indonesia has committed to reduce greenhouse gas emissions 29% by 2030, but then enhanced to 31.89% independently and up to 43.2% with international cooperation and support under the 2015 Paris Agreement. In addition, in 2014, the government has revived the National Energy Policy, aiming to not only achieve nearly 100% electrification by 2020 from the current 96% rate, but also achieve a renewable energy share in the energy mix, national volume at 23% by 2025 is made in RUPTL 2021-2030 [6]. The National General Energy Plan (Rencana Umum Energi Nasional [RUEN]) was established in 2017, prepared by the Ministry of Energy and Mineral Resources (MEMR) to achieve the objective of the *National Energy Policy* (Kebijakan Energi Nasional [KEN]). RUEN projected 6.5 GW of solar power generated electricity in 2025 and 45 GW in 2050 or 22% of the solar power potential of 207.9 GW [7]. Ministry of Energy and Mineral Resources (MEMR) encourages domestic households to adopt solar PV power system, where the target is 3.6 GW by 2025 [4]. Residential rooftop solar PV system is predicted to have a significant share in Indonesia renewable energy supply; however, the current installed capacity is still far from the target due to complexities of its development. Many stakeholders involved that have different interest, not to mention uncertainty of regulation & technology advancement. By Using system dynamics approach, several scenarios to be simulated to find the best option to develop residential rooftop solar PV system in Indonesia. This study will enrich the literature and knowledge related to residential rooftop solar PV system in Indonesia.

B. Indonesia Solar Energy Potential

Located in equatorial line, Indonesia is blessed with abundance of solar energy potential throughout the year. The country's geographical position along the equator guarantee consistent irradiance level thus solar level is uniformly distributed. With daily average solar irradiance of 4.8 kWh/m2/day [8], make it ideal for the development of solar photovoltaic (PV) system installation. (RUEN, 2017) [7] suggested Indonesia solar potential of 207.9 GW whilst (Veldhuis & Reinders, 2013) [9] suggested the total potential of grid-connected PV was around 1492 TWh. (Silalahi et al., 2021) [8] Identified that Indonesia's solar energy potential far exceeds the country's current and future energy demand and even larger than all other type of renewable energy sources combined altogether.

C. Solar Industry Profile

The rooftop photovoltaic system industry is a dynamic and rapidly growing sector in the renewable energy landscape. This involves installing solar panels on the roofs of residential, commercial, and industrial buildings to harness sunlight and convert it into electricity. According to Indonesia Solar Energy Outlook 2023 [10], China has been dominating 75% of 460 GW/year of global solar module manufacturing in recent years and more than 80% of each key manufacturing phases. This condition poses a supply chain disruption risk potential in the future. Any trade restriction to china makes the supply chain is vulnerable.

In local context, Indonesia's solar PV supply chain is only doing module assembly using imported cells, with total annual production capacity only 1.644 MWp from 21 manufacturers registered in the Association of Indonesia Solar Panel Manufacturer (APAMSI). 50% of the total production capacity is contributed by three manufacturers located in Batam Island with export orientation. Technical and economic obstacles make investments on the higher value chain is not currently feasible.

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II. LITERATURE REVIEW

Solar PV system development in Indonesia has the potential to play a significant role in the country's energy transition and reduction of carbon emissions. Indonesia, as an equatorial country, benefits from high solar energy availability throughout the year, with low seasonal variation in both energy demand and solar energy availability [8]. This eliminates the need for large-scale seasonal storage of energy, making solar PV systems a viable option for meeting the country's energy requirements. The vast solar energy potential in Indonesia has been recognized by major countries such as China, Japan, South Korea, the USA, and the European Union, which have expressed their intention to decarbonize their energy systems through renewable electrification [8]. It is estimated that Indonesia could meet a realistic upper bound on its entire energy requirements in 2050 from domestic solar energy, considering the projected increase in electricity consumption [8]. The study also highlights the availability of space for solar PV deployment, including rooftops, inland reservoirs, and mining wasteland [8]. However, despite the potential, the renewable energy sector in Indonesia, including solar PV, is still in the early stages of development. Indonesia aims to increase the share of renewable energy in its national energy mix to 23% by 2025.

System Dynamics (SD) has been widely used in research in the PV industry, but with different focuses [11]. (Salim et al., 2021) [12] presents the development of a System Dynamics (SD) model for management end-of-life (EoL) rooftop PV modules based on the circular economy concepts. Four socio-technical transition pathways examined in the study include *market-driven growth*, *conservative development*, *shared responsibility*, and *disruptive change*. However, this paper does not study related development of solar PV power but more of how to manage rooftop PV panel upon its EoL. (Sani et al., 2018) [13] introduce System Dynamics (SD) in solving the problematic Indonesia energy management. This paper shows that government policies regulating fossil energy investment, PLN tariff barriers, and various incentives that favor oil import cartels have led to robust fossil energy development and other ways in which new and renewable energy (NRE). However, this paper does not specifically study the solar PV power system as part of NRE power system.

A. Existing Studies

(Hsu, 2012) [14] uses system dynamics approach to develop simulation for assessing policies on feed-in tariffs (FITs) and capital subsidies to attract public society and private companies in Taiwan to invest in adoption of solar photovoltaic (PV) systems. The study revealed that when only adopting policy on FITs or capital subsidies with fixed upper limit of return on investment (ROI), the rise of FIT prices or subsidy was a good approach. In overall, the study concluded that the policy with higher subsidy and lower FIT price has a lower cost average cost of CO2 emission reduction. However, this study does not exercise other possible policy such as net metering scheme.

(Al-Refaie & Lepkova, 2022) [15] developed system dynamics models to evaluate the effects of policies on social acceptability to adopt solar PV systems, energy security, and CO2 emission reduction in the small-scale sector in Jordan. This study assessed feed-in-tariffs (FiTs), subsidy policies and annual net-metering tariff policy on the increment of solar PV adoption. The developed models are found a useful tool to measure the impacts of energy policies. However, a quantitative assessment is still needed to measure the extent to which these policies can meet the clean energy goals and support the policy's decision making. Jordan is expected to achieve a high level of clean energy security by 2050 to contribute to mitigating global warming.

(Hidayatno et al., 2020) [16] investigating policies on improving household rooftop photovoltaics adoption in Indonesia. Government could not provide a significant amount of investment to stimulate solar PV adoption in Indonesia, therefore, one solution is through household rooftop PV where the investment is by the homeowner. This study was aimed to assess the effectiveness of net metering and net billing policies by analyzing and understanding the dynamic complexity of the residential rooftop solar PV adoption in Indonesia. The study emphasizes the importance of taking a system perspective to understand the dynamic complexity of solar energy development. Unfortunately, no options of effective policies on improving the residential solar PV adoption were simulated.

B. Indonesian Regulation for Rooftop Solar PV

The Indonesian government has issued series of regulations to encourage development of rooftop photovoltaic (PV) system, from presidential regulation to ministry regulations. Following is the list of applied regulation in Indonesia:

Ministry of Energy and Mineral Resources (MEMR) Regulation no. 17/ 2013: this regulation focuses on regulations related to electricity procurement auction and pricing in Indonesia. MEMR set the feed-in tariff (FiT) of US$ 0.25/kW (using solar modules with less than 40% of local content) and US$ 0.30/kWh (using solar modules more than 40% of local content).

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Ministry of Energy and Mineral Resources (MEMR) Regulation no. 19/ 2016: this regulation replaced MEMR no. 17/ 2013 and focuses on regulations related to renewable energy development. FiT decreased between US$ 0.145/ kWh – 0.25/ kWh depend on the region. Total solar industry quota under this regulation is 250 MWp.

Ministry of Energy and Mineral Resources (MEMR) Regulation no. 12/ 2017: this regulation focuses on regulations related to electricity procurement and pricing in Indonesia. FiT range decreased further between US$ 0.48/ kWh – US$ 0.144/ kWh. Under this regulation, electricity tariff should be lower than national electricity production cost (National BPP) or no more than 85% of local electricity production cost (regional BPP).

Ministry of Industry (MOI) Regulation no. 5/ 2017: this regulation focuses on industrial development and operations. This regulation specifically regulates the minimum 40% local content requirement for solar industry, continued increase to 50 in January 2018 and 60% in January 2019. This condition has put barriers for solar PV development in Indonesia.

Ministry of Energy and Mineral Resources (MEMR) Regulation no. 49/ 2018: this regulation focuses on regulations related to the utilization of rooftop solar power generation by PLN consumers. Under this regulation, rooftop solar PV installation require verification and approval from PLN and net metering scheme is applied. Rooftop solar PV installation is limited to maximum of 100% of the PLN customer's installed electricity capacity. Excess electricity production from rooftop solar PV system is then exported into the grid and valued at 65% of PLN tariff as compensation. Electricity bill will be calculated monthly based on kWh import minus kWh export to the grid through net metering scheme.

Ministry of Energy and Mineral Resources (MEMR) Regulation no. 26/ 2021: this regulation is revision of MEMR regulation no. 49/ 2018 and focuses on regulations related to the utilization of rooftop solar power generation connected to licensees of power generator for public use. Electricity exported into the grid is valued at 100% compensation under this regulation.

III. RESEARCH METHODOLOGY

System thinking is known as principles of organization or theory of self-organization and the way of using it involves systematic or holistic thinking [17]. This research uses a system thinking approach since it deals with complex situations in development of residential rooftop solar PV in Indonesia. The study begins with literature review and data gathering to identify stakeholders and variables affecting residential solar PV growth and CO2 reduction impact. The system dynamics model is constructed by defining the model's boundary, identifying variables and parameters, designing causal loop diagram (CLD) and construct stock-flow diagram. Subsequently running the model for several scenarios and the final step is to analyze the result. Final step is to make recommendations dan propose solutions to the issues under the study.

The closed-system boundary is frequently used in system dynamic modelling to simplify the analysis and focus on the interactions within the system being studied. Closed-system boundary modelling assumes the system is isolated from external influences to provide a starting point for understanding the internal dynamics of the system. Several key variables have been identified which have essential role in residential rooftop solar PV system development and emission reduction in Indonesia: 1. Residential Rooftop Solar PV System Adoption, 2. CO2 Emission Reduction, 3. Public Awareness and Attitudes, 4. Government Policies (Net Metering Scheme), 5. Electricity Demand, 6. Cost of Solar PV Systems, 7. Technology Advancements, 8. Grid Electricity Prices, 9. Revenue from Excess Electricity Generation, 10. Installation Cost, 11. Operation & Maintenance Cost, 12. Total Cost of Solar PV Systems, 13. Return on Investment (ROI), 14. CO2 Emission Reduction Cost, 15. Population, 16. GDP (Economic Growth).

A. Causal Loop Diagram (CLD)

The causal loop diagram developed in this study is adapted from existing study by (Hsu, 2012) [14] with some modifications based on literature study and interview with some stakeholders.

Reinforcing Loop 1: Reinforcing loop 1 is highlighting CO2 emission reduction and adoption acceleration. Residential rooftop solar PV adoption increment reduces dependency on fossil fuels, resulting higher CO2 emissions reduction. Declining in CO2 emissions shows that rooftop solar PV adoption's effectiveness in mitigating climate change, bolstering broader public awareness and positive attitudes on solar power potential. High public demand for sustainable energy sources resulting government policies like the net metering scheme. Supportive government policies acting as incentive to rooftop solar PV adoption, causing increment

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in revenue from excess electricity generation. Higher revenue enhances solar PV return on investment (ROI) for homeowners, making rooftop solar PV adoption is more attractive. As CO2 emissions decrease, it bolsters the public perception that rooftop solar PV adoption is an effective way of climate change mitigation.

Reinforcing Loop 2: Reinforcing loop 2 is highlighting economic growth, technology advancements, and emission reduction. Economic growth subsequently increasing electricity demand. Increased electricity demand encourages solar PV system adoption. Higher solar PV adoption means more electricity is generated from rooftop solar PV. Increased rooftop solar PV adoption by households consequently more CO2 emissions reduction. As more CO2 emissions are reduced encourages investments in technological advancements on solar PV systems. Technological advancements reduce the cost of solar PV system installation and increase efficiency, making rooftop solar PV systems more attractive to homeowners that lead to adoption rate increment. Higher rooftop solar PV adoption rate subsequently increase CO2 emissions reduction. Declined CO2 emissions contribute to sustainable environment and economic growth.

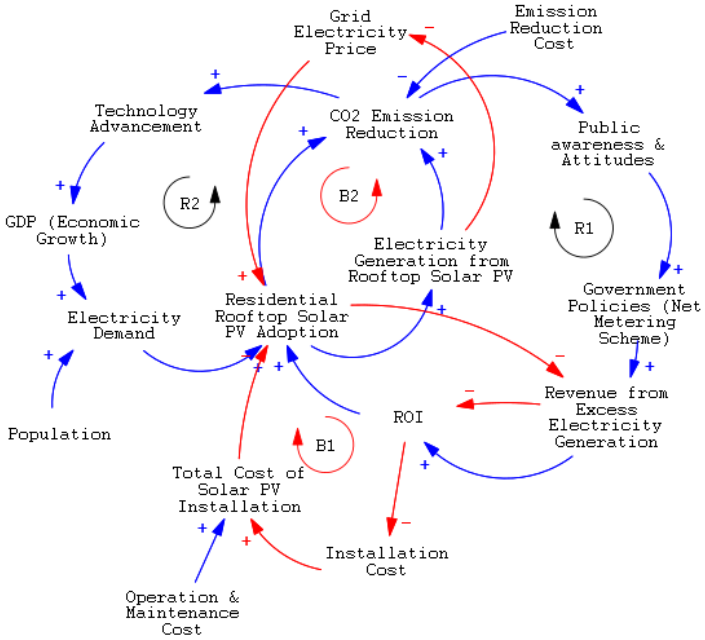


Figure 1. Causal Loop Diagram for Solar PV Development

Balancing Loop 1: Balancing loop 1 is highlighting Installation cost and Adoption Stabilization. In general, high installation costs have been an obstacle to rooftop solar PV adoption. Increment in the total installation costs has reduced the attractiveness of rooftop solar PV systems, leading to a decrease in adoption rates for households use. Lower adoption rates mean less revenue from excess electricity generation, consequently lower return on investment (ROI) for homeowners which reduces the rooftop solar PV adoption attractiveness. This condition is stabilizing the adoption rate and balancing the system.

Balancing Loop 2: Balancing loop 2 is highlighting Grid Electricity Price and Solar PV Adoption. Increase in grid electricity prices causing rooftop solar PV system adoption is becoming more financially attractive. As increased rooftop solar PV system adoption reduces demand for grid electricity, finally have potential in lowering grid electricity prices. Decreased grid electricity prices reduce the revenue from excess electricity generation and subsequently lowering the attractiveness of rooftop solar PV adoption, leading to a stabilized adoption rates and balancing the system.

B. Stock and Flow Diagram (SFD)

In modelling residential rooftop solar panel development and CO2 reduction in Indonesia, there are five stocks of the identified variables in the CLD as follows: 1. Residential Rooftop Solar PV System Installed, 2. CO_2 Emission Reduction, 3. Solar PV System Cost Reduction, 4. Net Metering Tariff, 5. Net Metering Cost. This study use "Vensim PLE 10.1.3" software to develop the model.

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CLD and SFD above to build a model for system dynamic is run using Vensim software. The equation for each variable is developed to ensure that the built model can simulate our intended scenarios. Initial values to be given for all the stock and all the flows will have a flow rate as basis for calculation. All parameters in SFD are defined as numerical values and parameter's relationships are calculated with function as shown in Table 1.

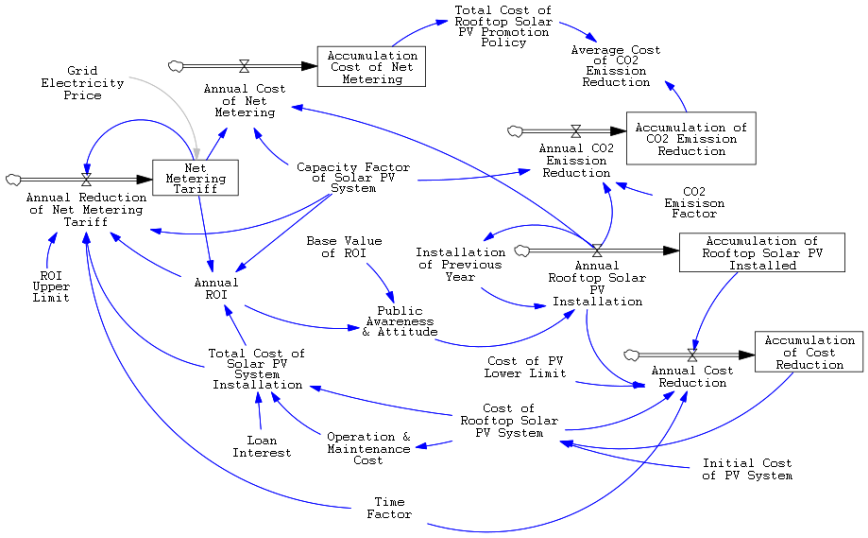


Figure 2. Stock and Flow Diagram for solar PV Installation and CO_2 Emission Reduction

Table 1. Parameter's Unit and Formulas of System Dynamics Modelling

No.	Parameter	Unit	Function
1	Net Metering Tariff (NMT)	Rp/kWh	(0.65*Grid Electricity Price) – INTEG (annual reduction of Net Metering Tariff)
2	Annual Reduction of Net Metering Tariff	Rp/kWh/Year	0 [if annual ROI < ROI upper limit] Net Metering Tariff – (base value of ROI * Total Cost of PV Installation)/ (365 * capacity factor of PV System) [if annual ROI > ROI upper limit] [b]
3	Accumulation of Solar PV Installed	kW	Initial accumulation of rooftop solar PV system + INTEG (Annual Rooftop Solar PV Installation) [c]
4	Annual Rooftop Solar PV Installation	kW/Year	Public Awareness * Installation of Previous Year
5	Installation of Previous Year	kW/Year	DELAY Fixed (Annual Rooftop Solar PV Installation, 1, initial solar PV system)
6	Public Awareness	-	Annual ROI/ Base Value of ROI
7	Annual ROI	-	(Capacity Factor of Solar PV * Net Metering Credit) * 365 (day)/ Total Cost of Solar PV Installations [d]
8	Total Cost of Solar PV Installation	Rp/kW	Cost of Rooftop Solar PV + Loan Interest + Maintenance Cost[e]
9	Maintenance Cost	Rp/kW	Cost of Solar PV System * 0.05[f]
10	Cost of Rooftop Solar PV	Rp/kW	Initial Cost of Rooftop Solar PV – Accumulation of Cost Reduction
11	Accumulation of Cost Reduction	Rp/kWh	INTEG (Annual Cost Reduction)
12	Annual Cost Reduction	Rp/kWh/Year	IF THEN ELSE (Cost of Rooftop Solar PV > Cost of

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No.	Parameter	Unit	Function
			PV Lower Limit, Cost of Rooftop Solar PV * ((Accumulation of Solar PV Installed + Annual Rooftop Solar PV Installation/ 1000/ Accumulation of Solar PV Installed) ^ (-3.32193), 0)
13	Accumulation of CO_2 Emission Reduction	$KgCO_2$/Year	INTEG (Annual CO_2 Emission Reduction)
14	Annual CO_2 Emission Reduction	$KgCO_2$/Year	Annual Rooftop Solar PV Installation * Capacity Factor of Solar PV * CO_2 Emission Factor * 365 (day) * 20 (Year)[g]
15	Total Cost of Rooftop Solar PV Promotion Policy	Rp	Accumulation Cost of Net Metering
16	Accumulation Cost of Net Metering	Rp	INTEG (Annual Cost of Net Metering)
17	Annual Cost of Net Metering	Rp/Year	Annual Rooftop Solar PV Installation * Capacity Factor of Solar PV * Net Metering Credit *365 (day) x 20 (Year)[h]
18	Average Cost of CO_2 Emission Reduction	$Rp/KgCO_2$	Total Cost of Rooftop Solar PV Promotion Policy/ Accumulation CO_2 Emission Reduction
19	Grid Electricity Price	Rp/kWh	Electricity price table

[a] NMT is the NMT in the first year of the simulation (USD/kWh). INTEG is an operation in Vensim software used to integrate the parameters inside the parentheses of each time step.
[b] When annual ROI is above the upper limit of ROI, NMT will be adjusted automatically so that annual ROI is approximately equal to the base value of ROI.
[c] the initial accumulation of Solar PV installed represents the sum of PV systems already installed in Indonesia prior to the simulation.
[d] the capacity factor of solar PV systems represents the daily average time for a solar PV system with 1kW of capacity to reach full loading in 1 year.
[e] Loan interest is calculated based on the sum of loan, annual interest rate (10%), and loan period (10 years).
[f] This study assumes each solar PV system has operational lifetime of 20 years and the maintenance cost is 5% of the cost of Rooftop Solar PV system.
[g] CO_2 emission factor is the average weight of CO_2 produced per kWh of electricity generated in Indonesia ($KgCO_2$/kWh). Indonesia CO2 emission factor in 2018 is 0,703 $KgCO_2$/kWh [18].
[h] the annual cost of NMC is the total cost for NMC for solar PV system from the period of installation to the next 20 years.

C. Data Collection Method

Data Source: The data used in this research are primary data and secondary data which are collected from several sources. Primary data are collected from interview with selected stakeholders and secondary data are collected from government reports related to renewable energy policy, energy consumption data form Handbook of Energy & Economic Statistics of Indonesia 2022, solar potential data, world and Indonesia GDP growth report, and some reports related to Indonesia energy transition outlook. All data then will be sorted out based on its relevance to be used to build the system dynamics model.

Data Collection Procedure: Some data required for this research are collected through published government report, published report from related International Organization, some stake holders' interview when necessary. Data from government reports are

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collected from official government websites. Data from International Organization (IRENA, IEA, IESR, etc.) are collected from the published report on their official website. Semi-structured Interview is required with using a list of guides to find out further in-depth information about the research topic from the stake holders' point of view.

D. Model Validation

Historical data on residential rooftop solar PV installations between 2018 and 2021 in Indonesia [19] were used to validate the result of the system dynamics model developed in this study. In this study, initial parameter values shown in Table 2 were adopted to simulate the system. Net Metering Tariff adopted is 65% of the grid electricity price as per MEMR Regulation no. 49/ 2018. The exact base value of the ROI is unknown, in this simulation, ROI base value 2.95% from (Hsu, 2012) [14] is adopted.

Table 2. Initial Value for Parameters (2018 to 2021)

Parameter	Value
Initial number of solar PV systems	910 kW (0,91 MW)[a]
Loan interest	10%[b]
Initial cost of solar PV systems	USD 1200/kW[c]
Capacity of solar PV systems	4,5 kWh/day/kWp[d]
Net Metering Tariff	Rp953,73/kWh (65% of Rp 1.467,28/kWh)[e]

[a] According to (EBTKE-MEMR, 2024) [19] installation accumulated in 2018.
[b] According to report of (World Bank, 2022) [20], Lending interest rate Indonesia floated between 10,53% and 8,92% between 2018 and 2021. We adopted mean value of 9,84% for this study but for simplification is rounded up to 10%.
[c] According to (Pujantoro, 2019) [21] capital cost for solar PV system in Indonesia ranges from 700 to 1200 USD/ kWh. Average Bank Indonesia Foreign Exchange rate [22] in 2018, USD 1 = Rp14,250.
[d] According to [8]
[e] According to [23] most residential PLN customers use power 2200 VA (Watt) and the most possible household solar PV users are with PLN installed capacity ≥2200VA according to [24]. Refer to [25] PLN tariff for electric capacity ≥2200VA is Rp 1467.28/kWh. Net Metering Tariff as per MEMR Regulation no.49/ 2018 is 65% of electricity price.

Accumulation of rooftop solar PV installation is modelled as a function of public awareness and installation of the previous year. Based on comparison between the model simulation and historical data of residential rooftop solar PV installation between 2018 to 2021 (Figure 3), the model showed the similar increasing trend with the actual historical data, means that the developed model is valid.



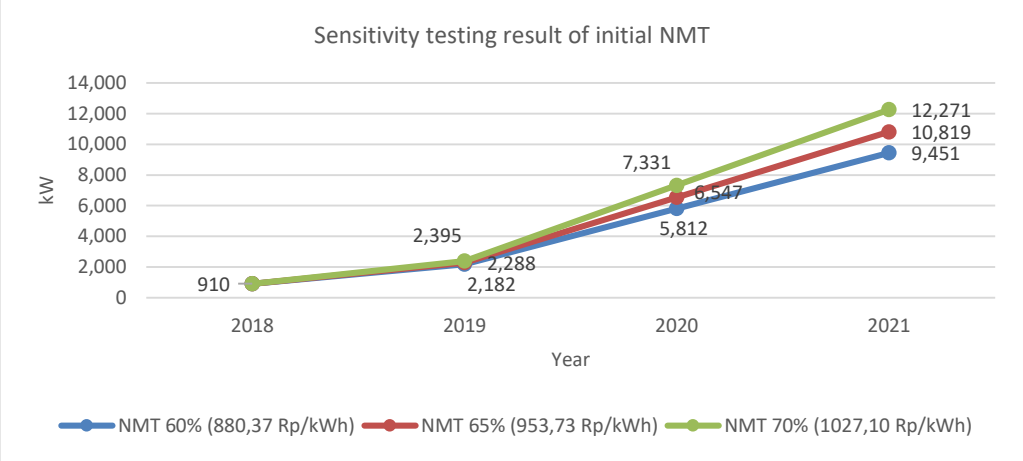
	2018	2019	2020	2021
Historical	910	3.180	6.260	12.430
Simulation Results	910	2.288	6.547	10.819

Figure 3: Simulation results of Solar PV installations in Indonesia from 2018 to 2021

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E. Sensitivity Analysis

Sensitivity analysis was conducted with using three different values of Net Metering Tariff (60%, 65%, and 70%) or equal (880,37 Rp/kWh, 953,73 Rp/kWh, and 1.027,10 Rp/kWh). Based on simulation with the initial NMT 880,37 Rp/kWh, the predicted number of solar PV system installations is 9.450,9 kW in 2021. When the initial NMT increases to 953,73 Rp/kWh, the predicted number of solar PV system installations in 2021 changes to 10.818,7 kW. For every 5% increment in the initial NMT, the number of solar PV systems in 2021 increases by 1.368 kW. When the initial NMT increases to 1.027,10 Rp/kWh, the predicted number of solar PV system installations in 2021 changes to 12.271,4 kW. For every 5% increment in the initial NMT, the number of solar PV systems in 2021 increases by 1.453 kW (Figure 4). We can conclude that the model is sensitive to NMT value changes.



	2018	2019	2020	2021
NMT 60% (880,37 Rp/kWh)	910	2.182	5.812	9.451
NMT 65% (953,73 Rp/kWh)	910	2.288	6.547	10.819
NMT 70% (1027,10 Rp/kWh)	910	2.395	7.331	12.271

Figure 4: Sensitivity test result of initial Net Metering Tariff

IV. RESULT AND DISCUSSION

Having successfully established, verified, and validated the system dynamics model, the developed model is then used to simulate residential rooftop solar PV development from year 2022 to 2030. Once the simulation results of accumulation of residential rooftop solar PV adoption in 2030, accumulation of CO_2 emission reduction, and the average cost of CO_2 emission reduction in 2030 are obtained. Next step is to set some scenarios of intervention on some variables in the model to see the impact on residential solar PV adoption, CO_2 emission reduction, accumulation cost of net metering, and the average cost of CO2 emission reduction.

By end of 2021, total number of rooftop solar PV installations in Indonesia reached 48,41 MW and for household or residential alone is about 12,43 MW (12.430 kW). In the following simulation from 2022 to 2030, initial solar PV adoption was set as 12,43 MW (12.430 kW). Electricity price for period of January to June 2022 is 1.444,70 Rp/kWh for all capacity (≥1.300 VA) and for period of July to December 2022 is 1.444,70 Rp/kWh for capacity ≤ 2.200 VA and 1.699,53 Rp/kWh for capacity ≥ 3.500 VA. The average price is 1.572,12 Rp/kWh, which will be used in the simulation.

Table 3. Initial Values for Parameters (2022 to 2030)

Parameter	Value
Accumulation Cost of Net Metering (2021)	Rp 220.066.000.000,-
Accumulation of CO2 Emission Reduction (2021)	228.827.000 $KgCO_2$ (0,23 million-ton CO_2)
Initial number of solar PV systems	16.810 kW (16,81 MW)
Loan interest	10%

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Parameter	Value
Initial cost of solar PV systems	1.200 USD/kW (17.100.000 Rp/kW)
Capacity of solar PV systems	4.5 kWh/day/kWp
Electricity Price	1.572,12 Rp/kWh
Net Metering Tariff (BAU)	1.021,88 Rp/kWh (65% of electricity price)

There are ten (10) scenario simulations in this study. The simulations were conducted using software Vensim PLE 10.1.3. Simulation results over time from 2022 to 2030 for accumulation of solar PV installations, accumulation of CO_2 emission reduction, average cost of CO_2 emission reduction, and accumulation cost of net-metering to be observed and analyzed.

Table 4. Scenario Summary

No.	Initial Net Metering Tarif (NMT)	Initial Solar PV Cost Reduction	Return on Investment (ROI)	Combination
1	A1 (NMT 80%)			
2	A2 (NMT 90%)			
3	A3 (NMT 100%)			
4		B1 (10% reduction)		
5		B2 (20% reduction)		
6		B3 (30% reduction)		
7			C1 (10%)	
8				D1 (A1+B3)
9				D2 (A2+B2)
10				D3 (A3+B1)

The simulation results of all ten scenarios show the effect of initial net-metering tariff (NMT), initial cost of solar PV system, upper limit of ROI, and combinations of NMT and initial cost of solar PV system are different. Summary of simulation results in 2030 are shown in Table IV.

Table 5. Comparison of the simulation results for all scenarios in 2030

Scenario	Accumulation of Solar PV System (MW)	Accumulation of CO_2 Emission Reduction (Mt)	Total Cost of Policy (billion Rp)	Average Cost of CO_2 Emission Reduction (Rp/KgCO_2)
A1	3.288,64	75,89	10.448	138,20
A2	3.888,09	89,73	12.312,30	137,21
A3	4169,96	96,24	13.720,80	142,57
B1	2.992,13	69,04	8.441,74	122,27
B2	3.359,79	77,53	8.606,65	111,01
B3	3.830,97	88,41	8.820,23	99,76
C1	7.719,07	178,20	45.260,40	253,98
D1	4.638,68	107,07	11.203,90	104,65
D2	4.393,91	101,41	12.313,90	121,42
D3	4.614,95	106,52	13.993,80	131,38

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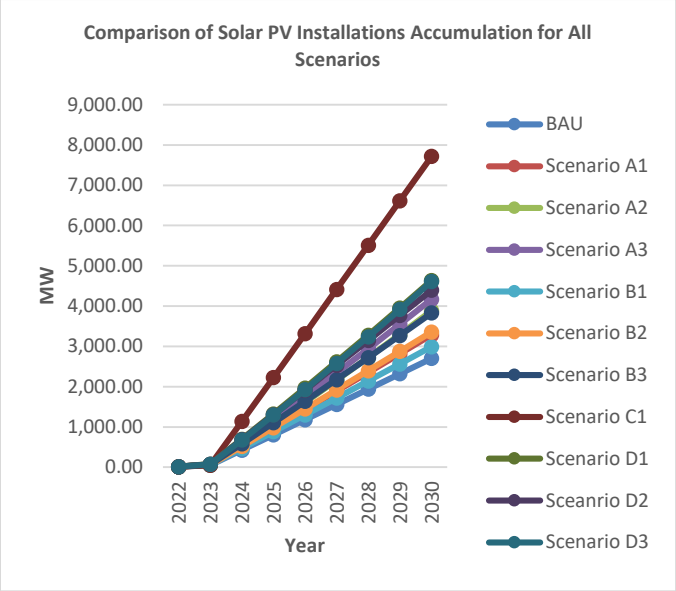


Figure 5: Solar PV Installation accumulation.

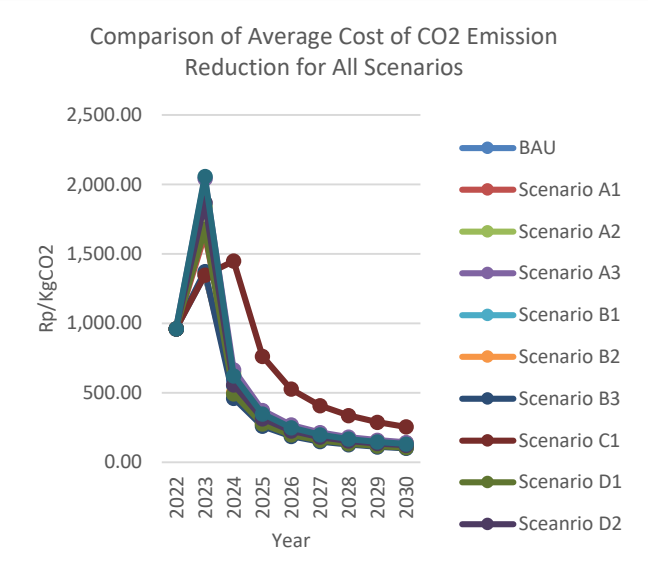


Figure 6: Average Cost of CO2 Emission Reduction

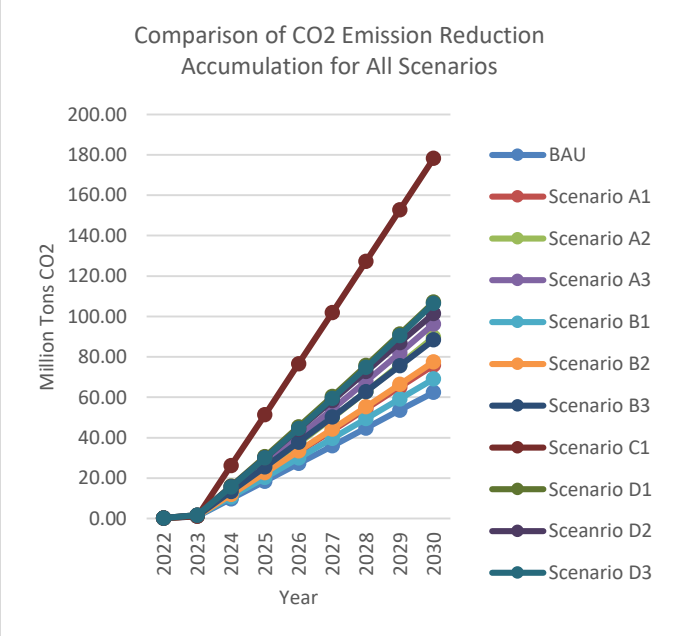


Figure 7: CO2 Emission Reduction Accumulation

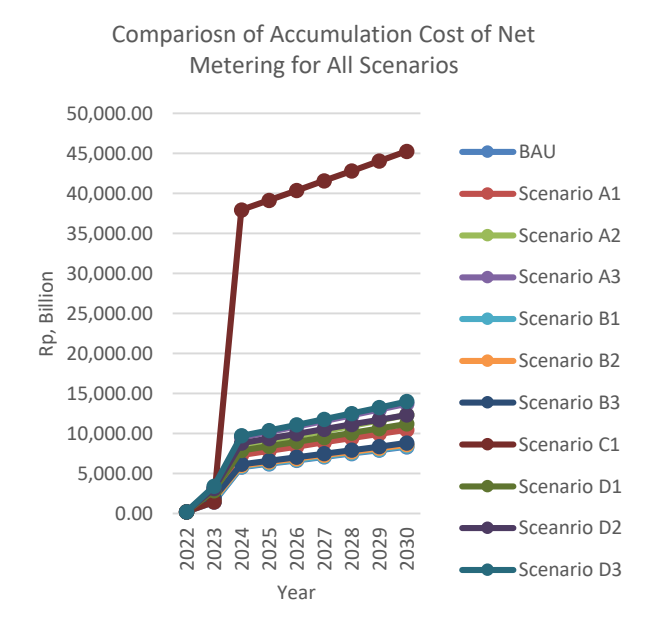


Figure 8: Average Cost of CO2 Emission Reduction

The highest number of accumulations of solar PV installations and accumulation of CO_2 emission reduction in 2030 is Scenario C1 with value 7.719,07 MW (7,72 GW) and 178,2 million tons, followed by scenario D1 with value 4.638,68 MW (4,64 GW) and 107,07 million tons. There is a huge gap between the highest and the second highest value as seen on Figure 5 and Figure 6, accumulation of solar PV installation gap is 3.080,39 MW and CO2 emission reduction gap is 71,14 million tons. However, between the second highest and other scenarios' difference range is between 23,73 MW to 471,18 MW for solar PV installations and 0,55 to 10,88 million tons for CO2 emission reduction. The lowest average cost of CO_2 emission reduction is scenario B3 with value 99,76 Rp/KgCO_2, followed by scenario D1 as the second lowest with value 104,65 Rp/KgCO_2. In term of accumulation cost of net-

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metering, scenario C1 is the highest cost with Rp 45.260,60 billion (Rp 45,26 trillion) and followed by scenario D3 in the second place with Rp 13.993,8 billion (Rp 13,99 trillion).

When the upper limit of ROI constant in scenario A1 to A3 and B1 to B3, higher initial net-metering tariff (NMT) means more solar PV system installations. Higher NMT means more income/ benefit to the solar PV system owners which improve the ROI that eventually increase public awareness and willingness to adopt solar PV system for households. However, higher number of solar PV adoption is also mean higher government spending and increases in spending consequently will also increases the average cost of CO_2 emission reduction.

Increasing the upper limit of ROI from 7,5% to 10%, significantly affect the accumulation of solar PV installations and accumulation of CO_2 emission reduction. However, the increment is showing an extreme value compared to another scenario in the second highest value. A careful analysis may be required to uncover the reason of such extreme result. Other than the upper limit of ROI (scenario C1), intervention combinations between increasing NMT and lowering initial cost of solar PV system in scenario D1 is showing the highest accumulation of solar PV systems and accumulation of CO2 emission reduction. Meanwhile for accumulation cost of net-metering (total policy cost), other than increasing the ROI, intervention combination between NMT 100% and lower reduction of initial cost of solar PV system (10%) has the highest cost due to higher NMT means higher government spending on compensation. A very careful analysis should be done by the policy makers for selection policy combinations to achieve residential rooftop solar PV installations target as well as reducing CO2 emission, but also to maintain government spending minimum.

V. CONCLUSION AND RECOMMENDATION

A. Conclusion

Despite of accumulation of rooftop solar PV system installations at the end of 2021 was only 12,43 MW, simulation results of all scenarios show that predicted installation in 2030 are ranged from 2.740 to 7.719 MW (2,74 – 7,72 GW). These numbers mean that from residential rooftop solar PV alone has a potential to fulfill solar PV target in RUPTL 2021-2030, which is 4,68 GW. This study used system dynamics to develop a simulation model for assessing residential rooftop solar PV system adoption in Indonesia. Net-Metering Tariff and initial cost of solar PV system highly affected public's willingness to adopt solar PV system for household since higher NMT and lower initial cost will increase customer's ROI. Higher NMT and lower initial cost of solar PV system affects the number of solar PV system installations. Higher solar PV system installations is directly proportional with CO_2 emission reduction. However, more installations mean more government's spending on compensation for excess electricity exported into PLN grid. The growth of solar PV system installations prediction in 2030 also means that there is a high potential in solar PV system business opportunity.

B. Recommendation

This study show that a careful policy combination can be used by the policy makers to improve residential solar PV system installations. A balance between government spending and improving number of solar PV adoption can be further assessed by simulating more scenarios. As simulations in this study show that Net-Metering Tariff and Initial cost of solar PV systems highly affected solar PV adoption, some measures like tax reduction can be implemented by the government to support reduction on solar PV system initial cost. This study only considers Net-Metering Tariff and other parameters' value are remained unchanged during simulation for simplification (ceteris paribus). Further study should be performed to include variance of policies like applying feed-in tariff (FIT) or initial cost subsidy or combination and comparing with other countries' policy.

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A Modeling of Voltage Protection Variation System Number of KWH Meter Rotation

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ABSTRACT
The main difference between prepaid and postpaid electricity lies in the payment method. As the name implies, 'postpaid' means paid after use. While 'prepaid', paid or purchased before use. This study is a comparison between Postpaid kwh meters and Prepaid kwh meters with the use of varying loads with voltage reduction treatment with a voltage of 230 volts, 220 volts, 198 volts and 165 volts. In the varying loads in the kwh meter rotation test, the prepaid rotation speed is longer than the postpaid rotation speed with a difference of 0.53 hours or 32 minutes. While in the Energy-saving lamp (LHE) load, the study found a very significant difference from the kwh meter rotation with a voltage of 198 Volts and the LHE load for 3.53 hours or 212 minutes between prepaid and postpaid, so prepaid is better than postpaid.

Keywords : Modelling, Voltage Protection, and KWH Meter Rotation.

INTRODUCTION

Electricity plays a very important role in life. Electricity is the main source of energy in every activity both in households and industries. PT. PLN (Persero) is the largest electricity service provider in Indonesia. Previously, PT. PLN (Persero) customers received a Postpaid electricity program service, namely using electricity first and then paying in the following month. PLN carries out billing to customers, sometimes there are customers who are late or do not pay, so PLN will cut off the electricity supply to customers if they are in arrears or late for a certain period of time (PLN 2013). To develop services to the community and reduce disconnections, the company tried innovation by issuing a prepaid electricity program or also called Smart Electricity. The prepaid electricity program is that the community pays in advance to buy the electricity they will consume in the form of a deposit (TOKEN), then the community can measure and calculate their own electricity usage every day.

The accuracy and stability of electrical energy measurement play a crucial role in power distribution systems. One of the key components in this process is the kWh meter, which records the amount of electrical energy consumed by customers. However, variations in supply voltage can significantly impact the rotation speed of electromechanical kWh meters or the digital readings of modern energy meters. These variations may lead to errors in energy measurement, resulting in over-registration or under-registration of electricity consumption. To address this issue, a voltage protection variation system is essential. This system regulates voltage fluctuations to ensure that kWh meters function within acceptable accuracy limits, reducing billing errors and improving overall power system reliability. By modeling such a system, we can analyze how different levels of voltage variation affect kWh meter performance and develop strategies to minimize measurement deviations.

Voltage fluctuations in power distribution networks arise due to several factors,

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including:

- Load imbalances and peak demand variations
- Power system faults and transient disturbances
- Harmonics and poor power quality
- Voltage drops in long-distance transmission

These fluctuations can cause inaccurate energy measurements, leading to financial losses for both electricity providers and consumers. Understanding the relationship between voltage variations and kWh meter rotation is essential for developing protection systems that enhance measurement precision.

LITERATURE REVIEW

KWH Meters and Energy Measurement.

A kilowatt-hour (kWh) meter is an essential device in electrical power distribution systems, used to measure the energy consumption of residential, commercial, and industrial users. The accuracy of kWh meters is crucial for fair billing, efficient energy management, and regulatory compliance **(**Singh & Gupta, 2020). There are two main types of kWh meters:

1. Electromechanical kWh Meters – These meters use a rotating aluminum disk whose speed is proportional to the power consumed. Variations in voltage and current can affect disk rotation, leading to measurement inaccuracies (Bollen, 2016).
2. Digital (Electronic) kWh Meters – These meters use microprocessors and sensors to record energy consumption. They are less susceptible to mechanical errors but may still be affected by voltage fluctuations if not properly calibrated (Mekhilef et al., 2018).

Previous Research on Voltage Protection and Meter Accuracy

Several studies have explored the relationship between voltage fluctuations and kWh meter performance:

- Hossain et al. (2020) analyzed the impact of overvoltage and undervoltage conditions on electromechanical meters, highlighting **a** ±7% deviation in recorded energy due to voltage instability.
- Patel et al. (2019) investigated the effectiveness of automatic voltage regulation in maintaining meter accuracy, concluding that AVRs reduce energy measurement errors by 90%**.**
- Zhao et al. (2021) explored the role of smart meters and AI-based error correction, finding that digital meters with real-time compensation algorithms achieve an accuracy improvement of 98%**.**

Types of KWH Meters

Kwh meters are classified into two main categories:

- Electromechanical Meters: These meters operate using **a** rotating aluminum disk, which moves at a speed proportional to the power consumed. Voltage fluctuations can significantly impact the disk's speed, affecting measurement accuracy (Gupta & Choudhary, 2019).

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- Electronic (Digital) Meters: These meters use solid-state components and microcontrollers to measure energy consumption. Although more resistant to mechanical wear, they still require stable voltage levels to ensure accurate readings (Mekhilef et al., 2018).

METHODS

Prepaid electricity services are considered to be able to help save people's expenses. This service is carried out with a credit system. Customers are welcome to buy credit according to their respective abilities, to then be able to use electricity. Credit will usually be in the form of a token number that is entered into the electricity meter. If successful, the credit increases and electricity can be used. In postpaid electricity services, customers are allowed to use electricity as much as they want for one month. Customers then have to pay the total electricity bill calculated based on usage for a month. Because there are no limits, the postpaid system sometimes causes electricity usage to swell. As a result, suddenly the bill at the end of the month jumps due to uncontrolled usage. Electricity from PLN that will be distributed to households (loads), is first distributed through the MCB which functions as a current limiter and safety device in the event of a short circuit. Then it is also distributed into the KWH meter. This aims to further utilize the existing KWH meter equipment.

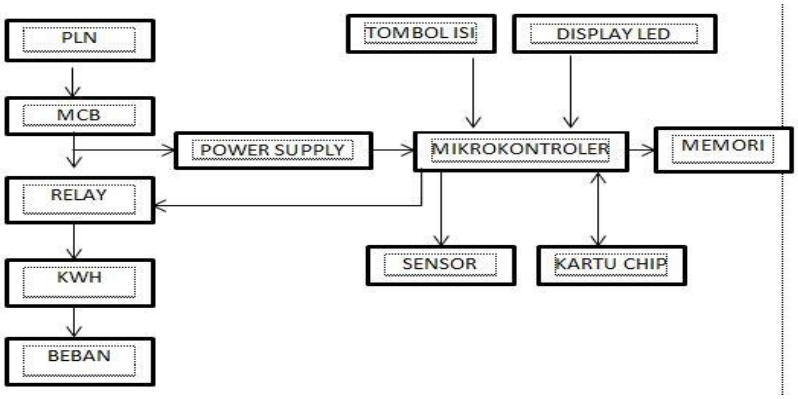


Figure 1. Block Diagram of Prepaid KWH Meter System

Table 1. Prepaid kWh meter specifications

Merek	Smart Meter
Tegangan (V)	230 volt
Kapasitas	5(60) A
Type	Smi-810
Putaran	1600 putaran 1 kWh

Below are the specifications of the Postpaid Kwh Meter used in the test, as follows:

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Table 2. Postpaid kWh meter specifications

Merek	Melcoinda
Tegangan (V)	230 volt
Kapasitas	5(25) A
Type	M2XS4V2
Putaran	1250 putaran 1 kWh

The test circuit from source to load is sequenced as in the picture below:

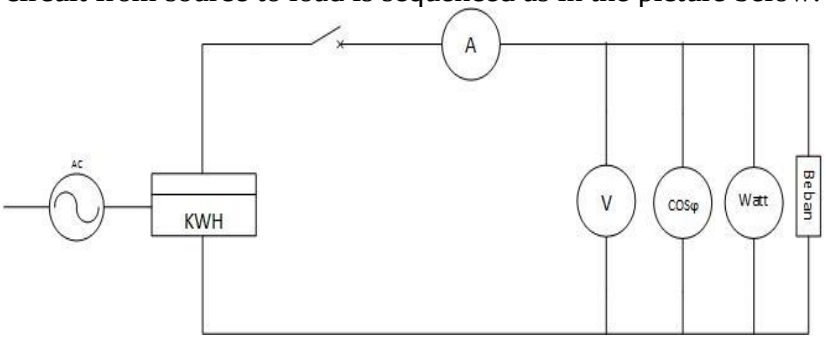


Figure 2. kWh meter load circuit

The source provides input voltage through a voltage regulator then connected to the kwh meter, and the kwh meter output is connected to the MCB (Miniature Circuit Breaker). Then from the MCB it is connected in series with an ampere meter (I), then paralleled with voltage, cos φ, watt meter, and load.

RESULTS AND DISCUSSION

Results

After conducting tests using an unloaded induction motor load, energy-saving lamps and a combination of energy-saving lamps and incandescent lamps with a normal source voltage of 220 volts, the following test data were obtained.

Table 3. Measurement results at 220 volts

NO	Beban	Arus (A)	Tegangan (V)	Cos φ	Daya (Watt)	Kwh Prabayar Detik/putaran	Kwh Pascabayar Detik/putaran
1	Motor induksi	1.6	220	0.4 lag	198	11.22 detik	13.45 detik
2	LHE	0.25	220	0.98 lead	56	38.41 detik	41.43 detik
3	LHE dan Pijar	0.5	220	0.98lead	132	16.79 detik	20.13 detik

Here is the calculation using manual:

$$tp = \frac{n.k}{3600}$$

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Where:

tp = Total time for 1 (one) cycle kwh
N= Number of one constant rotation in seconds
t = total time in hours 3600
K = constant meter rotation /kwh. for Prepaid kwh meter 1600 input /kwh and for Postpaid kwh meter 1250 input /kwh

To find the time difference value, the following formula is obtained:

$$ts = t_{max} - t_{min}$$

Where:

t_s = Total time difference
t_{max} = The largest time value
t_{min} = Smallest time value sum

The following is to calculate the amount of time required for 1 (one) Kwh Meter rotation using a 220 Volt source voltage on the load:

a. Measuring based on induction motor load
   Prepaid kWh meter
   11.22 seconds x 1600 = 17.952 seconds
   =299.8 minutes =4.98 hours
   Postpaid kWh meter
   13.45 seconds x 1250 = 16.812 seconds
   =280.2 minutes =4.67 hours
   t maximum – t minimum = 299.8 – 280.2 = 19.6 minutes or 0.32 hours, hours, after doing the calculation, the total difference in rotation time of the Postpaid kWh meter and the Prepaid kWh meter is 19 minutes or 0.32 hours.
b. Measuring based on energy saving lamp (ELP) load
   Prepaid kWh meter
   38.41 Seconds X 1600 = 61.456 seconds
   =1024.2 minutes =17.07 hours
   Postpaid kWh meter
   41.43 seconds x 1250 = 51.787 seconds = 863.125 minutes = 14.38 hours
   t maximum – t minimum = 1024.2 – 863.125 = 161 minutes or 2.68 hours, after doing the calculation, the total difference in rotation time of the Postpaid kWh meter and the Prepaid kWh meter is 161 minutes or 2.68 hours
c. Measuring based on the load of energy-saving lamps (ELS) and incandescent lamps with a source voltage of 220 volts
   Prepaid kWh meter 16.79 seconds x 1600 = 26.864 seconds = 447.7 minutes = 7.46 hours
   Postpaid kWh meter 20.13 seconds x 1250 = 25.162 seconds = 419.3 minutes = 6.98 hours
   tmaximum – tminimum = 447.7 – 419.3 = 29 minutes or 0.48 hours, after doing the calculation, the total difference in rotation time of the Postpaid kWh meter and the Prepaid kWh meter is 29 minutes or 0.478 hours.

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To calculate the current and electric power based on the analysis, it can be calculated based on the load as follows:

a. Induction motor load

$I=\frac{P}{V}$

$I = \frac{195}{220}$

$I = 0{,}9A$

and the amount of electrical power is:

$P = I.V.cos\varphi$

$P = 0.8x220x\ 0.4$

$P = 78\ watt$

b. Energy saving lamp load

$I=\frac{P}{V}$

$I = \frac{59}{220} = 0.26\ A$

the amount of electrical power is:

$P = I.V$.cos φ

$P = 0.26\ x220$x 0.98 leads

$P = 57.82\ watt$

c. Variation in load of energy saving lamps (ELS) and incandescent lamps

$I=\frac{P}{V}$

$I = \frac{139}{220} = 0{,}63\ A$

the amount of electrical power is:

$P = I.V$.cos φ

$P = 0.63\ x220x0.98\ lead$

$P = 136.2\ watt$

Using 230 volt voltage

Below are the results of testing and measuring prepaid kWh meters and postpaid kWh meters using a 230 volt source voltage on induction motor loads, energy-saving lamps (EWS), and incandescent lamps. The EWS are as follows;

Table 4. Measurement results at 230 volts

NO	Beban	Arus (A)	Tegangan (V)	Cos φ	Daya (Watt)	Kwh Prabayar Detik/putaran	Kwh Pascabayar Detik/putaran
1	Motor induksi	1.7	230	0.4 lag	232	09.22 detik	11.40 detik
2	LHE	0.25	230	0.99 lead	58	37.94 detik	40.39 detik
3	LHE dan Pijar	0.5	230	0.98lead	138	16.02 detik	19.41 detik

a. Measuring based on induction motor load

Prepaid kWh meter

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09.43 seconds x 1600 = 15.088 seconds = 251.4 minutes = 4.19 hours
Postpaid kWh meter
11.40 seconds x 1250 = 14,250 seconds = 237.5 minutes = 3.95 hours
tmaximum – tminimum = 251.4 – 237.5 = 14 minutes or = 0.23 hours, after doing the calculation, the total difference in rotation time of the Postpaid kWh meter and the Prepaid kWh meter is 14 minutes or 0.23 hours.

b. Measuring based on the load of energy-saving lamps (ELS)
Prepaid kWh meter
37.94 seconds x 1600 = 60.704 seconds = 1.011 minutes = 16.86 hours
Postpaid kWh meter
40.39 seconds x 1250 = 50.487 seconds = 841 minutes = 14.02 hours
tmaximum – tminimum = 1,011 – 841 = 170 minutes or = 2.83 hours, after doing the calculation, the total difference in rotation time of the Postpaid kWh meter and the Prepaid kWh meter is 170 minutes or = 2.83 hours

c. Measuring based on the load of Energy Saving Lamps (ELP) and Incandescent Lamps
Prepaid kWh meter
16.02 seconds x 1600 = 25.632 seconds = 427.2 minutes = 7.12 hours
Postpaid kWh meter
19.41 seconds x 1250 = 24.262 seconds = 404.3 minutes = 6.73 hours
tmaximum – tminimum = 427.2 – 404.3 = 24 minutes or = 0.4 hours, after doing the calculation, the total difference in rotation time of the Postpaid kWh meter and the Prepaid kWh meter is 24 minutes or 0.4 hours.

a. Induction motor load

$I = \frac{P}{V}$

$I = \frac{232}{230}$

$I = 1\,A$

And the amount of electrical power is:

$P = I.V.\cos\varphi$

$P = 1x230x\ 0.4lag$

$P = 92{,}8\,watt$

b. Energy saving lamp load

$I = \frac{P}{V}$

$I = \frac{59}{220}$

$I = 0{,}25\ A$

the amount of electrical power is:

$P = I.V.\cos\varphi$

$P = 0{,}25\ x230$ x 0.99 leads

$P = 58.41\,watt$

c. Variation in load of energy saving lamps (ELS) and incandescent lamps

$I = \frac{P}{V}$

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$$I = \frac{139}{230}$$
$$I = 0{,}60\ A$$

the amount of electrical power is:

$P = I.V \cos \varphi$
$P = 0{,}60\ x230$ x 0.98 leads
$P = 136{,}22\ watt$

CONCLUSION

Based on the test results on the comparison of the performance of prepaid and postpaid KWh meters at various voltage conditions and types of loads, several important findings were obtained. Prepaid KWh meters are proven to have more stable and efficient performance than postpaid KWh meters, especially at low voltages. This is shown through the difference in more consistent rotation times on prepaid KWh meters, both for induction motor loads, energy-saving lamps (ELP), and a combination of incandescent lamps and ELP. For the induction motor load, the postpaid KWh meter also recorded a faster rotation time of up to 2.03 hours compared to prepaid. Even in the combination of LHE and incandescent lamp loads, the difference in rotation time was recorded at 0.53 hours. With these results, the prepaid KWh meter is not only more accurate in measuring electrical energy consumption but also more efficient in maintaining rotation stability at various load and voltage variations. This makes it a better choice to support efficient power consumption, especially in systems that require high accuracy in energy management. This research also confirms the superiority of prepaid technology in providing more modern and measurable electricity services, so that it can help users to monitor and control electricity consumption independently.

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Akurasi Pengukuran kWh Meter Analog Terhadap Losses Energi Listrik

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ABSTRACT

Every measurement of electrical energy has a vital and very decisive role. Kilo Watt Hour (kWh) meter is an equipment used to measure a value or price of electricity usage (watt hour) in the period of time used. The problem of losses that occur in the kWh Meter is one of the problems. The problem faced is how to make readings and measurements of the use of electricity measured properly. In this study, the objectives to be achieved are to find out when the kWh meter deviation calculation shows results of no more than the permissible kWh deviation tolerance, namely -2% and +2% results and to correct electrical energy losses, ranging from technical and non-technical kWh meter errors. technical. Based on the results of research conducted using manual calculations and using special software. With the software makes it easier for studies to be carried out. In this case, it is the non-technical determination of kWh that usually accounts for the biggest losses, because this is not 100% pure damage from the kWh Meter, but there are PLN Consumers who are not responsible for the losses given. From the results of technical testing of the 3 kWh Meter which obtained data and specifications up to the deviation of the kWh Meter and from the results of studies conducted on non-technical testing, it turns out that this is what contributes to losses on a large scale.

Keywords*: kWh meter, Losses, Measurement, Accuracy*

ABSTRAK

Setiap pengukuran energi listrik memiliki peran yang vital dan sangat menentukan. Kilo Watt Hour (kWh) meter merupakan peralatan yang digunakan untuk dapat mengukur suatu nilai atau harga dari penggunaan listrik (watt jam) dalam kurun waktu yang digunakan. Permasalahan losses yang terjadi pada kWh Meter menjadi salah satu masalah. Permasalahan yang dihadapi bagaimana cara agar pembacaan dan pengukuran dari penggunaan lisrtrik terukur dengan baik. Pada studi ini tujuan yang ingin dicapai adalah mengetahui saat perhitungan deviasi kWh meter menunjukkan hasil tidak lebih dari toleransi deviasi kWh yang diperbolehkan yaitu hasil -2% dan +2% dan untuk memperbaiki losses energi listrik, mulai dari kesalahan kWh Meter secara teknis maupun non-teknis. Berdasarkan hasil penelitian yang dilakukan menggunakan perhitungan secara manual dan menggunakan software khusus. Dengan adanya software tersebut mempermudah studi yang dilakukan. Dalam hal ini, penentuan kWh secara non-teknis lah yang biasanya menyumbang rugi-rugi paling besar, dikarenakan ini bukan 100% murni kerusakan dari kWh Meter, melainkan ada Konsumen PLN yang tidak bertanggung jawab atas losses yang diberikan. Dari hasil pengujian secara Teknis terhadap 3 kWh Meter yang dimana didapatkan data dan spesifikasi hingga deviasi kWh Meter dan dari hasil studi yang lakukan terhadap pengujian secara Non Teknis, tenyata hal inilah yang menyumbang losses dalam skala yang besar.

Kata kunci: *kWh meter, Losses, Pengukuran, Akurasi*

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1. PENDAHULUAN

kWh meter sendiri adalah suatu alat ukur yang melakukan transaksi energi, dalam hal ini harus disetujui oleh pelanggan dan juga perusahaan yang bersangkutan dan tentunya harus mendapat verifikasi dari pemerintahan tersebut. Dalam kesalahan pengukuran pada saat transaksi energi, hal ini dapat menyebabkan pelanggan melakukan complain terhadap perusahaan listrik yang menyediakan jasanya tersebut. Pada hakikatnya, jumlah energi listrik yang telah digunakan oleh pelanggan akan terukur dan tercatat secara langsung melalui stand meter yang ada pada alat ukur kWh meter pelanggan masing-masing. Apabila pelanggan merasa tagihan listrik yang tiba-tiba menjadi murah sedangkan pelanggan memakai energi listrik dengan selayaknya dari penggunaan bulan-bulan sebelumnya, tetapi pelanggan tidak melaporkan hal ini ke pihak perusahaan listrik tersebut, maka hal ini pelanggan dapat terkena pelanggaran yang sanksinya berupa Tagihan Susulan (TS) yang dihitung dari penggunaan energi listrik rata-rata pada bulan-bulan sebelumnya.

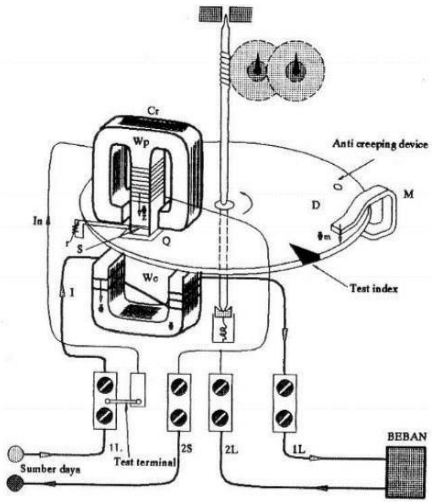
Apabila pada kWh meter terjadi kerusakan pada komponen ataupun pelanggan yang melakukan pencurian listrik yang mengakibatkan suatu pengukuran pada kWh meter menjadi tidak normal, maka dengan hal ini dapat dikenakan sanksi P1, P2 dan P3. Untuk kasus pencurian listrik seperti melakukan penggantian MCB yang tidak sesuai dengan daya kontrak PLN (P1), memasang kawat/lempengan tembaga pada Terminal 1 dan 3 yang diparalel (P2), dan selanjutnya pelanggaran yang lebih parah lagi yaitu dengan cara pelanggan melakukan pencurian langsung melalui sumber kemudian menyuntikkan langsung kabel SR sehingga pada kWh meter tidak mengukur (P3). Kemudian kasus berikutnya apabila terjadi kejanggalan seperti tagihan listrik tiba-tiba menjadi murah yang berkemungkinan besar terjadi kerusakan pada komponen-komponen kWh meter namun pelanggan tidak memberi tahu permasalahan ini ke pihak PLN, dalam hal ini pelanggan dapat terkena sanksi K1/K2 yaitu suatu pelanggaran yang disebabkan oleh kelainan yang terjadi pada komponen kWh meter, maka dari hal tersebut PLN memberikan Tagihan Susulan (TS) pada pelanggan yang terkenal pelanggaran tersebut. Tagihan Susulan (TS) ini dihitung berdasarkan sesuai dengan penggunaan energi listrik rata-rata pada beberapa bulan sebelumnya.

2. METODE PENELITIAN

Pada hakikatnya, suatu usaha untuk melakukan proses mengukur yang menyatakan sifat dari suatu alat/komponen yang dituangkan dalam bentuk nilai baik itu angka maupun harga, itulah yang dinamakan pengukuran. Landasan kita dapat memberikan suatu angka atau harga pada saat melakukan pengukuran dengan cara alat yang akan dilakukan pengukuran dengan membandingkan alat yang sudah dinyatakan akurat dikarenakan standarisasinya diperbandingkan dengan alat yang akan kita ukur nantinya.Kilo Watt Hour (kWh) meter adalah alat yang digunakan untuk dapat mengukur suatu nilai atau harga dari penggunaan listrik (watt jam) dalam kurun waktu yang digunakan. Jadi pada kWh meter ini sudah terpasang 1 buah disc (piringan) serta alat hitung yang biasa disebut penghitungan mekanis. Pada alat ukur ini tersusun oleh kumparan voltase yang terhubung secara parallel dengan bebannya dan pada kumparan arusnya yang terhubung secara seri dengan beban juga.

Total dari energi listrik yang dihasilkan oleh kWh meter diubah dalam bentuk energi mekanis, hal ini terjadi karena berguna untuk memutar piringan kWh meter dan juga counter stand meter pada kWh meter, hal ini dapat terjadi karena jumlah energi listrik yang kita gunakan dengan perputaran piringan dan juga counter pada stand meter sesuai atau masih berlaku secara normal.

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Gambar 1. Kontruksi kWh Meter Sumber: (*Journal of Electric Technology*)

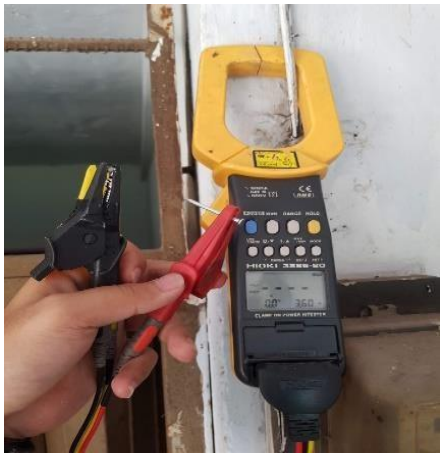
Metode yang digunakan untuk melakukan pengujian kWh Meter ini dengan menggunakan metode pengukuran secara Teknis dan Non Teknis, kemudian alat yang digunakan sebagai penunjang studi ini ada 2, yaitu:

- Tang Ampere (*Clamp Ampere*)



Gambar 2. Tang Ampere (*Clamp Ampere)*

- Tang kW



Gambar 3. Tang kW

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Teknik pengambilan sample dengan menggunakan 3 tipe kWh Meter, yaitu ada kWh Meter **Melcoinda**, **Fuji Dharma Electric** dan **Sigma Electric**. Variable yang diukur nantinya meliputi Daya yang terukur melewati kWh Meter, Daya aktif yang diukur melalui tang kW dan Kesalahan kWh Meter (*Error %),* dimana persamaan sebagai berikut:

- Daya yang Terukur Melewati kWh Meter

$$P1 = \frac{3600 \times n}{t \times c} \quad (1)$$

Keterangan:
a) P1 = Daya yang Dihitung dari Hasil Uji (kWh Meter) Putaran Dengan Menggunakan Stopwatch/Sensor Waktu
b) 3600 = Detik/Jam
c) N = Banyak Putaran
d) t = Waktu (Detik)
e) c = Konstanta kWh Meter

- Daya Aktif yang Diukur Melalui Tang kW

$$P2 = V \times I \times \cos \varphi \quad (2)$$

Keterangan:
a) P2 = Daya yang Didapatkan dari Hasil Uji (kWh Meter) Pada Tang kW
b) V = Tegangan (Volt)
c) I = Arus pada Beban (Ampere)
d) Cos φ = Faktor Daya

- Kesalahan kWh Meter (*Error %)*

$$\text{Error \%} = \frac{P1-P2}{P2} \times 100\% \quad (3)$$

Tabel 1. Spesifikasi dan Nameplate kWh Meter Melcoinda

Spesifikasi dan Nameplate kWh Meter Melcoinda	
Tipe kWh Meter	MF-97E
Pengawatan	Fasa Tunggal 2 Kawat
Tegangan	230 Volt
Frekuensi	50 Hz
Konstanta	900 Putaran/kWh
Kelas kWh Meter	Kelas 2
Batas Pengukuran kWh Meter	5(20) A
Tahun kWh Meter	2008

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Tabel 2. Spesifikasi dan Nameplate kWh Meter Fuji Dharma Electric

Spesifikasi dan Nameplate kWh Meter Fuji Dharma Electric	
Tipe kWh Meter	FA14AI1Z
Pengawatan	Fasa Tunggal 2 Kawat
Tegangan	230 Volt
Frekuensi	50 Hz
Konstanta	900 Putaran/kWh
Kelas kWh Meter	Kelas 2
Batas Pengukuran kWh Meter	5(20) A
Tahun kWh Meter	2012

Tabel 3. Spesifikasi dan Nameplate kWh Meter Sigma Electric

Spesifikasi dan Nameplate kWh Meter Sigma Electric	
Tipe kWh Meter	SE 88 A3
Pengawatan	Fasa Tunggal 2 Kawat
Tegangan	230 Volt
Frekuensi	50 Hz
Konstanta	900 Putaran/kWh
Kelas kWh Meter	Kelas 2
Batas Pengukuran kWh Meter	5(20) A
Tahun kWh Meter	1996

3. HASIL DAN PEMBAHASAN

a) Pengujian Teknis

- Daya yang Terukur Melewati kWh Meter Melcoinda

$$P1 \frac{3600 \times n}{t \times c}$$

$$P1 = \frac{3600 \times 3}{6{,}39 \times 900}$$

$$P1 = 1{,}88 \text{ kW}$$

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- Daya Aktif yang Diukur Melalui Tang
  kW P2 = V x I x Cos φ
  P2 = 220 x 10 x 0,85
  P2 = 1,87 kW

- Kesalahan kWh Meter Melcoinda (*Error %*)

$$Error\,(\%) = \frac{P1-P2}{P2} X\ 100\%$$

$$Error\,(\%) = \frac{1,88-1,87}{1.87} X\ 100\%$$

$$Error\,(\%) = \frac{0,01}{1,87} X\ 100\%$$

$$Error\,(\%) = 0,42\%$$

Pada hasil pengujian seperti ini, kecepatan putar pada piringan aluminium sebanding dengan daya listrik yang dikonsumsi (Kecepatan Piringan Putar = Daya Listrik yang Dikonsumsi).

- Daya yang Terukur Melewati kWh Meter Fuji Dharma Electric

$$P1 = \frac{3600 \times n}{t \times c}$$

$$P1 = \frac{3600 \times 3}{6,07 \times 900}$$

$$P1 = 1,97\ kW$$

- Daya Aktif yang Diukur Melalui Tang
  kW P2 = V x I x Cos φ
  P2 = 220 x 10 x 0,85
  P2 = 1,87 kW

- Kesalahan kWh Meter Fuji Dharma Electric (*Error %*)

$$Error\,(\%) = \frac{P1-P2}{P2} x\ 100\%$$

$$Error\,(\%) = \frac{1,976-1,87}{1.87} x\ 100\%$$

$$Error\,(\%) = \frac{0,10}{1,87} x\ 100\%$$

$$Error\,(\%) = 5,71\%$$

Pada hasil pengujian seperti ini, kWh Meter mengalami abnormal dimana pada kecepatan putar pada piringan aluminium tidak sebanding dengan daya listrik yang dikonsumsi (Kecepatan Putar Piringan > Daya Listrik yang Dikonsumsi).

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- Daya yang Terukur Melewati kWh Meter Sigma Electric

$$P1 = \frac{3600 \times n}{t \times c}$$

$$P1 = \frac{3600 \times 3}{7{,}92 \times 900}$$

$$P1 = 1{,}51 \text{ kW}$$

- Daya Aktif yang Diukur Melalui Tang

kW P2 = V x I x Cos φ
P2 = 220 x 10 x 0,85
P2 = 1,87 kW

- Kesalahan kWh Meter Sigma Electric (*Error %*)

$$\textit{Error}\,(\%) = \frac{P1-P2}{P2} \times 100\%$$

$$\textit{Error}\,(\%) = \frac{1{,}51-1{,}87}{1.87} \times 100\%$$

$$\textit{Error}\,(\%) = \frac{-0{,}354}{1{,}87} \times 100\%$$

$$\textit{Error}\,(\%) = -18{,}97\%$$

Pada hasil pengujian seperti ini, kWh Meter mengalami abnormal dimana pada kecepatan putar pada piringan aluminium tidak sebanding dengan daya listrik yang dikonsumsi (Kecepatan Putar Piringan < Daya Listrik yang Dikonsumsi).

(b) Pengujian Non Teknis

- Penentuan kWh Meter Non Teknis Golongan I (P1)
  Pelanggaran Golongan I (P1) adalah pelanggaran yang dapat mempengaruhi pembatas daya tetapi tidak mempengaruhi daripada pengukuran energi.
- Penentuan kWh Meter Non Teknis Golongan II (P2)
  Pelanggaran Golongan II (P2) adalah pelanggaran yang dapat mempengaruhi daripada pengukuran energi listrik, tetapi tidak dapat mempengaruhi pembatas daya nya. Pada kasus tersebut, hal ini tentu dapat menyebabkan *losses* yang dapat terbilang cukup besar, karena menurut studi penulis, dengan adanya kejadian seperti kasus diatas hal ini dapat menyebabkan deviasi kWh Meter minus (-), dikisaran -35% sampai dengan -70% (Besarnya Minus (-) dapat dipengaruhi oleh semakin besarnya luas penampang pada lempengan tembaga yang digunakan).
- Penentuan kWh Meter Non Teknis Golongan III (P3)
  Pelanggaran Golongan III (P3) adalah pelanggaran yang dapat mempengaruhi pembatas daya dan juga dapat mempengaruhi daripada pengukuran energi listrik.
- Kabel Sambung Langsung
  Kabel Sambung Langsung, hal ini tentu dapat menyebabkan *losses* yang dapat terbilang pelanggaran yang sangat besar, dikarenakan dengan adanya

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kejadian seperti kasus diatas hal ini dapat menyebabkan deviasi kWh Meter minus (-) -100 %, dikarenakan komponen yang di *connect* kan tidak akan terukur oleh kWh Meter, sehingga hal ini dapat menyebabkan *losses* yang sangat besar sekali dan tentunya dapat merugikan perusahaan.

Dari hasil pengujian secara Teknis terhadap 3 kWh Meter yang dimana didapatkan data dan spesifikasi hingga deviasi kWh Meter, yaitu pada kWh Meter tipe Melcoinda didapatkan deviasi kWh Meter sebesar 1,216282325950168 %, hal ini terbilang cukup baik dari segi pengukuran dikarenakan sudah sesuai dengan aturan yang telah ditetapkan oleh SPLN. Berikutnya ada kWh Meter merk Fuji Dharma Electric didapatkan deviasi kWh Meter sebesar 5,718489282788149 %, hal ini bisa dibilang baik bagi perushaan, karena menguntungkan PLN sekitar 3,718489282788149 % dari pembayaran yang dilakuakan oleh konsumen PLN dan begitu juga sebaliknya hal ini merugikan Konsumen PLN tetapi hanya dalam skala yang kecil.

Berikutnya ada kWh Meter merk Sigma Electric dimana pada kWh meter ini didapatkan deviasi kWh Meter sebesar -18,97585480473181 %, hal ini tentu sangat merugikan PLN, dikarenakan PLN losses sebesar -16,97585480473181 % pada pemakaian kWh Meter merk Sigma Electric, dan ini tentu sangat jauh sekali dari aturan yang telah ditetapkan oleh SPLN. Berikutnya dari hasil studi yang dilakukan terhadap pengujian secara Non Teknis, tenyata hal inilah yang menyumbang *losses* dalam skala yang besar, dikarenakan pada kasus ini dapat menyumbang *losses* pada deviasi kWh minus sekitar -35% sampai -70%, hingga kasus yang paling parah ialah dapat menyumbang *losses* pada deviasi kWh sebesar -100%.

4. KESIMPULAN DAN SARAN

4.1. Kesimpulan

Dari hasil pengujian secara Teknis terhadap 3 kWh Meter yang dimana didapatkan data dan spesifikasi hingga deviasi kWh Meter, bahwasannya kWh Meter bertipe ke 3 tesebut didapatkan deviasi kWh sebesar: Melcoinda = 1,216282325950168 % (Layak), dikarenakan pada kondisi seperti ini, kecepatan putar pada piringan aluminium sebanding dengan daya listrik yang dikonsumsi (Kecepatan Piringan Putar = Daya Listrik yang Dikonsumsi). Fuji Dharma Electric = 5,718489282788149 % (Merugikan Konsumen), dikarenakan pada kondisi seperti ini, kWh Meter mengalami abnormal dimana pada kecepatan putar pada piringan aluminium tidak sebanding dengan daya listrik yang dikonsumsi (Kecepatan Putar Piringan > Daya Listrik yang Dikonsumsi). Sigma Electric = -18,97585480473181 % (Merugikan Perusahaan), dikarenakan pada kondisi seperti ini, kWh Meter mengalami abnormal dimana pada kecepatan putar pada piringan aluminium tidak sebanding dengan daya listrik yang dikonsumsi (Kecepatan Putar Piringan < Daya Listrik yang Dikonsumsi).

4.2. Saran

Dari hasil pengujian secara Teknis yang telah dilakukan, sebaiknya kWh Meter yang memiliki pengukuran deviasi kWh Meter yang buruk, harap dapat diperbarui dengan kWh Meter yang lebih baik, contoh seperti kWh Meter Melcoinda, sehingga pada hal ini dapat menekan *losses* menjadi lebih kecil/rendah lagi.

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ANALISIS AKURASI KWH METER ANALOG PASCA BAYAR DAN KWH METER DIGITAL PRABAYAR

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Abstract

The accuracy level of the kWh meter to be measured in this study is to measure the load usage on analog kWh meters (postpaid) and digital kWh meters (prepaid) and seen from the percentage of error readings on the two kWh meters. Based on the measurement data, calculations and analyzes that have been carried out, it can be concluded that the level of accuracy on analog and digital kWh meters when viewed from the use of the load, the average results obtained in the calculations and measurements of the two kWh meters are found to be accurate. Digital meters are more accurate than analog kWh meters where the energy consumption of digital kWh meters is lower, namely 0.873705 kWh, while analog kWh meters are 0.9494377 kWh. And if it is seen from the average percentage of reading errors, digital kWh meters are lower, namely 0.299%, while for analog kWh meters it is 0.30%.

Keywords: *accuracy, analog kWh meter, digital kWh meter*

PENDAHULUAN

Kwh meter bekerja menggunakan metode induksi medan magnet, menggerakkan piringan yang terbuat dari aluminium, kumparan tegangan dapat berputar dengan bebas, sehingga tenaga listrik dapat diukur, baik dalam satuan WH/KWH. KWh meter analog (pascabayar) merupakan KWH yang menggunakan metode induksi dengan prinsip kerja *electromechanical*, memanfaatkan prinsip elektrik dan mekanik di dalamnya. Komponen KWH meter analog terdiri dari: terminal input, kumparan arus (*coil current),* kumparan tegangan *(coil voltase*), piringan (*disc), braking magnet* dan *register.* KWH meter digital (prabayar) tidak menggunakan prinsip kerja induksi kumparan untuk mengukur arus dan tegangan melainkan telah memanfaatkan sensor untuk pengukurannya. Prinsip kerja KWH meter digital (prabayar) melalui *voucher* khusus yang berisi besaran digital yang berfungsi sebagai pulsa sebagai pembanding besaran energi yang digunakan. Sistem secara otomatis akan memutuskan tegangan rumah apabila besaran tersebut mencapai nol. Perbedaan penggunaan KWH meter analog dan digital terletak pada tingkat akurasi yaitu pengukuran aktual dan tepat mendekati standar terhadap pemakaian beban. Sehingga perlu menentukan perbandingan tingkat akurasi KWH meter analog (pascabayar) dan KWH meter digital

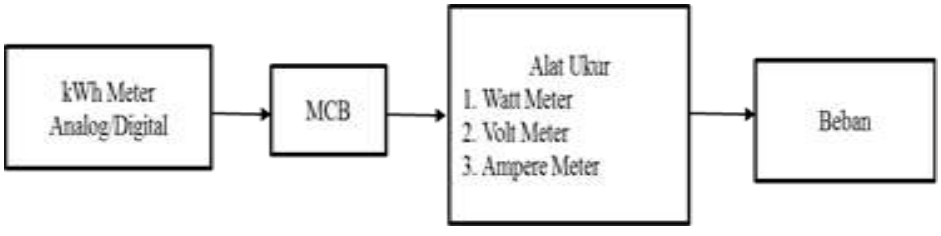
(prabayar) ditinjau dari pemakaian beban. Terkait hal tersebut tujuan penelitian ini menganalisa perbandingan tingkat akurasi dari KWH meter analog (pascabayar) dan KWH meter digital (prabayar) dengan pemakaian beban reaktif dan induktif. Muhammad Ridho Rohman Zuhri (2017), rata-rata persentase kesalahan pembacaan terbesar untuk beban resistif (cos Φ= 1) sebesar 11.49% yang terdapat pada KWH meter digital. Mengetahui tingkat ketelitian KWH meter analog maupun digital dengan cara diberi beban motor induksi 1 fasa sebagai beban induktif faktor daya < 1 antara 0,8-0,1 nilai positif menghasilkan KWH meter analog sebesar 27,9% dan KWH meter digital dengan rata-rata kesalahan baca 27,5%. oleh (Muhammad Panji, 2018).

METODE PENELITIAN

Metode yang digunakan dalam kegiatan penelitian ini adalah riset dan pengembangan yaitu suatu metode yang dipakai untuk mengembangkan model, alat atau aplikasi tertentu berdasarkan proses penelitian. Teknik pengambilan data berupa observasi dan studi literatur. Sedangkan data penelitian berupa data primer dan sekunder.

HASIL DAN PEMBAHASAN

Rancangan sistem analisis akurasi KWH meter analog dan KWH meter digital ditunjukkan pada gambar 1.

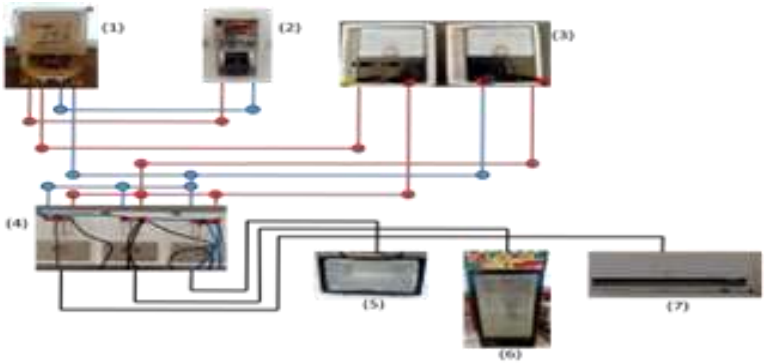


Gambar 1. Blok diagram rancangan sistem

Pada gambar 1, merupakan blok diagram rancangan, yaitu *output* KWH meter (analog/digital) masuk ke *input* MCB, kemudian keluaran dari MCB dihubungkan ke alat ukut (*Watt* Meter, *Volt* Meter dan *Ampere* Meter, dari alat ukur akan di *couple* ke beban. Beban yang digunakan yaitu beban induktif dan resistif berupa freezer, AC dan lampu sorot, sebagai beban pada KWH meter analog dan KWH meter digital.

Perancangan sistem KWH meter analog (pascabayar)

Gambar 2, menunjukan rancangan dari sistem KWH meter analog untuk perhitungan pemakaian beban pascabayar.



Gambar 2. Rancangan KWH analog
Sumber : Penulis, 2020

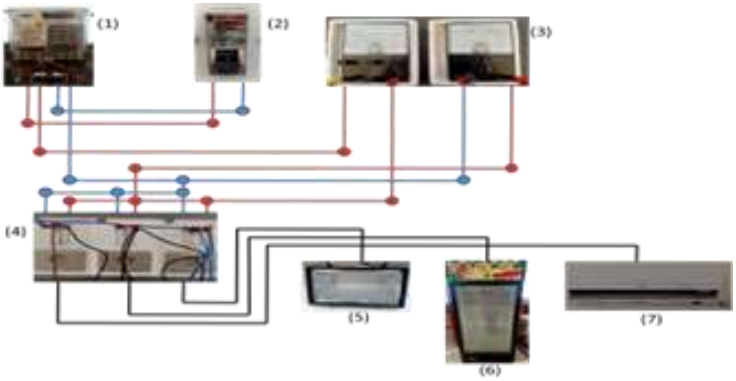
Keterangan gambar :

1 = kWh meter Analog
2 = MCB
3 = Volt meter dan Amper meter
4 = Stop kontak
5 = Lampu sorot
6 = Freezer
7 = AC

= Kabel penghubung fasa
= Kabel penghubung netral
= Kabel keluaran ke beban

Perancangan sistem KWH meter digital (prabayar)

Rancangan dari sistem KWH meter digital untuk perhitungan pemakaian beban prabayar, pada gambar 3.



Gambar 3. Rancangan KWH digital
Sumber : Penulis, 2020

Keterangan gambar :
1 = kWh meter Digital
2 = MCB
3 = Volt meter dan Amper meter
4 = Stop kontak
5 = Lampu sorot
6 = Freezer
7 = AC
= Kabel penghubung fasa
= Kabel penghubung netral
= Kabel keluaran ke beban

Hasil pengukuran KWH meter analog (pascabayar)

Hasil pengukuran diperoleh dari pengambilan data KWH meter analog (pascabayar) dan KWH meter digital (prabayar). Pengambilan data dilakukan dengan mengambil data arus, tegangan, dan waktu yang diperoleh menggunakan stopwatch untuk menghasilkan setiap 1 KWH.

Tabel. 1
Data tegangan, arus dan waktu pengukuran KWH analog

Percobaan Ke-	Tegangan (V)	Arus (A)	Waktu(Jam)
1	218.6	9.8	0.49
2	218.6	9.6	0.5
3	219	9.6	0.5
4	219.2	9.7	0.48
5	219.5	9.6	0.47
6	219.5	9.7	0.5
7	219.5	9.6	0.5
8	219.5	9.7	0.5
9	219.5	9.6	0.5
10	219.5	9.5	0.49
Rata-rata	219.24	9.64	0.493

Tabel. 2
Data tegangan, arus dan waktu pengukuran KWH digital

Percobaan Ke-	Tegangan (V)	Arus (A)	Waktu(Jam)
1	218.4	10.5	0.47
2	218.3	9.5	0.47
3	218.3	9.4	0.47
4	218.8	9.6	0.48
5	218.6	9.3	0.47
6	218.5	9.5	0.48
7	218.5	9.4	0.48
8	218.7	9.3	0.48
9	218.7	9.5	0.47
10	218.5	9.5	0.48
Rata-rata	218.53	9.55	0.475

Hasil Perhitungan KWH meter analog (pascabayar)

Pada perhitungan Cos φ menggunakan daya yang diperoleh dari beban yaitu 2000W diperoleh dari pemakaian AC Split (LG) 800W, freezer (Modena) 200W dan lampu sorot (halogen) 1000W, serta data percobaan ke-1 dengan hasil pengukuran tegangan 218,6V dan arus 9,8A.

Perhitungan :

$$Cos\ \varphi = \frac{2000W}{218{,}6V\ x\ 9{,}8A}$$

$$= \frac{2000W}{2.142{,}28VA} = 0{,}9$$

$$P = 218{,}6\,Vx\ 9{,}8A\ x\ 0{,}9 = 1.928{,}05\text{W}$$

$$kWh = \frac{1.928{,}05W\ x\ 0{,}49}{1000} = 0{,}9447445$$

Hasilnya ditunjukkan pada tabel 3, sebagai berikut:

Tabel. 3
Hasil perhitungan KWH meter analog

Percobaan Ke-	Tegangan (V)	Arus (A)	Cos φ	Waktu (Jam)	Daya (P)	Energi yang digunakan (KWH)
1	218.6	9.8	0.9	0.49	1.928,05	0.9447445
2	218.6	9.6	0.9	0.5	1.888,70	0.9443520
3	219	9.6	0.9	0.5	1.892,16	0.9460800
4	219.2	9.7	0.9	0.48	1.913,62	0.9185376
5	219.5	9.6	0.9	0.47	1.896,48	0.8913456
6	219.5	9.7	0.9	0.5	1.916,24	0.9581200
7	219.5	9.6	0.9	0.5	1.896,48	0.9482400
8	219.5	9.7	0.9	0.5	1.916,24	0.9851200
9	219.5	9.6	0.9	0.5	1.896,48	0.9482400
10	219.5	9.5	0.9	0.49	1.876,73	0.9195977
Rata-rata	219.24	9.64	0.9	0.493	1.902,11	0.9404377

Tabel 3, menjelaskan energi yang digunakan KWH meter analog dengan pemakaian beban resistif dan induktif dengan waktu yang berbeda ditunjukkan pada stopwatch dan menghasilkan daya yang berbeda. Hal ini dipengaruhi oleh tegangan dari sumber PLN yang berubah-ubah (tidak konstan). Hal ini juga mempengaruhi nilai arus berbeda sehingga menyebabkan perbedaan pada nilai energi (KWH) yang dikonsumsi.

Hasil Perhitungan KWH meter digital (prabayar)

Pada perhitungan Cos φ menggunakan daya yang diperoleh dari beban yaitu 2000W diperoleh dari pemakaian AC Split (LG) 800W, freezer (Modena) 200W dan lampu sorot (halogen) 1000W, serta data percobaan ke-1 dengan hasil pengukuran tegangan 218,4V dan arus 10,5A.

Perhitungan :

$$Cos\ \varphi = \frac{2000W}{218{,}4V\ x\ 10{,}5A}$$

$$= \frac{2000W}{2.294{,}25VA} = 0{,}8$$

$$P = 218{,}5V\ x\ 10{,}5A\ x\ 0{,}8 = 1.834{,}56W$$

$$kWh = \frac{1.834{,}56W\ x\ 0{,}47}{1000} = 0{,}8622432$$

Hasilnya ditunjukkan pada tabel 4, sebagai berikut:

Tabel. 4
Hasil perhitungan KWH meter digital

Percobaan Ke-	Tegangan (V)	Arus (A)	Cos φ	Waktu (Jam)	Daya (P)	Energi yang digunakan (KWH)
1	218.4	10.5	0.8	0.47	1.834,56	0.8622432
2	218.3	9.5	0.9	0.47	1.866,47	0.8772409
3	218.3	9.4	0.9	0.47	1.846,82	0.8680054
4	218.8	9.6	0.9	0.48	1.890,43	0.8885021
5	218.6	9.3	0.9	0.47	1.829,68	0.8599496
6	218.5	9.5	0.9	0.48	1.868,18	0.8780446
7	218.5	9.4	0.9	0.48	1.848,51	0.8687997
8	218.7	9.3	0.9	0.48	1.830,52	0.8603444
9	218.7	9.5	0.9	0.47	1.869,89	0.8788483
10	218.5	9.5	0.9	0.48	1.868,18	0.8967264
Rata-rata	218.5	9.55	0.89	0.475	1.855,32	0.8737050

Tabel 4, merupakan tabel energi yang digunakan KWH meter digital dengan pemakaian beban resistif dan induktif (pemakaian beban yang sama dengan KWH meter analog)

dengan waktu yang berbeda ditunjukkan pada stopwatch dan menghasilkan daya yang berbeda juga. Hal ini dipengaruhi oleh tegangan dari sumber PLN yang berubah-ubah (tidak konstan). Hal ini mempengaruhi nilai arus berbeda sehingga menyebabkan perbedaan pada nilai energi (KWH) yang dikonsumsi.

SIMPULAN

Berdasarkan data hasil penelitian, menghasilkan beberapa hal sebagai berikut :

1. Tingkat akurasi pada KWH meter analog dan digital jika dilihat dari pemakaian bebannya maka energi yang digunakan pada KWH meter analog dari 10 kali percobaan nilai konsumsi energi terendah didapatkan pada percobaan ke-5 yaitu 0,8913456 KWH dan nilai konsumsi energi tertinggi didapatkan pada percobaan ke-8 yaitu 0,98512 KWH. Sedangkan energi yang digunakan pada KWH meter digital dari 10 kali percobaan nilai konsumsi energi terendah didapatkan pada percobaan ke-5 yaitu 0,8599496 KWH dan nilai konsumsi energi tertinggi didapatkan pada percobaan ke-4 yaitu 0,8885021 KWH.
2. Rata-rata kesalahan pembacaan terbesar terdapat pada KWH meter analog dengan kesalahan rata-rata 0,58%. Untuk rata-rata kesalahan pada KWH meter digital yaitu 0,299%
3. Hasil rata-rata yang didapatkan dalam perhitungan dan pengukuran kedua KWH meter didapati hasil akurasi bahwa KWH meter digital lebih akurat dibandingkan dari KWH meter analog dimana untuk konsumsi energi KWH meter digital lebih rendah yaitu 0,873705 KWH, sedangkan KWH meter analog yaitu 0,9494377 KWH.

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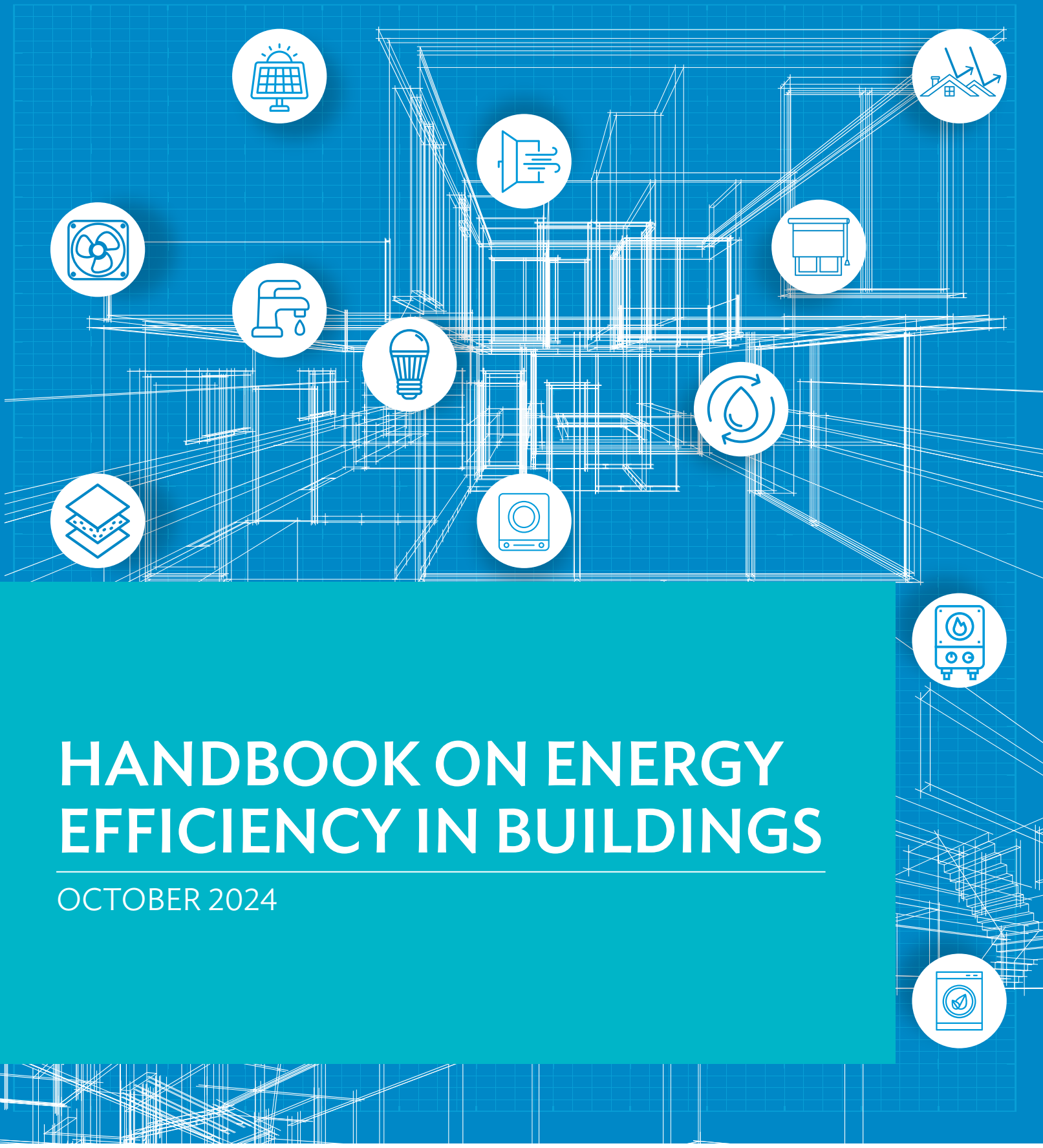
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HANDBOOK ON ENERGY EFFICIENCY IN BUILDINGS

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FOREWORD

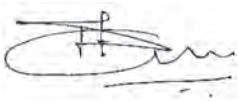
The Asian Development Bank (ADB) has committed to becoming the climate finance bank for Asia and the Pacific. We have increased our level of climate financing to $100 billion cumulatively from 2019 to 2030. Increasing our level of climate financing means that any building financed by ADB from now onward will have to be sustainable, climate-resilient, energy-efficient, and/or be a certified green building. This handbook on energy efficiency in buildings provides detailed guidance and tools for ADB staff, technical experts, and governments on best practices and solutions.

According to the International Energy Agency, the buildings and building construction sector alone is responsible directly and indirectly for around one-third of global energy- and process-related carbon dioxide emissions. This includes emissions from the manufacture of cement, steel, and aluminum for building construction. With increasing urbanization and demand for cooling, the amount of energy used by buildings and cities is expected to increase considerably in Asia and the Pacific, where most housing is yet to be built. To meet the goals of the Paris Agreement, buildings across the globe will need to reduce energy consumption by 30%–50% per square meter. This represents a tremendous effort.

In December 2023, governments agreed at the Conference of the Parties of the UNFCCC to double the global average annual rate of energy efficiency improvements by 2030. Following this pledge, ADB has established a OneADB Taskforce on Energy Efficiency in Buildings as well as a Special Initiative on Accelerating Energy Efficiency. The aim is to embed energy efficiency in all projects across all sectors, particularly buildings.

ADB is supporting its developing members in several areas of energy efficiency, including clean and efficient cooling solutions, supply and demand-side energy efficiency, energy efficiency policies and regulations across all sectors including building energy codes, innovative financing instruments, and mobilization of private sector resources. In 2021, ADB launched its new energy policy, which has energy efficiency at its core. We believe that accelerating progress on energy efficiency gains across the region can contribute to the agendas of energy security and energy access while also delivering cost savings and environmental benefits.

We look forward to working closely with both the public and private sectors to implement the necessary policies and technologies highlighted in the handbook to accelerate investment in low-carbon, climate-resilient, efficient, and affordable buildings across Asia and the Pacific.



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ABBREVIATIONS

ABS	asset-backed security
ADB	Asian Development Bank
ASEAN	Association of Southeast Asian Nations
BEA	Berlin Energy Agency
BEE	building energy efficiency
BOT	build-own-operate
BSEEP	Building Sector Energy Efficiency Project
DMC	developing member country
EBRD	European Bank for Reconstruction and Development
EERF	Energy Efficiency Revolving Fund (Thailand)
EPC	energy performance contract
ESA	energy service agreement
ESCO	energy service company
ESP	Energy Savings Partnership
ETS	emission trading systems
EU	European Union
GDP	gross domestic product
HVAC	heating, ventilation, and air-conditioning
IDB	Inter-American Development Bank
IEA	International Energy Agency
IFC	International Finance Corporation
KeTTHA	Ministry for Energy, Green Technology and Water (Malaysia)
LABEEF	Latvian Baltic Energy Efficiency Facility
MDV	Malaysian Debt Ventures
MEPS	minimum energy performance standards

Mtoe	million tons of oil equivalent
NDC	nationally determined contribution
PACE	Property Assessed Clean Energy
PCG	partial credit guarantees
PPA	power purchase agreement
SMEs	small and medium-sized enterprises
SPV	special purpose vehicle
SUNShINE	Save your bUildiNg by SavINg Energy
TA	technical assistance
VAT	value-added tax

EXECUTIVE SUMMARY

The Asian Development Bank (ADB) recognizes the importance of supporting its developing member countries (DMCs) in scaling up energy efficiency investments in buildings. ADB has been providing financial and technical assistance to its DMCs to promote energy efficiency in buildings through various modalities, such as policy-based lending, project loans, results-based lending, guarantees, grants, and knowledge products.

This handbook provides practical guidance and tools for ADB staff and other stakeholders involved in designing, implementing, and evaluating energy efficiency projects in buildings. It covers the key stages of the project cycle, from project identification and preparation to implementation and monitoring. It provides a comprehensive overview of the range of actions and measures needed to help reduce emissions and ultimately decarbonize the sector such as the promotion of energy-efficient design strategies and technologies, the development of optimized financing instruments, and business models for future scale-up. It showcases good practices and lessons learned from ADB's experience and other international experiences. This handbook is a contribution to opening a sensible avenue for the transition to a zero-carbon, efficient, and resilient building stock.

The buildings and building construction sector is among the most emission-intensive sectors and offer considerable potential for carbon dioxide (CO_2) emission reduction. In 2020, the sector consumed about 36% of global total final energy consumption and generated 37% of energy-related CO_2 emissions. The global building stock is expected to increase by 75% from 2020 to 2050, 80% of which is projected to be in emerging and developing economies. Asia and the Pacific is the fastest-growing region in the world. It accounts for nearly 40% of global gross domestic product and generates about 50% of energy-related CO_2 emissions. The buildings and building construction sector in Asia is booming. In 2018, buildings in the Association of Southeast Asian Nations (ASEAN), the People's Republic of China (PRC), and India consumed 27% of these countries' total final energy consumption, slightly lower than the world average of 30%, and emitted 24% of energy-related CO_2 emissions, or 3.2 gigatons of CO_2, which accounted for nearly one-third of the global amount. The continuous economic growth, rapid urbanization as well as increasing population, are driving the fast expansion of buildings stocks, especially in developing and emerging economies. The International Energy Agency (IEA) projected that 65% of the new floor area to be constructed from 2017 to 2050, about 70 billion square meters, will be in the PRC, ASEAN, and India.

To decarbonize the buildings and building construction sector, electrification and energy efficiency are the two major measures, followed by fuel switching. Improving energy efficiency in buildings can reduce energy costs, enhance energy security, and mitigate greenhouse gas emissions. However, many barriers hinder the adoption of energy-efficient technologies and practices in the buildings and building construction sector, such as lack of information, awareness, and skills, high up-front costs, split incentives, and regulatory gaps. To accelerate the adoption of energy efficiency in the buildings and building construction sector (both new and existing buildings), first, it is imperative that governments reconsider the use of inefficient fossil fuels subsidies, improve availability and access to building energy use data, set national energy efficiency targets for buildings, and enable local governments

to adopt and effectively enforce mandatory building energy codes. Second, green building certification and energy labeling can help building owners identify buildings that go beyond the national standards, and help the government provide incentives to cover the incremental costs or even expedite the permitting process of green buildings. Third, capacity building of government staff and the private sector will be important to ensure there is sufficient skilled workforce to deliver sustainable and efficient buildings in the country. Energy efficiency can contribute significantly to new job creation, particularly in building retrofit. Fourth, it is essential to have enhanced information and awareness on energy efficiency policies and technologies at different levels of government, building owners, developers, real estate companies, and even the banking and utility sectors.

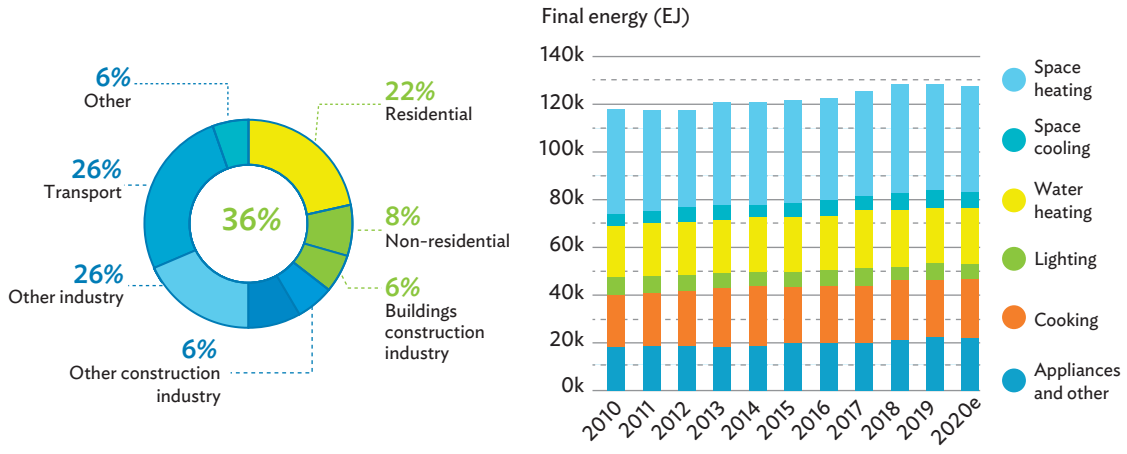
The handbook is organized into four parts. Part I provides an overview of the global and regional trends and challenges in the buildings and building construction sector, the potential and benefits of energy efficiency, and the role of ADB in supporting DMCs. Part II presents the main elements and steps involved in developing energy efficiency projects in buildings, such as conducting market and policy assessments, identifying project opportunities, selecting appropriate financing and delivery mechanisms, and preparing project proposals. Part III discusses the key aspects of implementing and monitoring energy efficiency projects in buildings, including procurement, supervision, quality assurance, reporting, and evaluation. Part IV summarizes the main conclusions and recommendations of the handbook and provides some useful references and resources for further reading.

1 INTRODUCTION

This technical handbook has been prepared for energy communities working in the buildings and building construction sector (e.g., engineers, architects, building developers) in members of the Asian Development Bank (ADB), as well as ADB operations teams to support demand-side investment projects and technical assistance.

There is growing consensus that over 50% of global emissions need to be reduced by 2030, from 2010 levels, to be on track for the 1.5-degree Celsius (°C) target by 2050.[1] The buildings and building construction sector is among the most emission-intensive sectors and offer considerable potential for carbon dioxide (CO_2) emission reduction. In 2020, this sector consumed about 36% of global total final energy consumption (i.e., residential, nonresidential, and buildings construction industry), as shown in Figure 1, and generated 37% of energy-related CO_2 emissions (i.e., construction and operation of buildings). Some progress has been made since 2015 in decoupling energy consumption from floor space expansion as well as the adoption of efficient heating technologies, particularly because of policy adoption in developed countries. In 2020, the buildings and building construction sector emitted 11.7 gigatons of CO_2, an unprecedented drop of emissions by 10% from 2019, largely due to the coronavirus disease

Figure 1: Share of Buildings and Building Construction Sector of Total Final Energy Consumption (left) and Building Energy Consumption by End Use from 2010 to 2020 (right), 2020



EJ = exajoule.

Source: United Nations Environment Programme (UNEP). 2021. *2021 Global Status Report for Buildings and Construction: Towards a Zero-Emission, Efficient and Resilient Buildings and Construction Sector*. United Nations Environment Programme.

[1] United Nations, Net Zero Coalition.

(COVID-19) pandemic. However, the sector is not on track to meet the climate commitments by 2050, according to the International Energy Agency (IEA). In 2021, there was a sharp rebound of CO_2 emissions globally, nearly back to the pre-pandemic level, adding the urgency for concrete and immediate actions.[2] Energy efficiency offers the most cost-effective and one of the fastest measures to cut emissions. It is thus essential to improve energy efficiency and ultimately decarbonize the buildings and building construction sector.

This handbook covers in detail a range of actions and measures needed to help reduce emissions and ultimately decarbonize the sector, such as the promotion of energy-efficient design strategies and technologies, the development of optimized financing instruments, and business models for future scale-up. It is to develop capacity and knowledge of ADB operations, decision-makers, and professionals in developing member countries (DMCs) of ADB by providing a practical reference for the design of building energy efficiency projects. This handbook is a contribution to opening a sensible avenue for the transition to a zero-carbon, efficient, and resilient building stock.

Energy efficiency improvements typically refer to the utilization of less energy to provide the same services. Buildings, together with transport and industry, are among the key areas for energy efficiency improvement. In the global discussion, a distinction is made between supply-side energy efficiency (SSEE), aiming at decreasing energy losses in energy production and in the delivery of electricity or heat, while demand-side energy efficiency (DSEE) focuses on the consumption of less energy for the same level of service[3] in energy consuming sectors such as industry, buildings, and transport. Yet, buildings can be energy producers as well. Further, decarbonizing the buildings and building construction sector requires efforts to cut emissions throughout the entire life cycle, including land use and urban planning, design, construction and retrofits, manufacture of building materials, operation, decommissioning, and appliances. Energy efficiency in buildings usually covers building construction and operation, including building envelope, appliances, and equipment (e.g., lighting, space heating, cooling, ventilation, water heating, management system). This handbook looks at the efficiency at the point of consumption in buildings (DSEE) and focuses on heating, ventilation, and air-conditioning, which make up around 40% of energy use, in the technology chapters.

Energy-efficiency measures can be applied to all types of buildings. This handbook will differentiate between new construction and building retrofits where necessary. Most technologies considered apply to both levels irrespectively. As the first step, it is important to make an initial survey of the building types being considered, as shown in Figure 2, before formulating the energy efficiency project or program.

Figure 2: Examples of Types of Buildings

Public Buildings	Residential Buildings	Commercial Buildings	Industrial Buildings	Infrastructure
• hospitals • schools/universities • administrative • buildings/ ministries, etc.	• single-family houses • large multi-family buildings/condos • mixed buildings	• shopping center • individual shops • 24/7 convenience stores • hotels	• manufacturing • warehouse/logistic	• power plants • water and waste facilities

Source: Author.

[2] International Energy Agency. 2021. Tracking Buildings.
[3] See also 2017. Evaluation report of ADB. Asia Energy Efficiency Accelerator.

This handbook also aims to raise awareness of building energy efficiency measures and provide a better understanding of the potential, proven technologies, and financing instruments applicable to this sector to foster project opportunities within DMCs.

This handbook comprises the following chapters:

- Chapter 1 provides the objectives and scope of this handbook.
- Chapter 2 presents the latest building energy efficiency data in the world and in Asia and the Pacific, the key stakeholders of the buildings and building construction sector, four enabling factors of improving energy efficiency, the co-benefits, and ADB's efforts in this field.
- Chapter 3 focuses on green building[4] certification schemes, also known as rating tools, and provides an overview of international schemes and national schemes in Asia, and examines the energy criteria followed by cases applied in DMCs.
- Chapter 4 elaborates on selected sustainable cooling strategies and technologies throughout the design and operation phases. It looks broadly at the control of heat gains, ventilative cooling, cooling technologies and sources, and air distribution.
- Chapter 5 continues the technical discussions on heating and explores clean heating options, including heat pumps, solar space heating, and solar water heating.
- Chapter 6 provides an overview of investment in building energy efficiency and presents proven financial instruments, including traditional and specialized innovative instruments.
- Chapter 7 explores business models for building energy efficiency projects by presenting three successful examples from Europe and Asia.
- Chapter 8 concludes the handbook and provides policy recommendations.

Case studies and examples from developing and advanced economies from Asia and other regions are identified and illustrated in boxes.

[4] Green building is a holistic concept that starts with the understanding that the built environment can have profound effects, both positive and negative, on the natural environment, as well as the people who inhabit buildings every day. Green building is an effort to amplify the positive and mitigate the negative of these effects throughout the entire life cycle of a building. See more at https://www.usgbc.org/articles/what-green-building.

2 BACKGROUND

Key Stakeholders

Building energy efficiency (BEE) is not a single-party problem—it is cross-sectoral and involves different stakeholders. Collaboration among developers, users, owners, and others is essential. It applies to both public sector proponents as well as for the private sector ones.

Stakeholders within the public sector, policymakers and officials at all jurisdictional levels must cooperate. As BEE involves several ministries and public offices, it is critical that one of the ministries is mandated and responsible for BEE but respects the competence and professionalism of others.

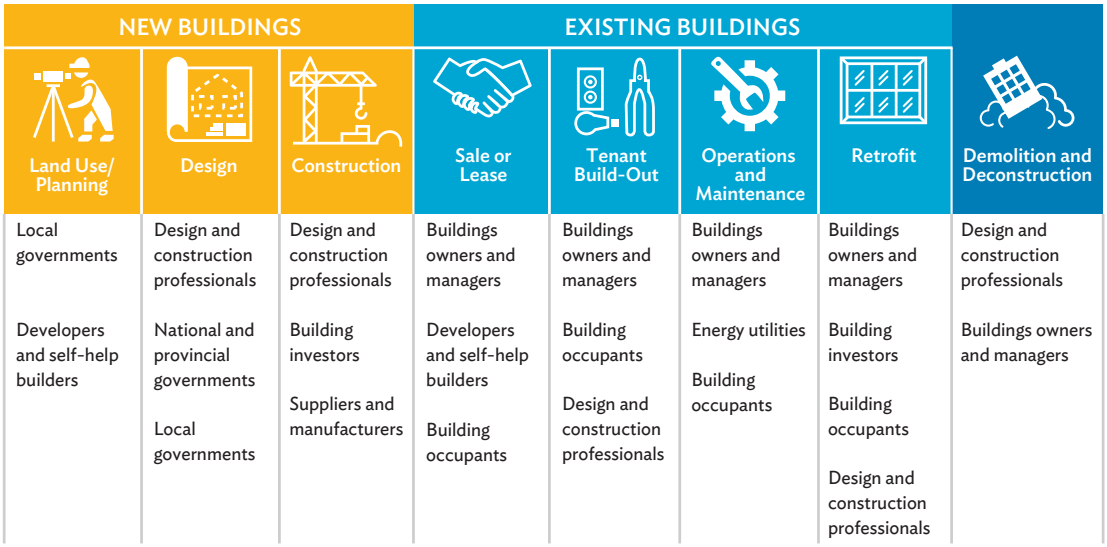
The value chain for BEE is complex and varies according to the building type. Comprehensive support and multi-stakeholder analysis might be required. It may involve urban planners, architects, developers, investors, construction companies, utilities, banks, and financial institutions as well as retailers—e.g., for household appliances, installers, technical consultants, energy auditors, the owners, the lessors, and facility managers, and finally specialized companies such as energy service companies (ESCOs). It is not a homogeneous group. They all have individual goals, levels of expertise, knowledge, and needs that may differ within the stages of the process and the countries in question. They may all need initial support. Programs must be comprehensive and inclusive and consider the market as a whole instead of singling out one party. The gaps between them need to be mended.[5] Careful analysis of the drivers of each stakeholder is required to ensure a common objective and deliver a positive outcome. Figure 3 illustrates the positions of various stakeholders.

Sector Overview

Globally, buildings and building construction sector consumed 36% of the global total final energy consumption in 2020 as shown in Figure 1, among which operational energy use accounted for 31% or around 127 exajoule (EJ), and constructions accounted for 5% or around 22 EJ. In terms of global buildings, energy consumption by end use, spacing heating, and cooling together make up about 40%. Space cooling has been the fastest-growing use of energy, particularly in countries that are not members of the Organisation for Economic Co-operation and Development (OECD). In 2020, the CO_2 emissions of the buildings and building construction sector amounted to 11.7 gigatons, around 10% down from 2019, mainly due to the slowdown of the global economy and construction activities. Countries like the United States (US) already saw a sharp bounce-back of emissions in 2021, increasing by 6% from the 2020 level (Plumer 2022). The 11.7 gigatons of CO_2 emissions accounted for 37% of energy-related

[5] Further reading: Zedan, S. and W. Miller. 2018. Quantifying Stakeholders' Influence on Energy Efficiency of Housing: Development and Application of a Four-Step Methodology. *Construction Management and Economics*. 36 (7). pp. 375–393.

Figure 3: Stakeholders' Roles Throughout the Entire Life of Buildings



Source: World Resources Institute (WRI). 2016. *Accelerating Building Efficiency: Eight Actions for Urban Leaders*.

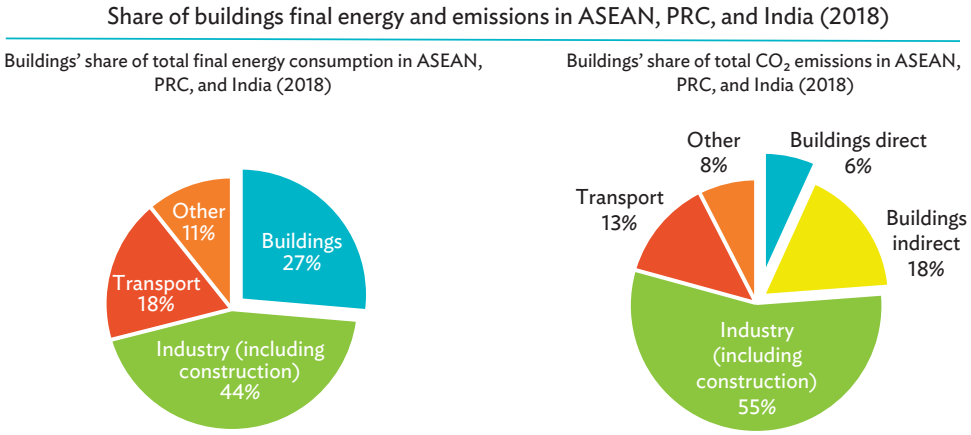
emissions: 27% from building operations, and 10% from construction and materials, i.e., embodied emissions[6] considering the carbon footprint across the entire life cycle of buildings. Embodied emissions have gained increasing attention over the recent years, as the sector is moving toward zero-carbon emissions, and a significant number of carbon-intensive buildings are still expected to be constructed. Several European countries have taken early actions to regulate embodied emissions that need to have comprehensive regulations in place.

The global building stock is expected to increase by 75% from 2020 to 2050, 80% of which is projected to be in emerging and developing economies (IEA 2021d). Asia and the Pacific is the fastest-growing region in the world and accounts for nearly 40% of the global gross domestic product (GDP) (IMF 2021) and generates about 50% of emissions. The buildings and building construction sector in Asia is booming. In 2018, buildings in the Association of Southeast Asian Nations (ASEAN), the People's Republic of China (PRC), and India consumed 27% of these countries' total final energy consumption, slightly lower than the world average at 30% and generated 24% of energy-related CO_2 emissions, or 3.2 gigatons of CO_2, which accounted for nearly one-third of the global amount (Figure 4).

Continuous economic growth, rapid urbanization, and increasing population are driving the fast expansion of building stocks, especially in developing and emerging economies. IEA projected that 65% of the new floor area to be constructed from 2017 to 2050, about 70 billion square meters (m^2), will be in the PRC, ASEAN, and India, as shown in Figure 5. This coincides with GlobalABC's study showing that Asia will accommodate nearly half of all new constructions (UNEP 2021). The Asia Pacific Energy Research Centre (2019) estimated that Southeast Asia will lead the growth of building energy demand in Asia and the Pacific. This will likely lead to significant increases in fossil fuel consumption and CO_2 emissions if the transition toward efficient and low-carbon buildings is slow. Taking India as an example, two-thirds of the buildings that will exist in 2040 in the country are yet to be built, based on the current policy settings (IEA 2021c). The buildings and building construction sector, together with industry and transport, will largely shape the energy demand of the country in the coming decades. In addition, the higher airflow rates for ventilation and filtration and changes in working patterns may increase energy consumption in the post-pandemic era.

[6] Embodied emissions or embodied carbon refer to the emissions across the entire life cycle of buildings, because of material manufacturing, construction, maintenance, renovation as well as deconstruction. The major emissions come from the production stage.

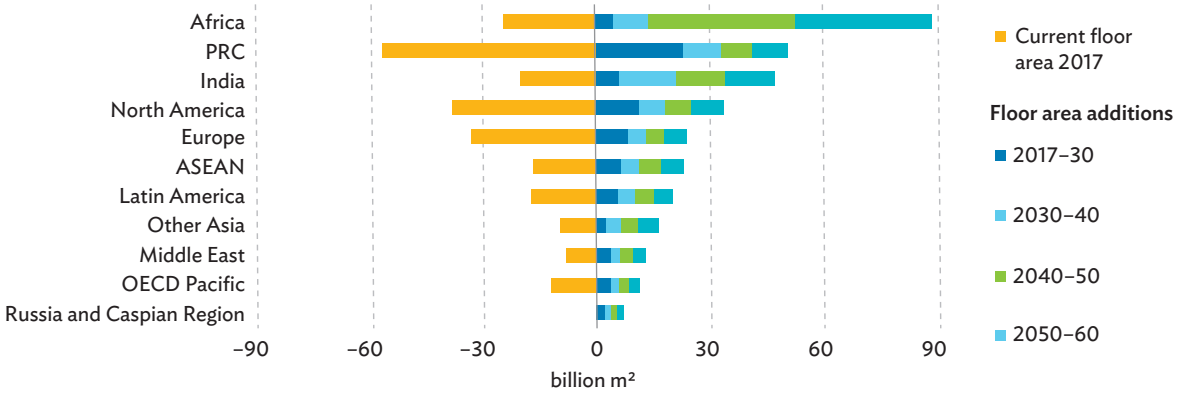
Figure 4: Buildings' Share of Total Final Energy Consumption and Total Carbon Dioxide Emissions in ASEAN, People's Republic of China, and India



ASEAN = Association of Southeast Asian Nations, CO_2 = carbon dioxide, PRC = People's Republic of China.

Sources: GlobalADB/IEA/UNEP. 2020. *GlobalABC Regional Roadmap for Buildings and Construction in Asia 2020-2050: Towards a Zero-Emission, Efficient, and Resilient Buildings and Construction Sector*.

Figure 5: Total Building Stock in 2017 and Expected Growth to 2060 in Key Regions



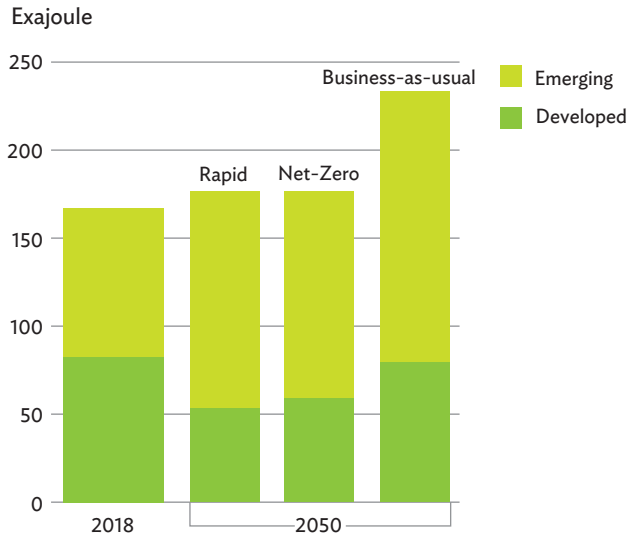
ASEAN = Association of Southeast Asian Nations, OECD = Organisation for Economic Co-operation and Development, PRC = People's Republic of China.

Source: International Energy Agency (IEA). 2017. Energy Technology Perspective 2017.

To decarbonize the buildings and building construction sector, electrification and energy efficiency are two major measures followed by fuel switching. According to British Petroleum's projection, all the growth of primary energy demand will come from the developing world (Figure 6). Under British Petroleum's net-zero scenario, which aligns with the 1.5°C target, the total primary energy demand of buildings is expected to rise only around 4.7% from 2018–2050, driven by energy efficiency improvement as well as behavioral changes, in comparison to a growth of 38% under the business-as-usual scenario, assuming the building stock grows by more than 75% over the same period.

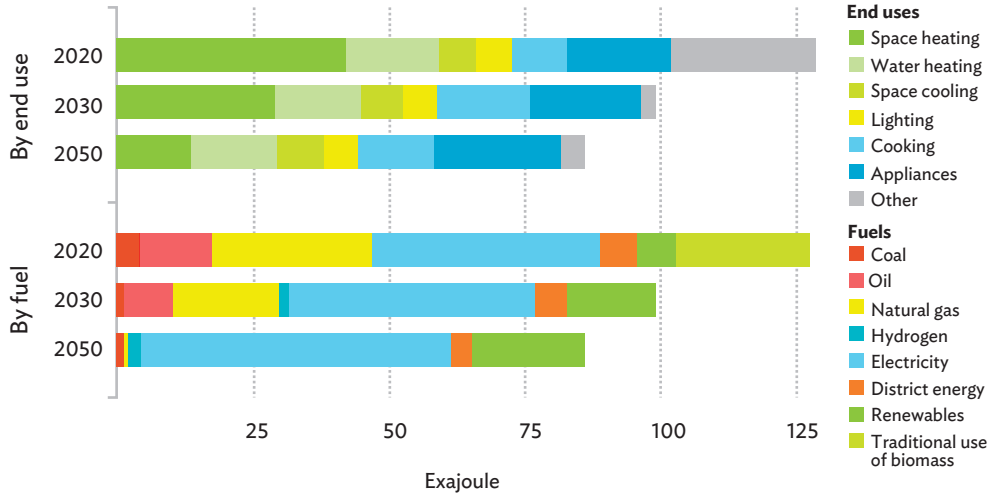
Overall, the primary energy demand of buildings has to decrease by around 20%–30% by 2050 from the current level to achieve the 1.5-degree target. Meanwhile, electricity will become the dominant energy use, and on-site fossil fuels will be nearly eliminated, as shown in Figure 7. At the country level, fuel use varies significantly in Asia. For instance, electricity accounted for 35% of building energy consumption in the PRC in 2019 but only 19% in India.

Figure 6: Historical and Projections for Building Primary Energy Demand Under the Rapid, Net-Zero Scenario and Business-as-Usual Scenarios by 2050 for Emerging and Developed Economies



Source: BP. 2020. BP Energy Outlook 2020 edition.

Figure 7: Historical and Projection of Building Final Energy Consumption by End Use (Upper) and by Fuel (Lower) Under the Net-Zero Scenario for 2030 and 2050



Source: International Energy Agency (IEA). 2021d. Net Zero by 2050: A Roadmap for the Global Energy Sector.

In terms of end use, the share of space heating is likely to decrease significantly, contributed by improved efficiency of buildings and appliances, as well as a warmer climate in the future. The heating market is transitioning slowly from inefficient carbon intensity status toward low-carbon solutions. Besides heat pumps, solutions like solar thermal heating and biomass boilers still need to be further and faster scaled up. In contrast, spacing cooling demand will see substantial growth. In particular, India and ASEAN countries, among the hottest regions in the world, are expected

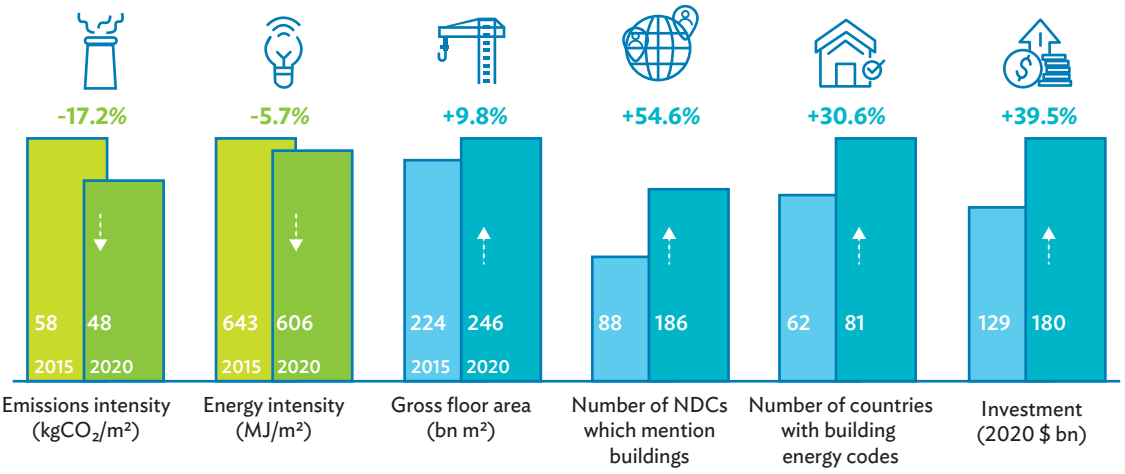
to have a great rise in cooling demand as living conditions improve from their existing low access rate to cooling facilities. Therefore, cooling design and efficient technology have been identified as the priority areas for action (GlobalADB/IEA/UNEP 2020). Chapter 4 will elaborate more on this topic.

Since the Paris Agreement, progress has been made in energy efficiency for the buildings and building construction sector in terms of energy consumption, enabling policies as well as investment (Figure 8).

Over the last 2 decades, the global building energy intensity improved by roughly 0.5%–1% annually. However, this is not sufficient to offset the growth of building stock. The global building energy intensity will need to drop at least 2.5% per year, i.e., 31% down in 2030 from 2019 level, to achieve the 2°C scenario. Europe is expected to achieve the intensity reduction of 23%; other developing Asia, 15%; and the PRC, 45% by 2030, as shown in Figure 9. Without accelerated actions, the global emissions from the buildings and building construction sector can be doubled or even tripled by midcentury (Broadwater 2016).

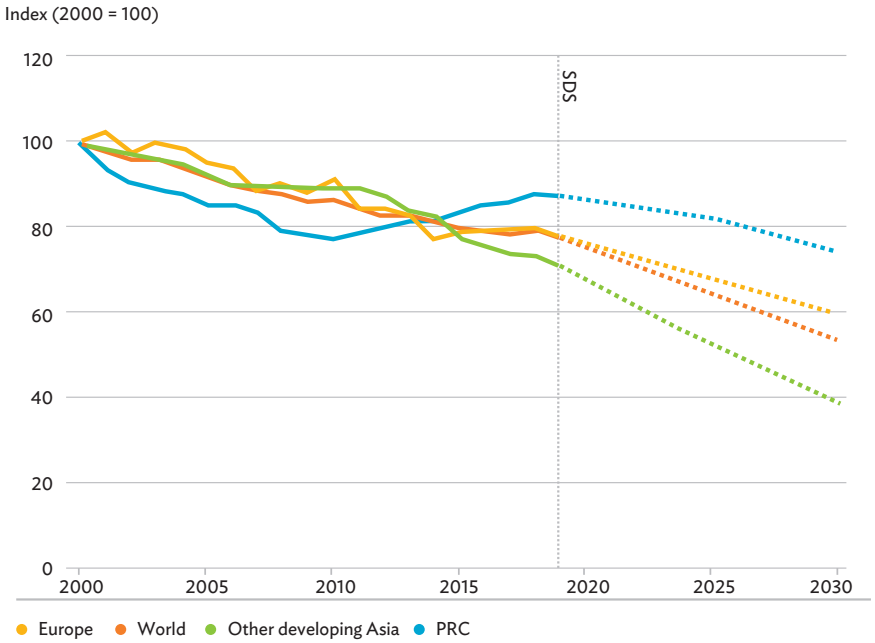
Energy efficiency is more than simply saving energy and mitigating emissions. It is a paradigm shift. First, policymakers need to understand the wider implications to be able to put out relevant policies, laws, and regulations. Second, the transition toward zero-carbon emissions will primarily rely on technological advancement, including digital or smart solutions and behavioral change. Third, investment and financing in zero-carbon buildings will be crucial. Last, the availability and the quality of data are worth mentioning separately concerning the lack of data and information at both global and regional levels, in particular in developing economies, which has become one major challenge. The following section will elaborate more on the four enabling factors for BEE.

Figure 8: Summary of Key Changes in the Global Building Sector Between 2015 and 2020 Based on Six Different Indicators



bn = billion, CO_2 = carbon dioxide, kg = kilogram, m^2 = square meter, MJ = megajoule, NDC = nationally determined contribution.
Source: UNEP. 2021. *2021 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector*. United Nations Environment Programme. .

Figure 9: Historical and Projected Building Energy Intensity in the Sustainable Development Scenario from 2000 to 2030 for Europe, World, Other Developing Asia, and the People's Republic of China



PRC = People's Republic of China, SDS = sustainable development scenario.
Source: GlobalADB/IEA/UNEP. 2020. *GlobalABC Regional Roadmap for Buildings and Construction in Asia 2020-2050: Towards a Zero-Emission, Efficient, and Resilient Buildings and Construction Sector*; International Energy Agency. 2021e. Tracking Buildings 2021.

Enabling Factors

Political Framework and Regulations

Energy efficiency needs to be treated as a first fuel and by that receives the same attention and position as renewable energy. A successful policy should cover new and existing buildings of any type and the entire life cycle from planning to decommissioning phases.

Clear Target

It is vital to set up clear and specific targets for building energy efficiency in climate strategies and plans at the country level. From 2020, economies were requested to communicate their new or updated nationally determined contributions (NDCs) to the Secretariat of the United Nations Framework Convention on Climate Change (UNFCCC) as part of the 5-year cycle of reviewing their climate targets and commitments under the Paris Agreement. As of September 2021, 192 economies had submitted their first NDC, 113 of which were updated, and 11 economies had submitted their second NDC. Across the communicated NDCs, improvement in building energy efficiency has been explicitly mentioned in 63% of the NDCs, becoming the second most frequently indicated mitigation option following renewable energy generation (UNEP 2021).

About 72% of those economies in Central Asia, South Asia, East Asia, and Southeast Asia mentioned buildings in their NDCs by 2019. However, many still did not include specific actions to address buildings and building construction sector energy use and emissions (GlobalABC, IEA, and UNEP 2020). Following the new reporting phase beginning in 2020, various policy actions to support improvements in building energy performance and climate resilience have been increasingly mentioned in updated first or second NDCs submitted by many economies in Asia.

However, as shown in Table 1, the progress is far less than sufficient. The breadth and depth of the mitigation (and adaptation) measures for buildings and construction as laid out in most NDCs are not adequate to put the countries in the region on track with the envisaged net-zero emissions scenario by 2050. The increasing population, rapid urbanization, and growth demand for floor area and space conditioning are among the key factors that present a serious challenge to transforming the buildings and building construction sector in Asia toward energy efficiency, low-carbon emissions, and climate resilience. Based on the United Nations population growth projections, it has been expected that 73% of the 294.3 million population to be added in Asia from 2021 to 2030 will live in countries that have NDCs in which building codes and/or building energy efficiency measures are not mentioned (UNEP 2021). This indicates a significant gap in ambition and commitment, calling for increasing recognition of the strategic importance of buildings in NDCs and large-scale adoption of more explicit and ambitious actions and pathways to decarbonize buildings in line with the Paris Agreement.

Table 1: Building-Related Climate Actions in Nationally Determined Contributions of Selected Developing Member Countries of ADB

Country	Description	Building Standards	Appliance
Central and West Asia	Azerbaijan	Massive use of control and measurement devices in electrical, heat energy, and natural gas systems; application of energy-efficient bulbs; use of modern energy-saving technologies in heating systems; as well organization of public awareness programs on energy use.	First NDC (January 2017)
	Pakistan	Green building codes and certification for new and refurbished buildings, including revolving guarantee mechanism for energy-efficient appliance.	Updated first NDC (Oct 2021)
	Uzbekistan	Further introduced energy-saving technologies in construction.	Updated first NDC (October 2021)
East Asia	China, People's Republic of	Improved energy efficiency standards for new buildings and accelerate the development of ultra-low energy-consuming, near-zero energy-consuming, and low-carbon buildings on a large scale. Supported the energy-saving renovation of existing buildings in cities and towns as well as municipal infrastructures, improving their energy-saving and low-carbon level. Applied green building standards to all new urban buildings by 2025. Gradually launched limits management of energy consumption in buildings, practiced building energy efficiency labeling, and conducted performance assessment of low-carbon development in the building sector.	Updated first NDC (October 2021)
	Mongolia	Insulated old precast panel buildings in Ulaanbaatar City. Limited the use of raw coal in Ulaanbaatar City and switch to the use of improved fuel.	Updated first NDC (October 2020)
South Asia	Bhutan	Launched Energy Efficiency Roadmap 2030 covering buildings in 2019 covering 155 gigawatt-hours annually in materials, appliances, and construction. Solar photovoltaics on buildings. Energy-efficient building design.	Second NDC (June 2021)
	Maldives	Built labeling and building standards to improve energy efficiency. Improve building code for climate resilience.	Second NDC (December 2020)
	Nepal	Adopted national building code that emphasize low-carbon and climate-resilient urban settlements.	Second NDC (December 2020)
	Sri Lanka	Introduced mandatory building energy efficiency code in 2021–2022. Established sectoral databases for eco-certification system, minimum performance and energy efficiency labeling programs, green building, and building management system.	Updated first NDC (July 2021)

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Table 1 *continued*

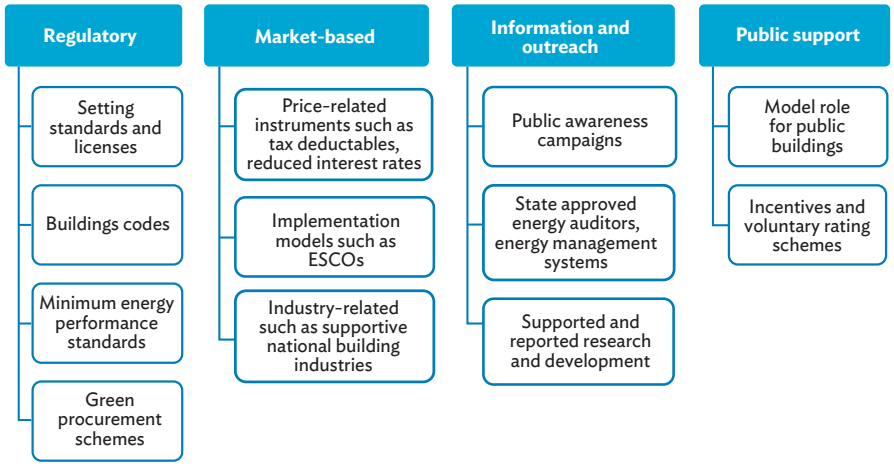
Country	Description	Building Standards	Appliance
Southeast Asia	Cambodia	Building codes, enforcement/certification for new buildings to reduce electricity consumption by 10% in 2030. Improved cooling in public sector buildings to reduce 43,000 tCO_2 per year. Passive cooling in buildings to reduce 74.5 tCO_2e.	Updated first NDC (December 2020)
	Thailand	Relies on the implementation of the National Energy Efficiency Plan B.E. 2558–2579 (2015–2036), which aims to reduce energy demand by 30% in 2036 compared to a business-as-usual trajectory	Updated first NDC (October 2020)
	Viet Nam	Reduced greenhouse gas emissions by replacing construction materials and improving the cement and chemical production processes together with reducing the consumption of Hydrofluorocarbons (HFCs). Improved, developed, and applied technology in manufacturing construction materials. Reduced clinker content and implemented other measures to reduce greenhouse gas emissions in cement production. Developed and used energy-saving construction materials and green materials in housing and commercial sectors	Updated first NDC (September 2020)
Pacific	Papua New Guinea	Improved building insulation and energy efficiency. Introduced building codes to mitigate impacts of heat waves and cyclones and for adaption.	Second NDC (December 2020)
	Tonga	Introduced energy efficiency standards for buildings and energy performance audits and minimum energy performance standards for appliances in buildings.	Second NDC (December 2020)

NDC = nationally determined contribution, tCO_2e = ton of carbon dioxide equivalent.
Source: UNFCCC. 2022. NDC Registry. United Nations Framework Convention on Climate Change.

Regulations

There is no single pathway to implement energy efficiency policies for buildings but a mix of various measures. They are broadly set along with the following categories.

Figure 10: Policy Categories for Energy Efficiency in Buildings



ESCOs = energy service companies.
Source: Author.

Building codes are probably the most important individual measure in promoting energy efficiency. Especially in countries with a fast-growing real estate sector, such as in developing and emerging Asia, the decisions laid out by the building codes today have far-reaching consequences in the future.

Building energy codes, a subset of building codes, set up baseline requirements for buildings' energy performance and building construction. Codes are either prescriptive, meaning that they describe in detail the technical standard or performance base, where the energy level of a building must meet a certain level, or even outcome-based, requiring a specified performance to be achieved over a certain period (C40 2019). They can be mandatory or voluntary, issued at national or subnational level. Usually, they apply to both old and new buildings as well as to public and private ones. Codes usually regulate areas of construction such as insulation; window and door specifications; heating, ventilation, and air-conditioning (HVAC) equipment efficiency; and lighting fixtures (WBDG 2016). Often, public buildings are used to break reservations and act as best practice examples. This can be a successful way if the example is easily replicable, and the proponent has smooth access to all necessary permits and administrative clearances.[7]

To meet the 1.5°C target by 2050, all countries must have comprehensive mandatory building energy codes implemented by 2030. All new constructions need to be compliant with stringent building codes by 2030, while the majority of retrofits need to be compliant by 2050. IEA's tracking data as of 2021 shows that only 80 countries globally, most of which are advanced economies, have launched mandatory or voluntary building codes (IEA 2021e). Around two-thirds of countries, where floor areas grow at a fast pace, are yet to launch mandatory building energy codes. Codes should be developed to govern the building retrofit as well. Furthermore, the building retrofit rate is less than 1% per year in most key countries, which is far below the requirement of 2.5% till 2030 for the 1.5°C target. The rate shall increase to 1.5% by 2025, at least in Asia (GlobalABC/IEA/UNEP 2020). This requires immediate action from policymakers. Concerning the long life span of buildings (30–100 years) compared to other energy-consuming assets, there are risks of lock-in effects of inefficient buildings, in particular in developing Asia, if the renovation rate of existing buildings remains low or new constructions are poorly designed and operated.

In Asia and the Pacific, 24 economies have mandatory and 6 have voluntary building energy codes out of 62 tracked economies, while 9 economies are developing the codes, and 23 do not have building energy codes as of the end of 2021 (IEA 2021b). As shown in Figure 11, many economies in Asia have or are in the process of developing building energy codes. However, some of them were not properly aligned with supporting policies such as energy performance certificates, incentives, and voluntary rating schemes, and they lack enforcement and compliance as well as monitoring and data evidence. Enforcement is one of the main stumbling blocks in energy efficiency in buildings. It requires designated authorities and an independent evaluation system.

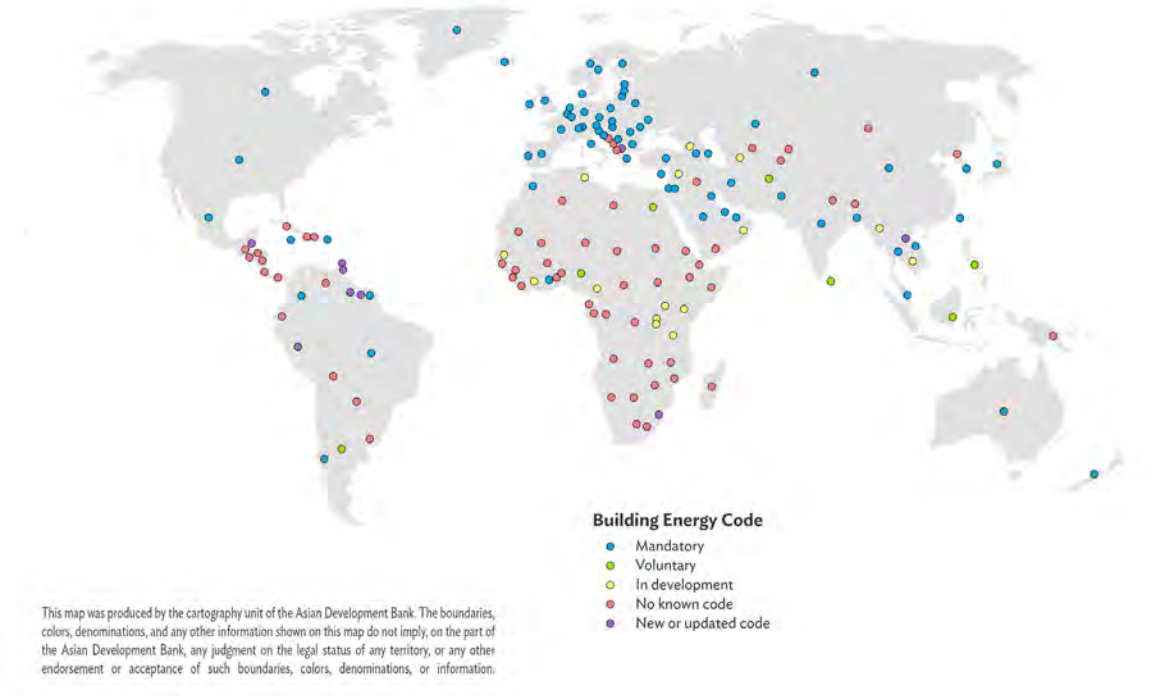
Besides building energy codes, building performance standards, or minimum energy performance standards (MEPS, for buildings) is another important policy approach that is relatively new (BECWG 2021). Several economies regulate energy consumption in buildings by setting mandatory energy performance standards, such as performance rating and carbon intensity levels. Besides the disclosure of building energy consumption and regulations on green procurement, there are other proven energy efficiency policy options.[8] MEPS can be adjusted over time, starting with a modest but short implementation period to more stringent requirements with longer implementation periods.[9] It can allow building owners a longer time to bring buildings into compliance. They are closely linked to energy performance certification for buildings, like rating systems already well-known for appliances, such as Energy Star of the US. Building certification and rating systems can provide energy-related benchmarks and a basis for performance standards. However, it is worth mentioning that building certification schemes include more than energy criteria. Chapter 3 will elaborate more on popular international and national green building certification schemes.

[7] The Republic of Korea provides nonmonetary benefits of several energy-efficient investments in buildings by speeding up approvals.

[8] ISO 20400 is the norm for sustainable procurement and gives guidance on a comprehensive procurement scheme. ISO 20400. 2017. Sustainable Procurement - Guidance.

[9] Further reading: How to set MEPs: Minimum Energy Performance, various reports.

Figure 11: Status of Building Energy Codes by Economy, 2019–2020



Source: UNEP. 2021. 2021 *Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector*. United Nations Environment Programme.

In the PRC, the central government decided on comprehensive MEPS for buildings in different climate zones and introduced a BEE labeling scheme. In India, the Bureau of Energy Efficiency under the Ministry of Power set up the Energy Conservation Building Codes that provide minimum requirements for the energy-efficient design and construction of residential and commercial buildings. In the United Kingdom (UK), it has been unlawful since 2018, under the Energy Act 2011, for landlords to rent buildings that have an energy performance certificate of F or G until their energy efficiency deficits have been addressed.

Other common policy tools include MEPS and labeling for appliances and equipment, which are already mainstreamed in Asia and the Pacific, the requirement for energy audits, etc. These policies could help reduce the energy demand of buildings (APERC 2019). To reach 2°C scenario by 2050, three factors should be in place to drive down the building energy demand, which is further scaling up of efficiency technology, improvement in building envelops, and fuel switching. Besides building codes, the adoption of MEPS for appliances is vital as well.

BEE policies are usually part of an entire codex of energy efficiency measures. As for other policies, they must come along with awareness programs, technical and financial assistance, and other supporting mechanisms. Equally important is their long-term view, clear timelines, and proper enforcement measures.

Institutions

Only 20% of the global BEE potential has been leveraged. The buildings and building construction sector is highly fragmented. The lack of appropriate aggregators or dedicated institutions controlling the whole value chain and coordinating across national and local stakeholders is holding back the development. It is recognized that commitment, institutions, and supporting evidence are the major issues with split interest and diffused decision-making, while technologies and tools are available and cost-effective.

Most countries have a ministry for building and community and a ministry for energy. It is mandatory for energy efficiency in buildings that policies and implementation are coordinated.[10] This is best done by establishing an independent institution that oversees the policy measures and is responsible for its implementation. It should be well-financed and staffed with technical and financial experts and have sufficient authority to penalize non-implementation.

In the PRC, for example, all new urban residential and public buildings must meet energy-saving design standards established by the Ministry of Housing and Urban–Rural Development (MOHURD). MOHURD has also developed a Green Building Action Plan, with green building evaluation standards and a labeling program. Implementation is conducted by provinces and municipalities, which may adjust the standards but may not go below certain thresholds.[11]

Some countries have set standards and building codes at the national level, which are to be adjusted to reflect local conditions. In that case, a model building code is developed and modified accordingly to effectively cover different regional situations such as climate, building stock, and local conditions. Delegation of power is advisable in large countries and countries with very different climate zones. Implementation is often seen as a major issue because it requires vertical integration of central, federal, and municipal levels.[12] It is not uncommon to have mismatches between the central government's ambitious targets and the local's different regulation priorities and limited resources. The lack of implementation, enforcement, and monitoring mechanisms are pervasive issues. It is thus necessary to include inspection schemes, time frames for revision, and penalties in case of noncompliance with any of the regulations. In addition, cross-sector coordination is still weak, for instance, the integration of the buildings and building construction sector with urban planning. Capacity building and engaging local policymakers and practitioners will be necessary. It is often forgotten, but energy efficiency requires a skilled workforce. Various measures such as university programs and a state-certification system e.g., energy auditors have proven to be successful. These policy instruments should be also combined with incentives and financing programs to improve their effectiveness.

Technology Development

As noted before, technology development will play a major role in improving building efficiency and ultimately decarbonizing the sector. The existing buildings can leverage cutting-edge devices and technologies to mitigate emissions through retrofitting, and the new constructions shall employ sustainable and low-carbon materials, designs, and construction practices. Proven and cost-effective technologies are widely available in the market (WRI 2016), such as heat pumps, efficient appliances, advanced materials, etc. In addition, the large number of technologies for buildings at the demonstration and early adoption stages deserve attention, as shown in Figure 12. These two stages refer to the "valley of death." High costs and performance gaps exist. Support from the public sector, in particular financing, is critical to stimulate continuous innovation and help overcome the valley of death. Chapter 4 and Chapter 5 will discuss more on heating and cooling design technologies and appliances.

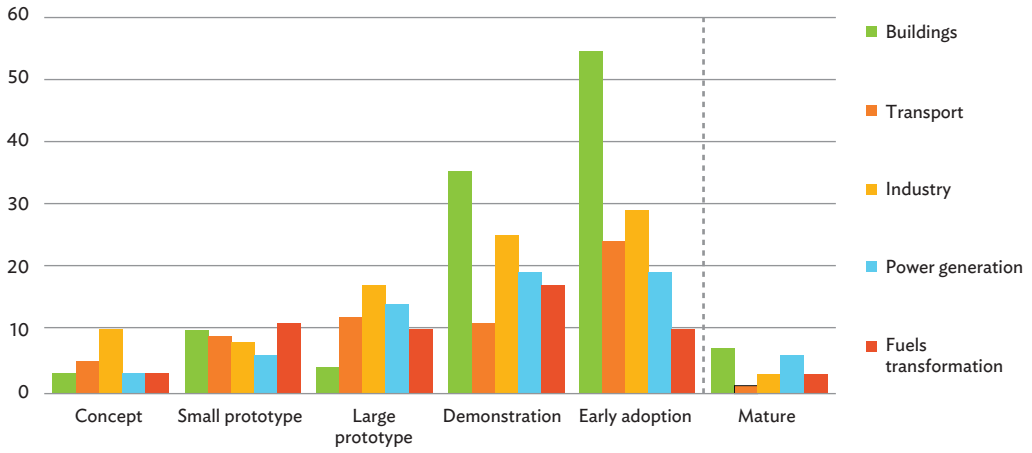
Moreover, the recent development of digital technologies creates chances to cater to diversified demands and accelerate the transition. Digital technologies have the potential to disrupt the whole-buildings and building construction sector, enable integration and information-sharing along the value chain, and unlock the improvement potential of the whole system. Concerning the complexity and diverse materials and structures, it is usually challenging to enforce building regulations on the ground. The smart meters and monitoring technologies, for instance, may help track the operational energy consumption, collect data for decision-making, and ultimately, optimize systematic performance and support behavioral changes.

[10] The Republic of Korea has set national targets for energy efficiency as part of the countries "green growth" strategy, passed in 2009.

[11] Further reading: World Green Building Council. China Green Building Council.

[12] Further reading: APEC Energy Working Group, 2017 results of the Asia-Pacific Building Code Forum. Asia-Pacific Economic Cooperation. 2017. Asia-Pacific Building Codes Forum Workshop Outcomes. Singapore; Asian Development Bank Institute. 2020. Energy Efficiency in ASEAN: Trends and Financing Schemes. *ADBI Working Paper 1196*. Tokyo.

Figure 12: Number of Clean Energy Technology Designs and Components Analyzed in the Energy Technology Perspectives According to Their Maturity Stage



Source: International Energy Agency. 2020b. Number of Clean Energy Technology Designs and Components Analyzed in the ETP Clean Energy Technology Guide.

However, the adoption of digital technologies or so-called digitization requires regime changes, breaking silos and integrating the fragmented industry to share information, and certainly investment in research and development (R&D) as well as training and adaptation. The existing applications happen predominantly in advanced economies and create great potential to be scaled up in developing countries.

Investment Status

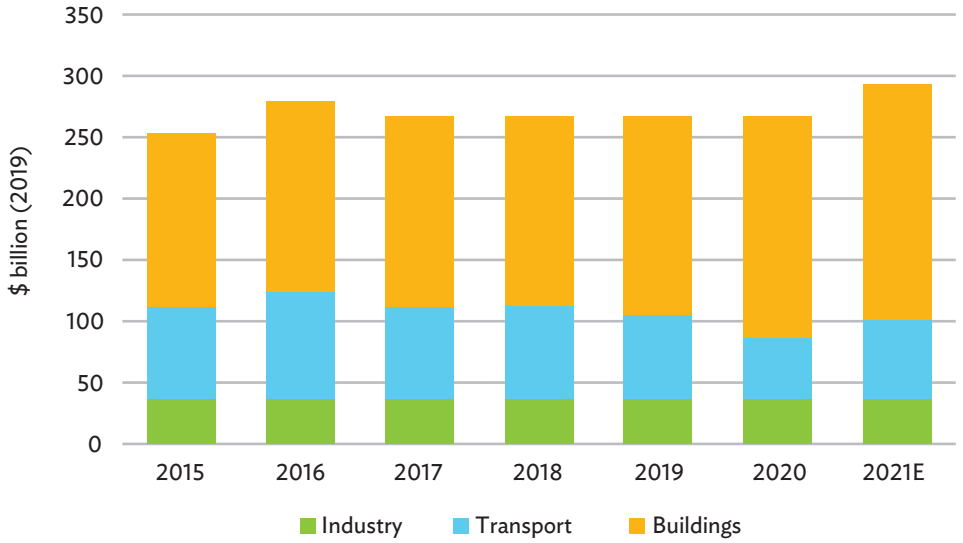
Governments often underestimate the economic and social benefits energy efficiency brings. The results are timid and unsuitable budgets. In supporting a strong policy framework, energy efficiency programs must have a consistently strong funding platform. Direct and indirect benefits need to be considered and valued, such as the reduction of CO_2 emissions, improved balance of trade, reduction in unemployment, and an increased net public budget.

In 2021, investments in energy efficiency were expected to reach a record high of $290 billion, increasing 10% from 2020, mainly due to the economic recovery. Among this, the buildings and building construction sector, the leading destination of efficiency spending, is likely to attract $190 billion, a spike of 11% from 2020, in contrast to the decline in industry and transport sectors (Figure 13). This strong growth in BEE is mainly driven by the increasing commitment of European countries but hides the sluggish development in other countries. In Asia, the growth has primarily concentrated in the PRC, the Republic of Korea, and Japan, while other countries, such as India, have seen contraction (IEA 2021b).

Europe continued leading the investment in BEE before the pandemic, while Asia and the Pacific has seen a high growth since 2015, thanks to the new constructions in the emerging economies (Figure 14). Meanwhile, it illustrates that Eurasia countries, including Russia and other eight DMCs in Central and West Asia, spent very limited in this sector.

The Asia Pacific Energy Research Centre (APERC) (2019) projected that the buildings and building construction sector in Asia-Pacific Economic Cooperation (APEC) member economies will need a total capital investment of $8.4 trillion and fuel costs of $15.3 trillion over 2017–2050 under the business-as-usual scenarios, and much higher capital investment at $19.1 trillion but 39% less fuel costs, which would be offset significantly by fuel saving from the reduced energy demand and improvided energy efficiency, under the 2°C scenario (Table 2).

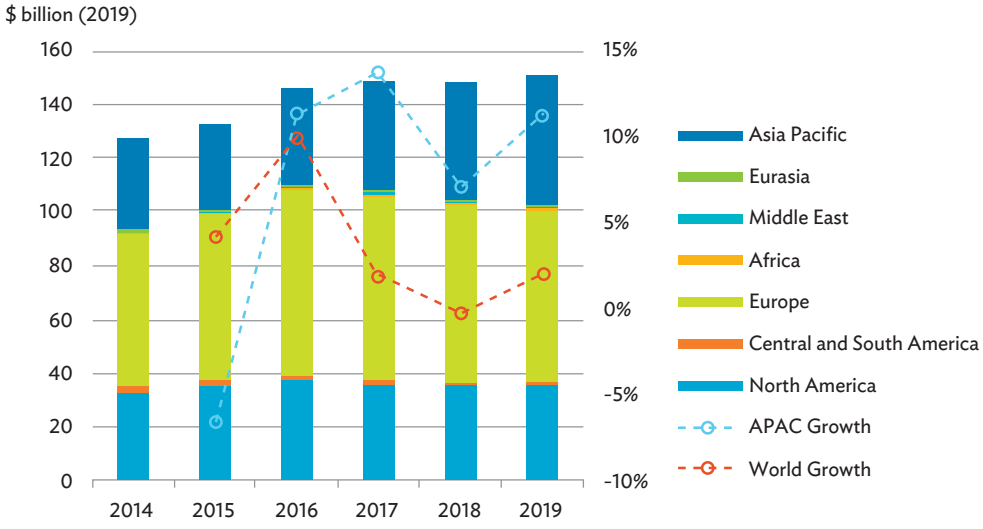
Figure 13: Global Investment in Energy Efficiency by Sector, 2015–2021



Note: An energy efficiency investment is defined as the incremental spending on new energy-efficient equipment or the full cost of refurbishments that reduce energy use. The intention is to capture spending that reduces energy consumption. Under conventional accounting, part of this is categorized as consumption rather than investment.

Source: International Energy Agency. 2021b. Energy Efficiency 2021.

Figure 14: Building Energy Efficiency Investment and Growth Rates by Region from 2014 to 2019



APAC = Asia and the Pacific.

Source: International Energy Agency. 2021a. Annual Investment in Building Energy Efficiency by Region, 2014–2019.

Table 2: Capital Investment and Fuel Costs in Business-as-Usual and 2°C Scenarios, 2017–2050 ($ trillion)

	Business-as-Usual Scenario			2°C Scenario		
	Capital	Fuel Costs	Sum	Capital	Fuel Costs	Sum
Total Energy Demand	13.6	49.2	62.8	25.5	32.3	57.8
Buildings Energy Demand	8.4	15.3	23.7	19.1	9.2	28.3

Source: APERC. 2019. *APEC Energy Demand and Supply Outlook 7th Edition 2019*. Vol. 1.

IEA projected that around $260 billion per year will be spent on energy efficiency improvement from 2021 to 2023, among which $70 billion will be from government direct investment, and the rest will need to be mobilized from public and private organizations (IEA 2021b). The current pledge on energy efficiency investment is insufficient toward the 1.5°C target. Moreover, the current investment growth is imbalanced among countries, and the largest gaps are in emerging and developing countries.

One promising trend is that energy-efficient buildings attract capital from green financing, such as green bonds. Green buildings rank second in terms of using green bond proceeds, following the energy sector, reaching around $76 billion by 2020. In ASEAN, buildings represented 48.6% of green debt investment (Climate Bonds Initiative 2021). Countries like India and Viet Nam are developing green taxonomy to quantify the building projects and attract international capital.

Technical development led by start-ups fosters new business models and financing measures. Building efficiency is one of the hot areas, which raised funding of $500 million in 2020, rising at a never-before-seen rate. Despite early-stage investment occurring in the US, Europe, and the PRC markets, there are still huge prospects for entrepreneurs to scale up these innovations aboard, particularly in developing economies. Energy-as-a-Service (EaaS) for buildings is a leading technology attracting investment (IEA 2021b).

Box 1: Energy-as-a-Service Business Model for Energy Efficiency in Buildings

Smart Joules Private Limited (SJPL) is cofinanced with the equivalent of ₹$2,000,000 by the Asian Development Bank (ADB) Ventures Investment Fund 1. The company is a provider of data-driven energy efficiency solutions for commercial buildings, targeting large hospitals as the beachhead market. SJPL delivers energy savings through a combination of (i) a proprietary internet of things-based sensing and analytics platform, and (ii) the application of an EaaS business model.The basic idea is that data are collected by the company and optimized to be able to react in real time and thus producing a continuously improved algorithm.

Source: Interview with project administrator Charles Cole Navarro on 21 April 2021.

Financing Sources

Investment in energy efficiency is not a one-size-fits-all matter. Equally, the starting position of energy efficiency considerations varies greatly among different building types. First, they do not have the same consumption patterns, and second, energy-consuming devices such as heating, cooling, installed equipment, and appliances vary due to the different usage of the buildings. It is important to survey which building types, as shown in Figure 2, are to be targeted and why, before formulating political programs establishing funding sources and creating financial support measures. Given the medium- to long-term effect BEE brings, it usually requires patient capital.

In addition to the usual taxed-based funding sources and external finance through multilateral development banks, creating national or international carbon pricing models must therefore play an important role. Currently, 64 carbon pricing instruments are operating worldwide, covering over 20% of global greenhouse gas emissions and generating $53 billion in revenue (World Bank 2021). Governments can take two ways to price carbon—through emissions trading systems (ETS) and carbon taxes. The PRC started its national ETS this year. It covers initially emissions in the power sector, meaning that 30% of national emissions are covered. Also, Germany and the UK start their national ETS this year, while the Netherlands and Luxembourg use the carbon tax system.[13] Income from CO_2 pricing is used to fund, among others, energy efficiency programs.

Another funding source is the private sector, which tends to be forgotten. It is estimated that half of the funding needed to refurbish buildings will have to come from the private sector. Hence, any funding platform needs to establish convincing business case situations for the private sector. A comprehensive approach covering the entire supply chain the private sector runs is useful.[14] However, emerging countries nowadays rely primarily on public sources for energy efficiency financing (IEA 2021b), which is not sustainable and hinders the scaling up of the market. High transaction costs, the uncertain future value of the building projects, and the asymmetry of information are among the major barriers to attracting private capital. The perceived costs of financing green buildings are higher, up to 30% more than the actual expense (Broadwater 2016). In addition, many financing bodies involved in BEE are small and medium-sized enterprises facing common challenges in accessing finance. Further, depending on the target the individual program has, key stakeholders may include technology suppliers, manufacturers, energy auditors, and banks. For all of them, the exercise may start with awareness-raising and educational measures. The private sector will buy into it and invest if risk and reward can be identified. It is, therefore, essential that de-risking instruments and the development of project pipelines are supported to create a market and the view of long-term profits. The funds spent on motivating the private sector can be leveraged at a large scale. Nonmonetary incentives such as expedited construction permits for green buildings, faster permits, and other administrative relaxations are also beneficial. Chapters 6 and 7 will provide a detailed analysis of BEE investment, available instruments, and best practices for innovative business models.

Data

In formulating a successful policy and developing useful financial supporting measures, a clear understanding of the building stock and the energy demand of different building types based on reliable data is required. It is, likewise, a prerequisite to analyze the situation, provide evidence-based information, decide, and communicate potential costs and benefits to stakeholders.

There are yet comprehensive data sources available for buildings globally in terms of energy performance and emissions (UNEP 2021). There is a lack of reliable and easily accessible building data at regional and country levels for developing Asia, for instance (Climate Bonds Initiative 2021). Also, project-level data and information are usually restricted to private access due to their confidential or sensitive nature, which presents serious challenges for (i) benchmarking the performance of site-specific buildings and setting up applicable targets and (ii) building owners and investors to evaluate the building asset portfolios. These data gaps may lead to a significant level of ambiguity for investment, research, policymaking, etc. Banks have been hesitant to invest in BEE projects partially due to the lack of data on loan performance (IFC 2019c). For instance, the operation data of existing buildings and retrofitted ones in Asia are missing, and so is the limited focus on building retrofits in the region (GlobalADB/IEA/UNEP 2020).

[13] Further reading: World Bank. 2022. State and Trends of Carbon Pricing 2022. State and Trends of Carbon Pricing. Washington, DC: World Bank.

[14] In the past, pure on-lending programs for banks have proven not to be successful because of a lack of demand.

Moreover, the quality of data varies tremendously due to the difference in the age of the building stock. Many old buildings do not have any other information on their energy use than the utility bill at the end of the month. Other buildings can provide leading-edge information and information technology, such as the Internet of Things and others. However, building data are heterogeneous. They are still stored in different formats at different locations and do not communicate. It is, thus, necessary to create a so-called high-level data-driven architecture for building data exchange (Marinakis 2020). It allows a better understanding of energy consumption and may lead if not too different business models at least to better fine-tuned ones.

Data is needed throughout the use of energy-efficient measures. Once policies can be based on a realistic set of data, incentives can be better targeted, and the success of implementation is better monitored and constantly controlled. Even for the end consumer, a set of reliable and easy-to-use data can herald consumption behavior, which could become a self-controlled and cost-effective strategy to reduce energy waste in buildings.[15]

Impacts of Building Energy Efficiency

Buildings have a huge influence on our well-being and environment. The German Sustainable Building Council (DGNB 2020) identified that sustainable buildings can address in particular five Sustainable Development Goals (SDGs): good health and well-being (SDG 3), affordable and clean energy (SDG 7), sustainable cities and communities (SDG 11), sustainable consumption and production (SDG 12), and climate action (SDG 13).

Economic and Financial Relevance

At the heart of energy efficiency is the saving of energy.[16] In addition to a reduction in greenhouse gases, energy efficiency has a lot of other benefits (non-energy impacts [NEI] or non-energy benefits[NEB]), such as economic, social, and environmental improvements, which in many countries are not accurately shown in the national account system. The core elements of such cost-effectiveness calculations are challenging to identify, and it is hard to quantify a common denominator to monetize them, e.g., the impact on public health and welfare effects. A general add-on of 15% to the costs of avoided energy had been used as a proxy in some US federal states in the past to make up for it.[17]

Macroeconomic

Macroeconomically speaking, the benefits are tremendous and have an impact—directly and indirectly—on GDP.[18] Saving energy reduces the need to import primary energy, which has a direct effect on the national balance of payment, as well as an increase in public budgets reinforced by the fact that fewer power plants need to be financed. Less consumption also leads to reduced investment needs on the side of (public) utilities and may even result in a decline in energy prices as demand drops when less energy is used. The cut in dependency on fuel imports stabilized in addition to energy security in the future. The IEA estimated that worldwide energy efficiency improved by an estimated 13% between 2000 and 2017, most of which was achieved in the industry and the buildings and building construction sector (IEA 2019a). The amounts that can be saved are shown in Figure 15 and give an idea of how much public funding can be made available to incentivize building owners. Taking a life cycle perspective,

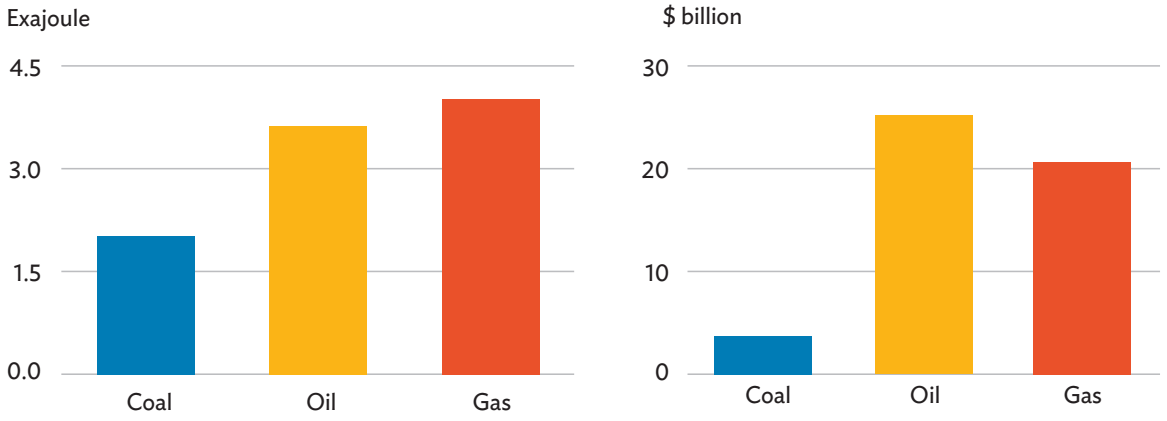
15 Further reading: Himeur, Y., A. Alsalemi, A. Al-Kababji, et al. 2020 Data Fusion Strategies for Energy Efficiency in Buildings: Overview, Challenges and Novel Orientations. *Science Direct*. 64. pp. 99–120; and Batra, N., A. Singh, P. Singh, et al. n.d. *Data Driven Energy Efficiency in Buildings*.

16 Further reading: European Commission. Energy; European Commission. 2016. *The Macroeconomic and Other Benefits of Energy Efficiency, Scenario in the EU with a 2030 perspective*. The EU Report. 2017.

17 Further reading: Northeast Energy Efficiency Partnerships, Inc. 2017. Non-Energy Impacts Approaches and Values: An Examination of the Northeast, Mid-Atlantic, and Beyond. United States.

18 See footnote 11, where calculations have been made for different scenarios, ranging from a 0.1% increase in GDP to up to 2.0%.

Figure 15: Reduction in Fossil Energy Imports in International Energy Agency Countries and Major Emerging Economies Due to Efficiency Improvements Since 2000, by Fuel



Source: International Energy Agency. 2019a. Multiple Benefits of Energy Efficiency.

efficient design and construction approaches can contribute up to 20% demand reduction for steel and over a 30% reduction for cement. Moreover, green buildings including energy efficiency improvement, feature a long value chain, involving multiple market players such as material manufacturers, planning, and design, and provide huge low-carbon investment opportunities in emerging countries, with a market size of $24.7 trillion by 2030 (IFC 2019c).

Cost-effectiveness. Energy efficiency, also called the "first fuel," results in a reduction in energy demand and greenhouse gas emissions. The monetary value of each unit of energy that can be saved needs to be seen against the expenses caused by generating, delivering, and storing the same amount of energy. Savings can be substantial if considering what it costs to generate energy versus how much energy efficiency measures cost. It seems that considerably less finance is needed to save energy by changing technologies than to generate energy. It supports the current discussion on the usefulness of DSEE. Generating electricity at the building site of larger residential areas and business centers and improving the energy efficiency standards of these buildings may even have a double effect when looking at network losses from source to delivery stations.

Employment effects. Employment effects have been noticed in the number of jobs created and in the level of productivity in different industries. Productivity also increased due to improvements in building quality, such as adequate temperature, air quality, and lighting. Further analysis must be made to calculate the indirect financial impact of decreased reported sick leaves of employees in office and commercial buildings related to energy efficiency upgrades.

Demand for more labor stems from conventional industries, but especially important for the buildings and building construction sector are new industries such as advanced manufacturing for new materials, data collection devices, innovative heat pumps, improved building design, and appliances. Locally made energy-efficiency equipment has the potential for high growth rates.

Employment opportunities in different industry sectors can lead to an average increase in available income at various levels of education. In some specific jobs, it stimulates further qualification and improves the overall skill set. Energy efficiency is said to be an employment machine. In the US, over 2 million jobs had been created in different sectors in 2016.

Figure 16: Energy Efficiency Employment by Industry Sectors in the United States, First Quarter, 2016



COVID-19 = coronavirus disease.

Source: BW Research Partnership. 2017. *U.S. Energy and Employment Report*. Report also shows development details in the different sectors.

The European Union report, 2017 supports this finding and projected the creation of 0.8 million jobs in 2020 due to energy efficiency measures. It was emphasized that energy service companies (ESCOs) are the main driver. In some of the main markets, the development has been consistently strong.

Table 3: Estimated Energy Efficiency Jobs in Selected Countries and Regions, 2020

Country/Region	Efficiency-Related Employment Numbers (pre-COVID-19 crisis)
Australia	60,000–236,000
Brazil	33,000–62,000
Canada	472,000
People's Republic of China	729,000–730,000
Europe	1 million–3 million
United States	2.4 million

COVID-19 = Coronavirus disease.

Note: For further information on energy efficiency and job creation: International Energy Agency. Energy efficiency jobs and the recovery.

Source: The EU in 2017.

Asset Value

Energy efficiency measures can increase the asset as well as the property value of buildings (Jensen, Hansen, and Kragh 2016). As studies show, the process, however, can be slow. In the case of Denmark, it took 15 years to show significant changes. Precondition is a building code that allows a recognized energy efficiency rating system. As also known, in the case of energy labeling for white goods, the efficiency labeling of buildings must be well communicated and needs a certain penetration before the market reacts.

Direct financial effects for building owners who undertake energy efficiency measures, including deep energy retrofits, can

- lower long-term operating and maintenance costs;
- lessen possibilities of becoming a stranded asset due to government regulations;
- potentially lead to higher returns on investment;
- potentially lead to higher asset value—lower risk—lower financing costs;
- potentially lead to higher sales price; and
- potentially lead to longer-term contracts with tenants as their utility costs are lower and quality of living standards higher, guaranteeing a more stable revenue stream.

An International Finance Corporation (IFC) report on green buildings states that there is evidence green buildings (new buildings) "can decrease operational costs by up to 37%, achieve higher sale premiums of up to 31% and faster sale times, have up to 23% higher occupancy rates and have higher rental income of up to 8%." (IFC 2019c, vi).

To transform technically doable and economically desirable energy efficiency measures into day-to-day reality experience shows that three preconditions should be in place: policies and implementation instruments, database, and a funding strategy.

SUMMARY BOX

Impacts of energy efficiency are felt macro-economically as well as in an increase in asset value. Energy efficiency has proven to be a source of employment and new types of jobs.

Social and Environmental Impact

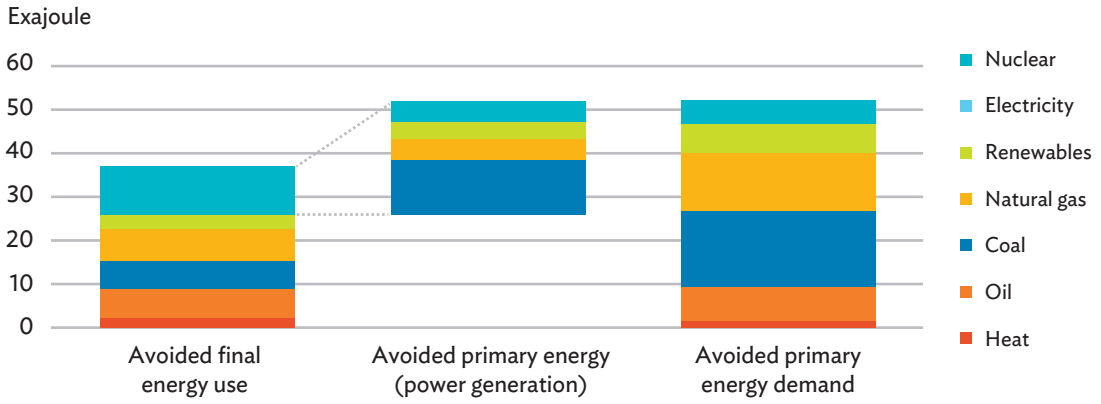
Environmental impacts

Energy efficiency delivers a number of environmental benefits, the largest of which is the reduction of greenhouse gases and other pollutant emissions, e.g., from the power stations that generate electricity. Addressing BEE is the most cost-effective approach to mitigate emissions (WRI 2019). IEA (2019b) calculated that in the ASEAN countries, the PRC, and India, the buildings and building construction sector accounted for 27% of energy use and 24% of CO_2 emissions in 2018 (Figure 4). These figures do not include emissions from the manufacturing of building materials.

In the same report, the annual emissions from buildings could be reduced by nearly 3,000 metric tons of carbon dioxide ($MtCO_2$) by 2040 if the current Stated Policy Scenario were replaced by the Sustainable Development Scenario.[19] In case the material life cycle of buildings was included, the reduction of greenhouse gases could even be greater, e.g., 80% in the PRC in residential buildings. A view at Figure 17 makes clear where the main greenhouse gas emission savings would come from. Coal, oil, and gas are the largest energy providers of electricity and the largest polluters. This the more if the entire logistics such as shipments, etc., are included in the calculation. A reduction in overall energy demand would also put a hold on the depletion of natural resources as would a shift from fossil to renewable energy.

[19] The Sustainable Development Scenario is fully aligned with the Paris Agreement, holding the global average temperature rise to below 1.8°C.

Figure 17: Avoided Energy Use of International Energy Agency Countries in 2017 from Efficiency Improvements Since 2000, by Fuel 2000–2017



Source: International Energy Agency. 2019a. Multiple Benefits of Energy Efficiency.

An often-neglected environmental impact is the extraction of resources for the generation of power, such as coal in particular, but also petroleum. These can have devastating effects on the landscape and the entire ecosystem of the region. If not attended to properly, the detrimental effects on water and air quality of that region are felt for ages. Indian Green Building Council's data show that green buildings consume 20%–30% less energy and save around 30%–50% water (Dhir 2021). Similarly, nuclear power generation has environmental impacts seldom accounted for. It is not only the risk that after the accident in Fukushima that has provided ample evidence of what can happen, but the severe issues nuclear waste is posing has so far not been solved by any of the nuclear power-producing nations and remains an environmental time bomb.

Social Impacts

At a social level, physical and mental health are one of the core benefits. Energy efficiency improves mainly indoor living quality and, to a certain extent, the outdoor environment by improving the air quality,[20] humidity, temperature, and noise levels. Residential homes, as well as workplaces, benefit from it.

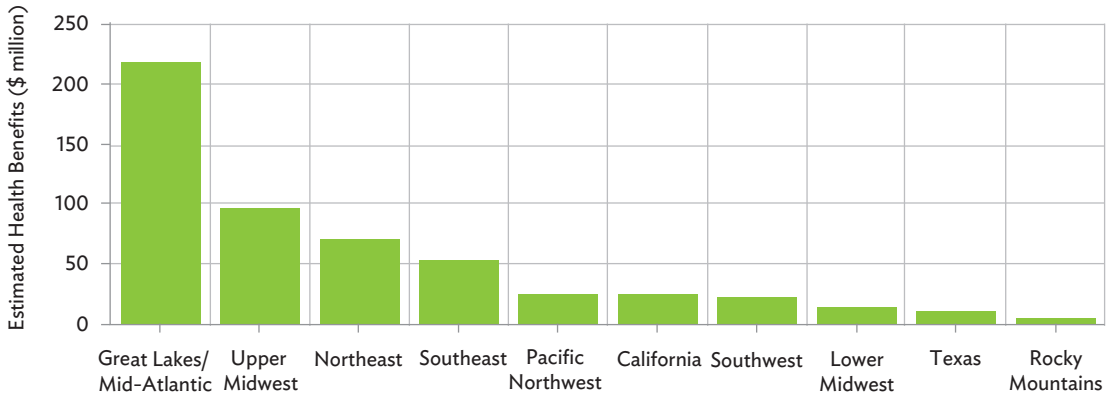
Especially for low-income groups who suffer from fuel poverty,[21] energy efficiency measures have a huge impact. Typically, this group lives in urban dwellings with poor building quality and relatively high energy costs. Poverty alleviation programs that encompass fully supported retrofit packages, and direct and indirect subsidies have proven to have positive results, whereby the retrofitting part was most successful. The New Zealand program "Heat Smart" showed that the monetized benefit after retrofitting for families from low-income groups was $531 annually compared to a control group at a higher income level, where $183 in benefits was achieved (WUNZ:HS 2012). Higher disposable income releases more people from fuel poverty.

Public health benefits were also found in the US due to improvements in air quality after utilities participated in an energy efficiency program. Not to speak of a reduction of overall hospital costs, which still needs to be quantified.

[20] Studies point mainly to various cardiovascular and respiratory diseases.

[21] Fuel poverty is defined as spending more than 10% of your available income on energy. Further reading: Liddell, C., and C. Morris. 2010. Fuel poverty and human health: A review of recent evidence. *Science Direct.* 38 (6). pp. 2987–2997.

Figure 18: One Year of Monetary Health Benefits Due to Avoided Emission from Utility Electric Efficiency Programs in 2017 in the United States



Source: ACEEE, Alliance to Save Energy, The Business Council for Sustainable Energy. 2020. Co-Benefits with Energy Savings; Energy Efficiency Impact Report.

Other social impacts of energy efficiency relate to the creation of new jobs and the demand for work also for non-skilled labor, for example, in construction. Most important, however, is the formation of a new industry that generates jobs at all levels. It offers opportunities to upgrade skills and technical knowledge as well as venture into entirely new jobs, such as energy auditors. The social impact, especially for an often younger but unemployed generation, is high. A stable, highly digitally developed industry has many positive effects and may stimulate the economy.

A social as well as an economic benefit of energy efficiency is the reduction in mainly imported fuels. A lot of the national wealth is transferred to foreign countries. If these expenditures can be saved society would benefit as more and stable financial flow is available for national projects.

Actions from ADB

ADB has a long-standing commitment to increase investment in energy efficiency, mainly SSEE, and renewable energy in its DMCs. Since 2010, ADB has spent, on average, over 20% of its portfolio in the energy sector, which amounted to over $42 billion. Many DMCs have yet to prioritize DSEE despite its great potential and co-benefits for financing power grid constructions and renewables (IED, ADB 2020). The PRC has taken proactive actions on energy efficiency, which, however, was initially driven by the purpose of air pollution control. Having recognized that, the bank invested $3.6 billion in energy efficiency from 2016 to 2020, among which $2.7 billion was on the supply-side and $838.7 million on the demand-side such as smart meter systems (ADB 2021).

In 2018, ADB approved the new long-term Strategy 2030 to respond to the region's changing needs.[22] It increasingly prioritizes DSEE through operational priority 3 on tackling climate change and emphasizes BEE and access to renewable heating and cooling through operational priority 4 on making cities more livable. In its bid to maximize the development impact and align with the significant changes in the energy landscape in DMCs, an independent evaluation of ADB's energy sector strategies and operations was carried out by ADB's Independent Evaluation Department (IED). The evaluation findings identified DSEE as one of the five key significant areas to be prioritized and scaled up in more DMCs (IED, ADB 2020).

[22] ADB. 2018. *Strategy 2030: Achieving a Prosperous, Inclusive, Resilient, and Sustainable Asia and the Pacific*. Manila.

In ADB's new energy policy[23] issued in 2021, the expanding efforts from the supply-side to DSEE and cross-sector operations have been highlighted. In particular, promoting cleaner cooling and heating has been identified as one of the prioritized operational areas under the energy policy's first guiding principle to securing energy for a prosperous and inclusive Asia and the Pacific. Recognizing the rapidly mounting demand for cooling and indoor thermal comfort in tropical and subtropical climate zones, ADB will support its DMCs in devising necessary policies and investment programs to accelerate the introduction and adoption of state-of-the-art sustainable cooling solutions. Renewable energy-based, energy-efficient, and thermally driven technologies and systems are among those considered highly relevant, applicable, and scalable in the context of fast-developing Asian cities. For heating, the energy policy has highlighted the competitive advantages of heat pumps and the strategic role they can play in decarbonizing heat generation and supply, which is still dominated by fossil fuels in many Asian countries. There is a large potential for various types of heat pumps, e.g., air-source, water-source, or ground-source, to be applied in these countries. As stated in the energy policy, ADB will help DMCs avail themselves of the benefits of heat pumps, through knowledge generation and demonstration projects that will help leverage project financing. In parallel with specific technologies, promoting DSEE through policy support, use of innovative financing instruments, and mobilization of private sector resources has also been identified by the energy policy as a priority for ADB operations. Residential and commercial buildings are among the key target areas of these cross-sector and cross-thematic interventions.

[23] Source: ADB. 2021. *Energy Policy*. Manila.

3 GREEN BUILDING CERTIFICATION SCHEMES

Green building certification schemes, also known as rating tools, rating systems, or certification systems, are comprehensive evaluation frameworks used to assess and recognize the compliance and performance of buildings or infrastructure projects from the perspective of life cycle resource efficiency and environmental sustainability. Usually, a scheme includes a set of explicit performance criteria against which a building seeking certification is evaluated, as well as related guidelines for the building design, construction, operation, and renovation toward meeting or exceeding the criteria. Commonly, a certification scheme can cover different types of buildings, with a specific module or a subset of the scheme applicable to a specific building type.

Green building certification schemes are playing an increasingly important role in promoting and transforming the sectoral development of a building. Baselines and benchmarks are established for measurement and comparison. Methods are provided to quantify the environmental effects of a building, which help inform sustainable integrated design solutions and facilitate decision-making. A certified building can have better quality and performance and less adverse environmental impacts as compared to what otherwise would have been the most likely case. There are also possible benefits relating to better occupant health and higher productivity that can be attributed to better indoor environmental quality, more access to natural daylighting, and healthier materials within green buildings. Beyond these benefits, green certification can differentiate a building and create monetary value, thus providing additional incentives to investors, developers, and owners (IFC 2021). In the broader context of sustainable development, the World Green Building Council (WGBC) highlights that green buildings can make a significant contribution toward meeting 9 out of the 17 SDGs defined by the United Nations (WGBC 2021).

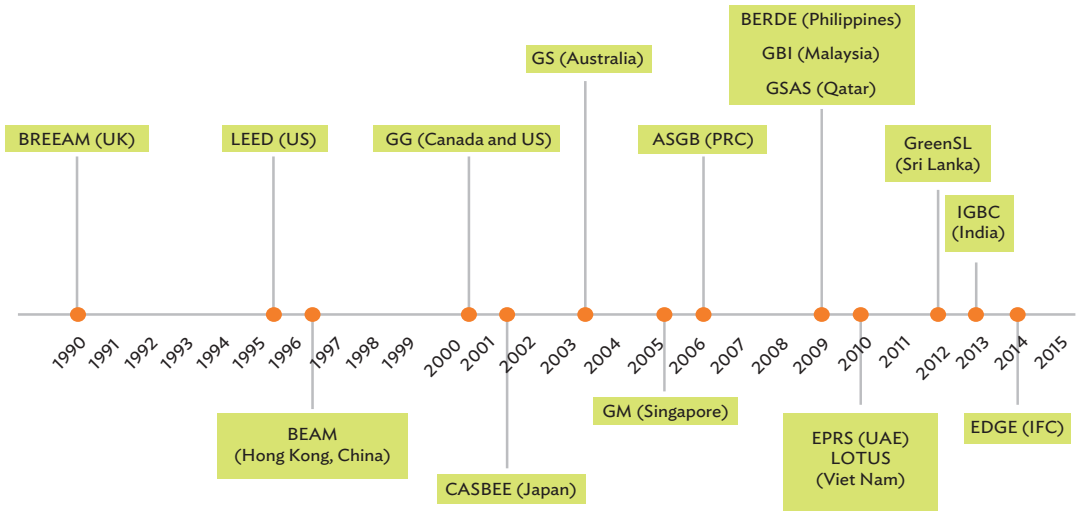
Overview of Prevailing Certification Schemes

Globally, several green building assessment tools and rating and certification schemes have been developed by independent bodies and government agencies over the past three decades. Among them, the Building Research Establishment Environmental Assessment Method (BREEAM) and the Leadership in Energy and Environmental Design (LEED) have emerged as the leading rating and certification schemes and have been the most popular and widely used worldwide. BREEAM was developed by the Building Research Establishment (BRE) in the UK in 1990, becoming the world's first sustainability rating scheme for the built environment. LEED was created in 1995 by the US Green Building Council in partnership with the Natural Resources Defence Council. Both BREEAM and LEED have been used as the basis for the development of many other schemes. For example, the Green Globes for existing buildings were developed by ECD Energy and Environmental Canada in 2000, based on the 1996 Canadian Standards Association publication of BREEAM Canada.

In Asia, the Hong Kong Green Building Council was a forerunner of green building certification. In 1996, it developed the Building Environmental Assessment Method (BEAM) for new office designs and existing office premises in the local context of Hong Kong, China. From 2001 onward, a series of green building certification schemes were launched in Asian countries and regions. In 2001, the Comprehensive Assessment System for Build Energy

Environment Efficiency (CASBEE) was launched by the Ministry of Land, Infrastructure, Transport and Tourism of Japan as a method to evaluate and rate the environmental performance of buildings and the built environment in Japan. In 2003, the Green Building Council of Australia launched the Green Star to set the standard for healthy, resilient, and positive buildings and places. In 2005, the Building and Construction Authority (BCA) of Singapore launched the Green Mark, a benchmarking scheme to drive Singapore's construction industry toward more environmentally friendly buildings. The PRC issued its Assessment Standard for Green Buildings (ASGB) in 2006. As a government-led program, ASGB aims to regulate the evaluation and promote the development of green buildings across the PRC. There were three schemes launched in 2009. Malaysia launched the Green Building Index (GBI) as its industry-recognized green rating system for buildings to promote sustainability in the built environment and raise awareness among developers, architects, engineers, planners, designers, contractors, and the public about environmental issues. Qatar launched the Global Sustainability Assessment System (GSAS), which was the first integrated and performance-based system in the Middle East and North Africa region, designed for assessing and rating buildings and infrastructure for sustainability impacts. In the same year, the Philippines' national voluntary green building rating system, Building for Ecologically Responsive Design Excellence (BERDE), was launched through the Philippine Energy Efficiency Project-Efficient Building Initiative. In 2010, the Abu Dhabi Urban Planning Council developed and launched the Pearl Building Rating System for Estidama (EPRS) as a rating framework for sustainable design, construction, and operation of communities, buildings, and villas. In the same year, the pilot of the voluntary green building rating system of Viet Nam, LOTUS, was released by Vietnam Green Building Council. In 2012, the GreenSL rating system for built environment was developed by the Green Building Council of Sri Lanka. A year later, India, through its Green Building Council, launched the Indian Green Building Council (IGBC) rating system. The system is a voluntary, consensus-based, and market-driven program aiming to facilitate the development of energy-efficient, water-efficient, healthy, more productive, environmentally friendly buildings in India. In 2014, the Excellence in Design for Greater Efficiencies (EDGE) as an innovation of IFC was launched, with the view of responding to the need for a measurable and credible solution to prove the business case for green buildings and to unlock financial investments, especially in emerging markets.

Figure 19: Timeline of Selected Green Building Certification Schemes



ASGB = Assessment Standard for Green Buildings, BEAM = Building Environmental Assessment Method, BERDE = Building for Ecologically Responsive Design Excellence, BREEAM = Building Research Establishment Environmental Assessment Method, CASBEE = Comprehensive Assessment System for Build Energy Environment Efficiency, EDGE = Excellence in Design for Greater Efficiencies, EPRS = Pearl Building Rating System for Estidama, GBI = Green Building Index, GG = Green Globes, GM = Green Mark, GreenSL = GreenSL Rating System Sri Lanka, GS = Green Star, GSAS = Global Sustainability Assessment System, IGBC = Indian Green Building Council, IFC = International Finance Corporation, LEED = Leadership in Energy and Environmental Design, LOTUS = Lotus Certification System, UAE = United Arab Emirates, UK = United Kingdom, US = United States.

Source: Author.

The timeline of the green building certification schemes is shown in Figure 20. The timeline is not intended to be an exhaustive coverage of all schemes in Asia, rather, it is a selective list covering some major economies to show the general evolution of green building certification schemes in the region. As can be seen, there has been a surge in certification schemes in Asia over the past 15 years. This can be largely ascribed to the good demonstration and successful implementation of BREEAM and LEED worldwide, including in Asia. In addition, what is not shown in the figure is the updating of these schemes from time to time to keep abreast of the development trend of green buildings against the backdrop of increasing emphasis on climate change mitigation and adaptation. Timely and appropriate updating of these schemes ensures their alignment with the continuously evolving building design standards and climate policies and enhances their applicability to the evaluation, rating, and certification of buildings in local contexts. For example, the BEAM in Hong Kong, China was updated to BEAM Plus in 2010. The ASGB in the PRC was revised twice: in 2014 and in 2019. The Green Mark of Singapore has undergone several rounds of updating since its launch in 2005, with the latest version being Green Mark 2021. The persistent development of new schemes and refinements of existing ones strongly demonstrate the increasing recognition and active pursuit of environmental, technological, economic, and social benefits of certified green buildings among governments, investors, planners, developers, architects, engineers, owners, and occupants.

The rest of this subsection provides an overview of these schemes. The subsequent two subsections focus on a brief discussion of key evaluation criteria of the schemes and case studies of certified green buildings in Asia, respectively.

Box 2: Overview of Selected Green Building Certification Schemes

BREEAM (United Kingdom)

Building Research Establishment Environmental Assessment Method (BREEAM) is an international scheme that provides independent third-party certification of the assessment of the sustainability performance of individual buildings, communities, and infrastructure projects. Launched in 1990 by the Building Research Establishment (BRE), BREEAM was the world's first environmental assessment method for buildings and is defined by building science and research. It aims to deliver sustainable solutions, encourage a holistic approach to sustainability that is based on sound science and measures what is important, and improve building environmental performance. As the world's longest established rating scheme for building sustainability, BREEAM is internationally recognized and has been widely used in 80 countries worldwide, with more than 2,250,000 projects registered and more than 565,000 certificates issued. BREEAM has also served as the basis for many of the prevailing green building certification systems, including LEED and Green Globes.

BREEAM is highly flexible and can be applied to a wide range of building types and locations, with various technical standards for new construction, in-use, refurbishment and fitout, infrastructure, and master planning of communities. BREEAM measures the performance and sustainable value of a development across a broad set of indicators clustered in ten categories, covering energy, health and well-being, innovation, land use, materials, management, pollution, transport, waste, and water. Each of these categories addresses the most influential factors, including carbon emissions reduction, design durability and resilience, adaptation to climate change, and ecological value and biodiversity protection. Weighting is applied to each category to encourage projects to focus on the categories with the highest environmental impact. Minimum standards are set to ensure that key aspects of performance across a category are met to achieve potentially higher levels of certification. This provides a level of flexibility for use while maintaining the rigor of the standard. Where a project does not fit the scope of an existing standard, BREEAM offers a bespoke service that tailors the criteria in the existing standards to the development's specific use, sustainability opportunities and its location without compromising the rigor of the standard. The ratings of BREEAM range from acceptable (for in-use version only) to pass, good, very good, excellent to outstanding and it is reflected in a series of stars on the BREEAM certificate. The rating enables comparability between projects, provides reassurance to developers and users, and in turn underpins the quality and value of the asset.

Further information: BREEAM.

continued on next page

Box 2 *continued*

LEED (United States)

Leadership in Energy and Environmental Design (LEED) is a voluntary green building rating and certification system developed by the U.S. Green Building Council in 1995. Available for virtually all building, community, and home-project types, LEED provides a holistic framework for healthy, highly efficient, and cost-saving green buildings. A LEED certification is a globally recognized symbol of sustainability achievement and leadership. LEED is one of the most widely used green building rating systems in the world, with more than 100,000 projects registered and 48,600 projects certified across 178 countries and territories as of 2020.

LEED is for all building types and all building phases including new construction, interior fit outs, operation and maintenance, and core and shell. It offers a range of specific rating systems, which are designed for building design and construction, interior design and construction, homes, building operation and maintenance, neighborhood development, and cities and communities. When several rating systems appear to be appropriate for a project that involves mixed construction or space usage type, the 40/60 rule is followed to make a decision. A particular system should be used if more than 60% of the project's gross floor area is appropriate for that system. If less than 40% is appropriate, then that system should not be used. If the appropriateness falls between 40% and 60%, the use of that system or a different one is at the discretion of the project team.

Projects pursuing LEED certification need to earn points for green building strategies across a range of categories, including location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design, regional priority, and integrative processes. One hundred points are available across these categories. While project teams are free to go for any points under these categories within the chosen specific rating system, there are mandatory prerequisites that set the minimum requirements that all buildings need to meet to achieve LEED certification. Based on the compliance with prerequisites and the number of points achieved, a project is awarded one of four LEED certification levels: Certified, Silver, Gold, or Platinum.

Further information: LEED.

continued on next page

Box 2 *continued*

ASGB (People's Republic of China)

Assessment Standard for Green Buildings (ASGB) is a government-led green building certification program established by the Ministry of Housing Urban–Rural Development (MOHURD) of the People's Republic of China. The standard was initially issued in 2006, revised in 2014, and further revised in 2019. The purpose of formulating this standard is to regulate the evaluation and promote the development of green buildings. The assessment standard, covering both residential buildings and public buildings, consists of five main categories of indexes: safety and durability, health and comfort, occupant convenience, resources saving, and environment livability. Each category is assessed using a set of "prerequisite items," which are either pass or fail, and a set of "scoring" items, which are scores within predefined ranges. In addition, there is a separate score-based bonus category for improvement and innovation items, which aims to encourage the adoption of innovative technologies and products for higher building performance. The total score of assessment forms the basis of the grade of a building, i.e., basic, one-star, two-star, or three-star green building. When all prerequisite items are met, a building is rated as being of basic grade. On top of that, depending upon the scores of scoring items and the compliance with additional technical requirements (thermal performance of envelope, sound insulation, indoor air quality, etc.), a building may be rated as a one-star, two-star, or three-star green building. When an assessed building intends to apply for green financial services, it is required that the building's energy-saving measures, water saving measures, energy consumption and carbon emissions shall be calculated and reported in detail. This standard is supported by the Assessment Standard for Green Retrofitting of Existing Buildings, which was made available to the public for comments in early 2021 and is currently being finalized.

Further information: Green Building Network.

CASBEE (Japan)

Comprehensive Assessment System for Build Energy Environment Efficiency (CASBEE) is a method for evaluating and rating the environmental performance of buildings and the built environment. It was developed by a research committee established in 2001 through the collaboration of academia, industry, and national and local governments in Japan. CASBEE aims to both enhance the quality of life for building occupants and reduce the life cycle resource use and environmental loads associated with the built environment. Under CASBEE, there are a set of different tools, each of which is tailored to a certain type of buildings and/or a specific purpose of assessment. The latest versions of the tools cover buildings (new construction, existing buildings, renovation), commercial interiors, detached houses (new construction), dwelling unit (new construction), heat island, cities, and market promotion, among others. The assessment areas focus on energy efficiency, resource efficiency, local environment, and indoor environment. Both indoor and outdoor spaces are considered as part of the assessment but are assessed separately.

Further information: CASBEE.

continued on next page

Box 2 *continued*

BERDE (Philippines)

Building for Ecologically Responsive Design Excellence (BERDE) is the Philippines' national voluntary green building rating system recognized by the Government of the Philippines, through the Department of Energy's Philippine Energy Efficiency Project-Efficient Building Initiative. It is a tool to measure the resource efficiency and environmental performance of building projects and certify how a building performs above and beyond existing national and local building and environmental laws, regulations, and mandatory standards. The development process of BERDE was guided by internationally recognized methodologies for developing standards, and by the Quality Assurance Guide for Green Building Rating Tools issued by the World Green Building Council. The core framework of BERDE defines credits and requirements essential to a green building, across energy, water, waste, materials, emissions, land, and ecology, among others. The latest version of the BERDE (version 4.0.0) was launched in 2021. It introduced further socioeconomic priorities for green building projects, including the contribution of projects to health and well-being, community engagement, and economic opportunities. This version also considered the learnings from previous BERDE projects, feedback from industry and updates on laws, regulations, and standards.

Further information: BERDE.

BEAM Plus (Hong Kong, China)

Building Environmental Assessment Method (BEAM) Plus assessment is Hong Kong, China's leading initiative to offer independent assessments of building sustainability performance. The local BEAM scheme was established in 1996, largely based on the United Kingdom's BREEAM. In November 2009, the scheme was revamped and renamed BEAM Plus. Recognized and certified by the HK Green Building Council (HKGBC), BEAM Plus sets a comprehensive set of performance criteria for a wide range of sustainability issues relating to the planning, design, construction, commissioning, fitting out, management, and operation and maintenance of a building. There are four assessment tools under BEAM Plus: New Buildings, Existing Buildings, Interiors, and Neighborhood, covering the whole-building life cycle. New buildings cover the demolition, planning, design, construction, and commissioning of a new building project. It can also be applied to major renovations, alterations, and additions. Existing buildings evaluate the actual performance of existing building in energy efficiency and green management policies to ensure the building is operated in a sustainable manner. Interiors cover the design and construction of fitout, renovation and refurbishment works in nondomestic occupied spaces, focusing on energy use, sourcing of environmental-friendly building materials, and indoor environmental quality. The neighborhood adopts a holistic approach to assessing sustainability performance at the early or inception stage of a project. The assessment concerns the design of space between buildings and places the emphasis on socioeconomic elements.

Further information: HKGBC.

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Box 2 *continued*

GM (Singapore)

The Green Mark certification scheme, launched by the Building and Construction Authority (BCA) of Singapore in January 2005, is a green building rating system designed to evaluate a building's environmental impact and performance. It provides a comprehensive framework for assessing the overall environmental performance of new and existing buildings to promote sustainable design, and best practices in construction and operations in buildings. Key criteria of the scheme cover climatic responsive design, building energy performance, resource stewardship, smart and healthy building, and advanced green efforts. For new buildings, the scheme encourages the design and construction of green, sustainable buildings that are more climate-responsive, energy- and resource-efficient, and have healthier indoor environments. For existing buildings, the scheme encourages the owners and operators to reduce the adverse impacts of their buildings on the environment and occupant health over the building's life cycle. The scheme also recognizes the role of building users in reducing energy consumption by having assessments specifically for office interior, retail outlets, restaurants, and supermarkets. To accelerate the adoption of environmentally friendly building technologies and building design practices, the Green Mark scheme has introduced a series of incentives in various forms. The currently available ones include the building retrofit energy efficiency financing scheme, which provides financing options to offset up-front costs of energy efficiency retrofits of existing building, and the built environment transformation gross floor area incentive scheme targeting private sector developments, which was recently introduced in November 2021.

Further information: Green Mark Certification Scheme.

Green Star (Australia)

Launched by Green Building Council of Australia (GBCA) in 2003, Green Star (GS) is Australia's only national, voluntary rating system for buildings, fitouts, and communities. It is an internationally recognized sustainability rating system setting the standard for healthy, resilient, and positive buildings and places. There are five GS rating tools, providing a means of certification for building design and construction, operation, fitouts, and communities. These tools have been developed by GBCA, in close consultation with industry and government, and continues to evolve. The GS Buildings guides the sustainable design and construction of schools, offices, universities, industrial facilities, public buildings, retail centers and hospitals. The GS Interiors rates the interior fitout works of buildings. The GS Communities assesses the planning, design, and construction of large-scale development projects at a precinct, neighborhood, and/or community scale. The GS Performance is dedicated to assessing the operational performance of existing buildings across various impact categories. The GS Homes, which was most recently launched in August 2021, is a standard assessing the health, resilience, and energy efficiency of homes. All GS rating tools include an "Innovation" category that rewards projects that implement new technologies and approaches or exceed current industry best practice.

Further information: Green Building Council Australia.

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Box 2 *continued*

Pearl Building Rating System for Estidama (United Arab Emirates)

The Pearl Building Rating System (PBRS) for Estidama (EPRS) is the green building rating system developed by the Abu Dhabi Urban Planning Council as part of the sustainable development initiative, *Estidama* ("sustainability" in Arabic). PBRS encourages water, energy, and waste minimization, local material use, and aims to improve supply chains for sustainable and recycled materials and products. PBRS has established three rating stages: design, construction, and operational. The design rating rewards measures adopted during the design development of the project that meet the intent and requirements of each credit. The construction rating ensures that the commitments made for the design rating have been achieved. The operational rating assesses the built-in features and operational performance of an existing building and ensures the building is operating sustainably. The PBRS is applicable to all building typologies, their sites, and associated facilities. In essence, any building constructed for permanent use and that is air-conditioned must meet the PBRS requirements. An Executive Council Order of May 2010 stated all new buildings must meet the one Pearl requirements starting in September 2010, while all government funded buildings must achieve a minimum of two Pearls. Following this mandate, significant effort has been made to align the PBRS with the Abu Dhabi Development and Building Codes.

Further information: Pearl Building Rating System.

Green Building Index (Malaysia)

The Green Building Index (GBI) is Malaysia's industry-recognized green rating system for buildings to promote sustainability in the built environment and raise awareness among developers, architects, engineers, planners, designers, contractors, and the public about environmental issues. The tool provides an opportunity for developers and building owners to design and construct green, sustainable buildings that can provide energy savings, water savings, a healthier indoor environment, better connectivity to public transport and the adoption of recycling and greenery for their projects and reduce the impact on the environment. The evaluation process consists of a design assessment, leading to a provisional certification, and a completion and verification assessment, leading to a final certification. To maintain the certification, reassessments are required every 3 years. The assessment of commercial and residential properties under the GBI is based on six main criteria, including energy efficiency, indoor environment quality, sustainable site planning and management, materials and resources, water efficiency, and innovation.

Further information: Green Building Index.

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Box 2 *continued*

IGBC (India)

The Indian Green Building Council (IGBC) rating system is a voluntary, consensus-based, and market-driven program aiming to facilitate the development of energy-efficient, water-efficient, healthy, more productive, environmentally friendly buildings. The system is applicable to all five climatic zones of India. It is designed to initiate a need to address national priorities and increase the quality of life for its occupants and it keeps pace with current standards and growing technology. The scope of the system covers new buildings and existing buildings across various types. The IGBC receives recognition from India's central and state government agencies which offers incentives to promote IGBC-related green building projects. For example, the Ministry of Environment, Forest and Climate Change offers fast track environmental clearance for green building projects which are pre-certified and/or provisionally certified by IGBC. Various state government agencies offer financial incentives in various forms, such as free-of-charge floor area ratio, exemption of building scrutiny fee, reduction on permit fees, reimbursement of certification fee, financial assistance at concessional rates, etc.

Further information: IGBC.

GSAS (Qatar)

The Global Sustainability Assessment System (GSAS) is the first integrated and performance-based system in the Middle East and North Africa region, designed for assessing and rating buildings and infrastructure for their sustainability impacts. It was developed by the Gulf Organisation for Research and Development and its collaborators. The primary objective of GSAS is to create a sustainable built environment that minimizes ecological impact and reduces resource use, while addressing the specific needs and environment of the Middle East and North Africa region. Representing green building regulations within Qatar construction specifications, GSAS takes an integrated life cycle approach to improve the design, construction, and operations of buildings. The system has three certifications, i.e., (1) GSAS Design and Build; (2) GSAS Construction Management; and (3) GSAS Operations. The sustainability assessment focuses on eight categories and criteria, including urban connectivity, site, energy, water, materials, indoor environment, cultural and economic values, and management and operations.

Further information: GSAS.

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Box 2 *continued*

Green Globes (Canada and United States)

Green Globes is an online assessment protocol, rating system, and guidance for green building design, operation, and management. It is interactive, flexible, and affordable, and provides market recognition of a building's environmental attributes through third-party assessment. Green Globes originated in Canada and was brought to the United States (US) by the Green Building Initiative (GBI) in 2004. Now it is being used in both Canada and the US. The Green Globes brand and associated rating systems are administered in the US by GBI and in Canada by its wholly owned, nonprofit subsidiary, GB Initiative Canada. Green Globes have modules for new construction and significant renovations, sustainable interiors, and existing buildings. These modules can be used for a wide range of commercial, institutional, and multi-residential building types. A series of performance criteria are assessed, including project management, site, energy, water, resources, emissions, indoor environment, space, and amenities. The weighting of specific criterion varies depending upon the module. Different from LEED, there are no prerequisites under Green Globes. Based on assessment outcome, five levels of certification are offered, from 1 as the lowest to 5 as the highest.

Further information: Green Globes.

EDGE (International Finance Corporation)

The Excellence in Design for Greater Efficiencies (EDGE) is a green building certification system focused on making buildings more resource-efficient. Now covering more than 170 countries, EDGE was created and launched in 2014 by the International Finance Corporation (IFC), a member of the World Bank Group, to respond to the need for a measurable and credible solution to prove the business case for green buildings and to unlock financial investments. EDGE enables design teams and project owners to assess the most cost-effective ways to incorporate energy and water saving options into their buildings. EDGE includes a cloud-based platform to calculate the cost of going green and utility savings. The state-of-the-art engine has a sophisticated set of city-based climate and cost data, consumption patterns, and algorithms for predicting performance results. There are three levels of certification, applicable to new construction, existing buildings and major renovations of various types of buildings. On the condition that at least 20% savings in water and materials are achieved, a project may be awarded (1) EDGE Certified, if a minimum of 20% energy savings are achieved; (2) EDGE Advanced, if a minimum of 40% energy savings are achieved; or (3) Zero-Carbon, if 100% energy savings are achieved either through renewables or carbon offsets. The consortium of Sintali-SGS and Green Business Certification Inc. are the approved certifiers who operate in most countries where projects can be designed and certified with EDGE.

Further information: EDGE.

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Box 2 *continued*

GreenSL (Sri Lanka)

The GreenSL rating system for built environment was developed by the Green Building Council of Sri Lanka as a "home-grown system" with all norms acceptable to leading rating systems. The formulation of GreenSL learned from the experiences and lessons of green building initiatives of India, the People's Republic of China, Indonesia, Malaysia, and Singapore. It followed an open, consensus-based process under the supervision of the Green Environmental Rating and Life Cycle Assessment Committee composed of a diverse group of practitioners and experts representing a cross section of the construction industry. GreenSL aims to encourage environmentally acceptable design, construction, and operation and maintenance of buildings. It consists of two major assessment categories, with one for new constructions and major renovations and the other for buildings in operation. A building is assessed across eight performance criteria, including management, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation and design process, and social and cultural awareness. Based on assessment outcome, a building is awarded one of the four levels of certification—certified, silver, gold, or platinum.

Further information: GreenSL.

LOTUS (Viet Nam)

LOTUS is a set of voluntary green building rating systems developed by Vietnam Green Building Council (VGBC) based on established building physics science and adapted to the conditions, climate, and regulations of the Viet Nam construction sector. The pilot program of LOTUS was released in 2010. With several updates and revisions, the latest version was released in 2019. LOTUS provides a holistic assessment framework for design, construction, and operation of buildings from a whole-building perspective. It assesses and recognizes performance in a series of key evaluation categories, including energy, water, material, indoor environment, and site. The set of evaluation categories and weighting of a specific category vary, depending upon building types and project scopes—new construction, major renovation, buildings in operation, single-dwelling homes, small non-housing projects, interior fitout projects, and small interior fitout projects. Points are awarded for the achievement of credit requirements in each category. In addition, there are certain prerequisites under each category that a building must meet to qualify for consideration of other credits. LOTUS certification has four levels of certification—certified, silver, gold, and platinum. To be certified, a project must earn a minimum of 40 points. The LOTUS assessment and training programs are managed by the Vietnam Green Building Social Enterprise Co. Ltd. registered by VGBC.

Further information: LOTUS Certification System.

Energy as a Key Evaluation Element of Green Building Certification Systems

A further review of the summarized green building certification schemes identifies a wide range of themes used to evaluate green building strategies and approaches across various aspects. Water, materials, and energy are all covered in the schemes. Subsequently, the themes covered in descending order include indoor environment, site, land and outdoor environment, and innovation. Associated with the seven themes are specific evaluation criteria for green buildings.

It is useful to further investigate the relative importance of the seven themes. Based on the manuals, guidelines, and instructions of the rating schemes, the respective weighting of the seven themes is calculated for each scheme. The average weighting of each theme across the examined schemes and the corresponding standard deviation are also calculated (Table 4).

Table 4: Weighting of 7 Essential Themes of 12 Rating Schemes

No.	Scheme	Energy	Site	Indoor Environment	Land and Outdoor Environment	Material	Water	Innovation
1	Assessment Standard for Green Buildings (ASGB)	19.0%	–	14.0%	17.0%	14.0%	16.0%	9.0%
2	Building Research Establishment Environmental Assessment Method (BREEAM)	20.0%	–	–	7.7%	12.5%	6.7%	10.0%
3	Comprehensive Assessment System for Build Energy Environment Efficiency (CASBEE)	20.0%	–	20.0%	15.0%	12.0%	3.0%	–
4	Pearl Building Rating System for Estidama (EPRS)	24.0%	–	8.5%	19.5%	16.0%	24.0%	2.0%
5	Green Building Index (GBI)	23.0%	33.0%	12.0%	–	8.0%	12.0%	8.0%
6	Green Globes (GG)	39.0%	12.0%	16.0%	–	13.0%	11.0%	–
7	Green Mark (GM)	18.0%	–	–	–	9.4%	9.4%	–
8	Global Sustainability Assessment System (GSAS)	24.0%	13.0%	16.0%	–	10.0%	16.0%	–
9	Green Star (GS)	25.0%	–	16.0%	10.0%	14.0%	10.0%	9.0%
10	Building Environmental Assessment Method Plus (BEAM Plus)	35.0%	25.0%	20.0%	–	8.0%	12.0%	–

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Table 4 *continued*

No.	Scheme	Energy	Site	Indoor Environment	Land and Outdoor Environment	Material	Water	Innovation
11	Indian Green Building Council (IGBC)	28.0%	14.0%	12.0%	–	16.0%	18.0%	7.0%
12	Leadership in Energy and Environmental Design (LEED)	28.0%	12.0%	14.0%	–	16.0%	9.0%	4.0%
Average weighting of each theme		25.2%	18.2%	14.9%	13.8%	12.4%	12.3%	7.0%
Standard deviation		6.4%	8.8%	3.6%	4.9%	3.0%	5.6%	2.9%
Average weighting of all themes across all schemes		14.8%						

– = not applicable.

Source: Adapted from (Hwang, B.-G. 2018. Green Building Rating Systems: Practices and Research Efforts. In *Performance and Improvement of Green Construction Projects: Management Strategies and Innovations*. Elsevier Science and Technology. pp. 23–44; Shan, M. and B. Hwang. 2018. Green Building Rating Systems: Global Reviews of Practices and Research Efforts. *Sustainable Cities and Society*. 39. pp. 172–180.).

The examined schemes have their weighting in a relatively wide range of 18% and 39%, with an average value of 25.2% and a standard deviation of 6.4%. The average weighting of 25.2% substantially exceeds that of the other six themes, namely site (18.2%), indoor environment (14.9%), land and outdoor environment (13.8%), material (12.4%), water (12.3%), and innovation (7%). It is also much higher than the average weighting of all seven themes across all schemes (14.8%). Despite having a relatively large standard deviation, energy has the highest weighting among the seven themes under 9 out of the 12 examined schemes. For each of the nine schemes, the difference between energy and the specific themes having the second highest weighting varies considerably, ranging from 2% to 23%. The three exceptions are CASBEE of Japan, which allocates the highest weighting (20%) to both energy and indoor environment; EPRS of the United Arab Emirates, which allocates the highest weighting (24%) to both energy and water (24%); and GBI of Malaysia, which defines a site as the most important criterion (33%) and energy as the second most important one (23%). The energy weighting under all 12 schemes is higher than the cross-scheme average weighting of all the seven themes, i.e., 14.8%. These results suggest that energy carries the most importance in evaluating the performance of green buildings. The reduction of energy use, particularly the reduction of peak load, use of energy efficiency appliances, equipment and systems, use of renewable energy, and energy monitoring and reporting are among the main indicators to evaluate the energy criterion, as defined in the examined schemes.

Case Studies of Certified Green Buildings in Asia

This subsection provides seven case studies of certified green buildings by selected certification schemes introduced in the preceding subsections. The case studies have been purposively selected to cover diverse geographical locations and climatic conditions across Asia—Azerbaijan, Bangladesh, India, Kazakhstan, the PRC, the Philippines, and Singapore. Some of the cases have been certified by two or more schemes. As energy is the most important evaluation theme of green buildings and the focus of this handbook, these case studies are presented to highlight the design features of energy-related strategies and technologies of the buildings. Where possible, the actual energy performance of the buildings is discussed. Typical energy efficiency strategies, technologies, and practices adopted in these case studies are described in more detail in chapters 2 and 3 of this handbook.

Box 3: Case Studies

CASE 1: MEGA SILK WAY SHOPPING MALL, KAZAKHSTAN (BUILDING RESEARCH ESTABLISHMENT ENVIRONMENTAL ASSESSMENT METHOD [BREEAM] 2020)

Summary of Certification

- Scheme and Version: BREEAM In-Use International 2015
- Certification Stage: In-Use
- Rating: Excellent
- Overall Score: 75.4%



Mega Silk Way, Kazakhstan
Source: Mega Kazakhstan.

Description of Building

MEGA Silk Way is the largest and most modern shopping and entertainment center in Kazakhstan, built in the capital of the country as a flagship cutting-edge facility among shopping and entertainment centers in Central Asia. It is an important project in terms of tourism and investment prospects of the capital, combining the best qualities of other MEGA network shopping malls. The mall was designed on the principle of a shopping street. It is a "city within a city" with its own streets and sheltered areas. The mall features a unique concept of social space. A total of 1.5 million cubic meters (m^3) of internal space is bright and airy. The building has three levels, including two elevated floors and one lower ground floor, and nine entrances, two of which are underground. It has parking capacity for 2,113 cars. The ratio of the commercial premises of the shopping and recreation center to the gross floor area is 53%. Monthly visit to the shopping and recreation center is about 1.1 million people.

Green Strategies

The architectural design with regard to orientation, facade, window, roof lights, and so on reduces the cooling and heating loads of the mall. The mall uses supply and exhaust units with heat recovery and frequency converters, as well as an intelligent Building Energy Management Systems. The building and the surrounding area are lit by 4,800 LED luminaries powered by renewable energy.

More than 18% of the building envelope is glazed and provides good access to daylight. Temperature zoning is provided in the mall, which meets design parameters throughout the year. The ventilation system mitigates air pollution by placing air intake grids of 74 air-handling units at the required distance from any sources of air pollution. The use of building materials and products with low emissivity of volatile organic compounds also contributes to keeping a high quality of indoor air.

The mall has more than 300 units of water-efficient sanitary equipment. A rainwater collection system is in place for irrigation of green areas. Local facilities for treatment of rainwater collected from the open car park and specialized well-insulated rooms for placing diesel generator sets and fuel tanks help to minimize the risks of contamination of soil and rainwater by oil products.

The facility is operated in compliance with the approved environmental policy, which contains performance targets for energy efficiency, water consumption reduction, minimization of general waste, and increasing the biodiversity of the facility.

continued on next page

Box 3 *continued*

CASE 2: BAKU WHITE CITY, AZERBAIJAN (BREEAM 2016)

Summary of Certification

- Scheme and Version: BREEAM International New Construction 2013
- Stage: Final
- Location: Baku, Azerbaijan
- Size: 15,861 square meters (m^2)
- Score and Rating: 48.5%, Good



Source: ArchDaily. 2013. Baku White City Office Building Proposal.

Project Background

The impetus for this redevelopment was provided in 2006 when the decree entitled "Comprehensive action plan for improving the ecological conditions in the Azerbaijan Republic during 2006–2010" was issued. The area formerly known as the Black City was being gradually transformed into a vibrant, comfortable business and residential destination, which was symbolic of Baku's development progress. The special meaning of the project for the country brought particular attention to environmental issues. In line with the ecological decree principles, the project team chose BREEAM as the international best practice standard practice for designing the buildings. The White City office building was the first project of the regeneration plan and aimed to provide class A offices with world-class specifications. Along with the building's accessibility and a host of local amenities, the state-of-the-art offices were designed to give its occupants a distinctive market presence.

Green Strategies

The building was developed by the architect to focus on reducing its impact on the local environment, as well as on improving the quality of the internal environment to provide a high standard of healthy office space. Each floor has its own balcony and the five top levels of the building feature extensive terraces. These provide occupants with access to fresh air and good views. Natural light and views create an inspiring environment for business on each floor. The facade of the building is designed as a "quiet" wall system that incorporates high-performance double-glazing to help minimize sound and provide a calm workplace. Modern and sustainable materials are used in the building structure and fitout. For cooling and heating, the building uses a high-efficiency fourth generation variable refrigerant volume system and high efficiency (92%) boilers. Fresh air is distributed with the use of mechanical ventilation, while air extract is performed in a natural manner. Daylight is combined with efficient LED and T5 artificial lighting, controlled through detection sensors. Energy use within the building is sub-metered to provide better building management. Water efficiency is achieved through measures to reduce water use (efficient sanitary fittings and irrigation) and avoidance of leakage. During the design stage a series of studies were conducted to make informed decisions on design alternatives, such as energy modeling in line with the American Society of Heating, Refrigerating and Air-Conditioning Engineers standards, or life cycle impact assessment of materials with the use of IMPACT tool.

continued on next page

Box 3 *continued*

CASE 3: SDE 4, NATIONAL UNIVERSITY OF SINGAPORE (BCA 2019; NUS 2020; NUS 2021A; NUS 2021B)

Summary of Certification

- Scheme and certification: Green Mark Platinum Zero Energy; WELL Gold
- Location: Singapore
- Occupancy type: Academic
- Typology: New construction
- Climate: Tropical
- Size: 8,588 m^2



Source: National University of Singapore.

Description of Building

School of Design and Environment Building 4 (SDE 4) is a new addition to the existing three buildings of the School of Design and Environment at the National University of Singapore. The new building, which was completed in 2019, functions as a living laboratory to promote research collaboration with public agencies and industry partners. With a gross floor area of 8,514 m^2, the building houses a mix of research laboratories, test-bedding facade, design studios, as well as teaching and common learning spaces. It also includes a 3D scanning lab, green building technologies lab, urban greenery lab, and NUS-CDL Smart Green Home.

SDE is characterized by its contemporary architecture design which demonstrates a deep understanding of the tropical climate of Singapore. The design concept incorporates a large overhanging roof, which together with the double facades on the east and west of the building, shade it from solar radiation and provide a cooler interior environment. The building design also makes use of the architectural concept of "floating boxes," where its shallow plan depth and porous layout allows for cross-breezes, natural lighting, and views to the outdoors. Weather permitting, rooms can also be opened to natural breezes, and air-conditioning is used only where it is needed, thereby reducing the electricity consumption of the building.

Net-Zero Energy Strategies

SDE 4 utilizes solar energy by having more than 1,200 solar photovoltaic (PV) panels installed on the roof. On days when there is insufficient solar energy, the building draws electricity from the power grid. When the solar energy is more than enough, electricity generated by the PV panels is supplied to the grid. Throughout a year, the net amount taken from the grid is zero, or even negative, thereby achieving net-zero energy consumption.

Integral to SDE 4's concept of net-zero energy consumption is the need to rethink air-conditioning, which typically accounts for up to 60% of a building's total energy consumption in a tropical country like Singapore. This has resulted in the adoption of an innovative hybrid cooling strategy to avoid overcooling of rooms, which is a common issue in buildings in Southeast Asian countries. Rooms are supplied with 100% fresh precooled air at higher temperature and humidity levels than a conventional system and this is augmented with increased air speeds from ceiling ventilators. This strategy, coupled with the building's tropical architecture design that encourages natural ventilation, creates a thermally comfortable indoor environment while ensuring much less energy consumption than conventional air-conditioning systems. In addition, with daylight utilization maximized through the architectural design, energy savings are further enhanced through a network of photocell and occupancy sensors.

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Box 3 *continued*

SDE 4 offers useful lessons to architects and engineers on how energy use and occupant comfort might be better balanced in future buildings. It also demonstrates that a building need not deliver the same conditions all day to everyone. Giving occupants the option to control indoor environment is a viable solution to achieve comfort.

Actual Energy Performance of SDE 4 (April 2019 to March 2020)

Actual energy use	470,750 kilowatt-hours (kWh)
Actual energy produced	619,345 kWh
Net energy use	(148,595 kWh)
Energy use intensity	55 kWh/square meter/year

Note: ( ) = negative

CASE 4: ARTHALAND CENTURY PACIFIC TOWER, PHILIPPINES (USGBC 2018A; IFC 2019A; WGBC 2019)

Summary of Certification

- Scheme and certification: Leadership in Energy and Environmental Design (LEED) Platinum; EDGE Zero Carbon; BERDE 5-stars
- Location: Taguig, Metro Manila
- Climate: Tropical
- Type: Commercial
- Size: 38,714 m^2



Source: Edge Buildings.

Project Background

Arthaland is a publicly listed company in the Philippines and the pioneer developer for premium green and sustainable projects. At the heart of every Arthaland project is sustainability, exceptional and innovative design, and high-quality construction standards. All residential and office projects of the company aim to adhere to global and national standards for green buildings, e.g., the LEED by the US Green Building Council and the BERDE by the Philippine Green Building Council. Arthaland is the world's first developer to earn the International Finance Corporation's EDGE Zero Carbon certification for its flagship office building, the ArthaLand Century Pacific Tower (ACPT). The building reduces energy use by 45% (with 100% hydroelectric energy supplied by the Pantabangan–Masiway Hydroelectric Plant), water use by 64% and embodied energy in materials by 34%. It is the only triple-certified project in the Philippines, having received the EDGE Zero Carbon certification, the LEED Platinum rating, and the BERDE 5-star certification. All these certifications are the highest and most prestigious awards in the mentioned three rating systems.

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Box 3 *continued*

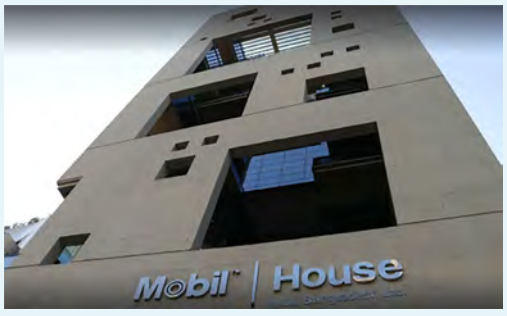
Energy and Carbon Strategies

- ACPT has been designed to achieve its exemplary sustainable energy performance by means of the following:
- The building is designed with triple- and double-glazed curtain wall systems strategically oriented to insulate the building from solar gain while allowing natural light to be transmitted in, thereby reducing the energy required for cooling and lighting.
- The mechanical systems optimize thermal zoning to consider the different cooling requirements of the interior spaces. This further minimizes the amount of energy required for air-conditioning.
- An energy recovery ventilation system is used to recover the cool air from the exhaust system. Through heat transfer, incoming hot outdoor air is precooled, thereby reducing the cooling load and energy consumption of the air-conditioning system.
- The ventilation system is designed with a variable speed drive to communicate with the carbon dioxide sensors located in regularly occupied spaces. The sensors identify the density of a space at a given time and allows the ventilation system to appropriately function only at the required speed, thereby avoiding unnecessary energy wastage when the space is not fully occupied.
- The lighting system of the building uses intelligent design such as daylight and occupancy sensors. The lamps can accommodate the needs of the space by adjusting the lux level of the lighting fixtures to complement available daylighting and shut off when the space is unoccupied.
- The energy required by the building, after the reduction and efficiency strategies, is supplied by renewable sources. ACPT is 100% powered by FirstGen's Pantabangan–Masiway Hydroelectric Plant located in Nueva Ecija, Philippines.

CASE 5: MOBIL HOUSE, DHAKA, BANGLADESH (USGBC 2019; NZEB ALLIANCE 2021F)

Summary of Certification

- Scheme and certification: LEED Platinum (score 85/110)
- Location: Dhaka, Bangladesh
- Occupancy type: Office
- Typology: New construction
- Climate: Tropical wet and dry
- Size: 6,673 m^2



Source: MJL Bangladesh PLC.

Description of Building

The Mobil House building is the head office of MJL Bangladesh Limited (formerly Mobil Jamuna Lubricants Limited), a joint venture between the state-owned Jamuna Oil Company and EC Securities Limited (a subsidiary of the East Coast Group) in Bangladesh. The building consists of office spaces, meeting areas, and conference halls. The building achieved a platinum LEED certification by following an integrative approach that engaged the clients, architects, engineers, energy

continued on next page

Box 3 *continued*

specialists, and green building consultants from the early design stage until post-occupancy. Their inputs at different stages were incorporated into the building design, construction, and operation to help ensure the cost-effectiveness and operational efficiency of the building. Compared to conventional office buildings in the region, the building consumes 30% less energy and 50% less water.

Green Strategies

The architectural design of the building features sizable courtyards and building cutouts that are populated with foliage and vertical gardens. They act as thermal buffers for the interior spaces of the building. This design compensates the building's lack of surface green cover due to site constraints.

The building envelope made of 300-millimeter (mm)thick concrete walls with high thermal mass and the windows using double-glazed panels with low emissivity and a U-value of 1.1 W/m2K reduce heat gain during the daytime. The building is oriented such that circulation elements like lift core and staircases are situated along the west facade. This shields the regularly occupied spaces, e.g., offices and reception, from the solar gains through the west facade. The northeast facade is exposed to less solar gain and therefore is designed to have large windows to allow daylight and outdoor views.

An efficient chilled water system is incorporated in the building's HVAC design to reduce energy consumption by cooling. The key technical features of this system include a chiller coefficient of performance of 6.3, a low approach cooling tower with variable-frequency drive, and an energy recovery wheel.

The lighting system of the building integrates daylight and occupancy sensors to provide the optimum levels of light during daytime. The sensors detect the ambient daylight levels as well as number of occupants to determine the light output. This strategy effectively reduces lighting electricity consumption.

The building utilizes renewable energy by installing a solar PV system on its rooftop. The PV system comprises of an array of 60 PV modules with a total capacity of 18 kilowatt-peak. Based on the average solar irradiance in Bangladesh, the system has the potential to generate 24,000 kWh per year.

CASE 6: UNNATI OFFICE, GREATER NOIDA, UTTAR PRADESH, INDIA (USGBC 2018B; NZEB ALLIANCE 2021I; NZEB ALLIANCE 2019; GAINWELL 2021)

Summary of Certification

- Scheme and certification: LEED Platinum (score 89/110)
- Location: Greater Noida, Uttar Pradesh, India
- Occupancy type: Office
- Typology: New construction
- Climate: Composite
- Size: 3,740 m^2



Source: One Click LCA.

continued on next page

Box 3 *continued*

Description of Building

The Unnati Office Building is the regional headquarter (north) for the heavy machineries and construction equipment company Gainwell Commosales Pvt. Ltd., located in its industrial campus in Greater Noida. With an energy performance index of 60 kWh/m^2/year, the building design of Unnati demonstrates how climate-responsive architecture is integral to achieving energy efficiency in a composite climate. It is the first building in India (and second in Asia) to achieve Platinum certification under LEED v4 BD+C.

Green Strategies

The three-story building is a cuboid with a central courtyard. It is oriented northeast-southwest, with the core areas distributed in the east and the west orientations. Passive design strategies have been integrated with the building design. With the design of form, central courtyard, shallow floor plates, appropriate sizing and distribution of openings, 90% of the office spaces, including the core and service areas, receive uniformly distributed daylight, thereby reducing electricity use for artificial lighting.

The building adopts climate-responsive facade concepts, including green wall and shading on all windows, to protect the interiors from direct sun and reduce heat gain. All external surfaces, including the walls, roof, and foundation, are insulated using polystyrene panels. The roof insulation also includes a 300 mm layer of green roof soil substrate. The window-to-wall ratio is 30%. High performance double-glazed windows provide improved protection against sunlight with integrated motorized blinds and shading.

Passive design features reduce the total cooling load to 208 kilowatts (kW) for 3,740 m^2. This load is met by a hybrid heating, ventilation, and air-conditioning (HVAC) system, which is a combination of water-cooled air-handling units and ceiling-embedded radiant cooling system. The water-cooled air-handling units meet 45% of the cooling load, whereas the ceiling-embedded radiant cooling system meets 55%. Based on indoor design conditions of 24°C and 55% relative humidity, the room dew-point temperature is 12°C and chilled water is supplied at 7°C to avoid any condensation on surfaces. Dry outdoor ventilation air is supplied through an externally mounted unit that dehumidifies the air before it is supplied to occupied space. This dry outdoor air acts as primary air to the chilled beams.

An energy-efficient lighting system with daylighting controls is used by the building. Occupancy sensors minimize the need of lighting. Lighting controls reduce internal heat gain and air-conditioning load. Access to daylight for 90% of regularly occupied spaces, e.g., offices, helps to substantially lower the lighting power density. The building utilizes renewable energy by installing a 100-kW solar PV system on its rooftop, which generates 146 megawatt-hours (MWh)/year meeting 40% of its energy demand per year.

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Box 3 *continued*

CASE 7: CONSTRUCTION INDUSTRY COUNCIL- ZERO CARBON PARK, HONG KONG, CHINA (ARUP 2021; HKGBC 2021; ZCP 2018; WGBC 2015)

Summary of Certification

- Scheme and certification: BEAM Plus Platinum
- Location: Kowloon East, Hong Kong, China
- Occupancy type: Multipurpose (office, exhibition, ecological park)
- Typology: New construction
- Climate: Subtropical
- Size: 14,700 m^2



Source: Meetings and Exhibitions Hong Kong.

Description of Building

Opened in June 2012, the Construction Industry Council's (CIC) Zero Carbon Park (ZCP) is home to the first zero-carbon building in Hong Kong, China. It acts as a test bed for state-of-the-art eco-building design and technologies and aims to promote a low-carbon mentality both locally and internationally. CIC-ZCP also serves as an exhibition, education, and information center to raise awareness on the importance of green building design, beyond the industry, and into the community. CIC-ZCP is designed to be energy-positive over the course of its life cycle. This exemplar project has achieved BEAM Plus Platinum rating, the highest rating for building environmental performance in Hong Kong, China. It has also received a series of awards relating to green buildings, such as the Green Building Awards 2012 - Hong Kong, Australian Institute of Quantity Surveyors 2013 International Project of the Year, World GBC's Asia-Pacific Leadership in Green Buildings Awards, among others.

Energy and Carbon Strategies

The ZCP building adopts a series of passive design strategies which collectively contribute to reducing energy consumption by 20%. The roof is covered with cellular glass insulation, screeding, and a protective surface membrane. About 85% of the roof area is covered with solar PV panels while the rest is green roof. The building's elongated form enables a suitable space depth between the northwest and southeast facade for daylighting. Light shelves on its southeast and northwest facades shade the periphery and distribute daylight further away from the windows and deeper into the space. A large glass wall on the northwest facade is positioned to face the relatively unobstructed sky to provide ample daylight, while being sheltered from direct sunlight or glare. The glazing around the model exhibition area on the ground floor is fitted with movable heat reflecting shades behind the glazing. The shade with an aluminum sheet on one side emits radiant heat that is absorbed while allowing the diffusion of light. Light pipes are installed to capture light from domes on the roof to provide light in windowless interior space of the building.

Cross-ventilation is a key strategy adopted by the building to address specific environmental challenges in the climatic conditions of Hong Kong, China. The building has an open-plan cross-ventilated layout, and its main facade faces southeast to optimize the use of prevailing summer breezes coming from that direction. There are also two wind catchers installed on the roof to supply the high-velocity outdoor air through the shaft down to the building. These design features, coupled with the use of high-volume-low-speed ceiling fans, promote a gentle and uniform air velocity throughout the building that can effectively counter the effects of the usually humid weather. This provides free cooling

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Box 3 *continued*

equivalent to approximately 30%–40% of the building's cooling load during a year. A number of high-level windows are centrally controlled by coordinating their operation with the air-conditioning strategy. At the same time, there are a number of low-level windows that can be controlled by the user to tailor the amount of ventilation and air velocity at the occupant zone.

The building is equipped with an earth cooling tube, which provides naturally precooled air to reduce the cooling load and energy use in the hotter months when the mechanical system is in operation. Stormwater (at a temperature of about 20°C) inside the box culvert running underneath is used as the condensing medium for the air-conditioning system. Chilled water is circulated to chilled beams to provide radiant cooling effect. To avoid having to overcool outdoor air for dehumidification as in the case of conventional systems, a desiccant dehumidification unit is used to pre-treat the humid outdoor fresh air. This reduces the load of the chillers. The separately cooled and dehumidified air is supplied to the room at a low velocity, through an underfloor displacement ventilation system. With thermal stratification of indoor air, only the occupied zone at low level in the room needs to be cooled. This low velocity and relatively high temperature of the supply air help to reduce the energy consumption of air-conditioning system.

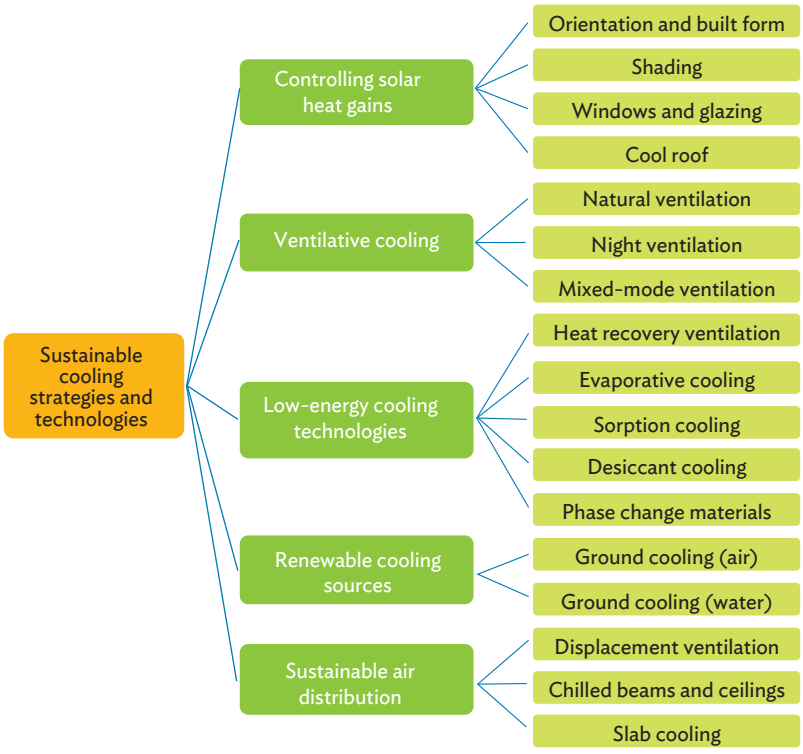
ZCP utilizes solar energy by installing PV panels at rooftop. Estimated annual power generation is 87 MWh/year. It also operates a tri-generation system which is powered by biofuel made of waste cooking oil. Thermal energy from combusting the biofuel is first used for electricity, which is estimated to be 143 MWh/year. Then the thermal energy at a lower grade is used for the adsorption chiller and the desiccant dehumidification process. This energy use in cascade yields an energy efficiency of 70%. Overall, ZCP produces more energy than its own needs, with a surplus of about 99 MWh/year.

Source: Compiled by authors.

4 SUSTAINABLE COOLING STRATEGIES AND TECHNOLOGIES

Integral to developing energy-efficient and low-carbon buildings, sustainable cooling strategies and technologies are expected to be able to reduce the use of mechanical ventilation and cooling systems while avoiding the occurrence of overheating and thermal discomfort in the summertime and ensuring reasonably good indoor air quality. Cooling load, cooling source, and air distribution are key metrics in designing and operating a cooling system aiming to achieve this overarching objective. In general, a sound sustainable cooling strategy should, to the extent realistically possible, explore the possibilities of controlling solar heat gains, choosing appropriate ventilative cooling techniques, applying low-energy cooling technologies, harnessing cooling energy from renewable sources, and using sustainable air distribution systems (Figure 20).

Figure 20: Sustainable Cooling Strategies and Technologies



Source: Author.

Controlling Solar Heat Gains

Orientation and Built Form

The form and orientation of a building have direct and substantial impacts on the building's exposure to solar radiation and heat gain and, therefore, are among the most important passive design strategies to reduce building energy consumption and ensure indoor thermal comfort. Different from individual building systems, equipment, and materials that can be improved in later stages through renovation or retrofit, the core characteristics of the built form are difficult and costly to alter to increase the building's thermal and energy performance once its geometry and orientation have been fixed. In other words, design strategies relating to form and orientation are largely "one-off" interventions at the design stage before a building is built, and can substantially affect the actual energy performance during the operational stage of the building. If the potential benefits of these interventions are missed, more complex and costly solutions would likely have to be devised and implemented at later stages to achieve similar benefits of energy savings and thermal comfort.

Solar geometry is the determining factor of heat gain, shading, and the potential daylight penetration of a building. Thus, the design of a building must be responsive to solar orientation on the site where the building is built. For a building in the northern hemisphere, the sun is at a low angle during winter and to the south of the east–west axis. During summer, the sun path is at a high angle and, depending on the latitude of the building, may be entirely north to the east–west axis (e.g., in a tropical climate) or partially north to the east–west axis (e.g., in a temperate climate). The change in path affects solar radiation penetration patterns during different seasons and the resultant heat gain and loss of a building (Figure 21).

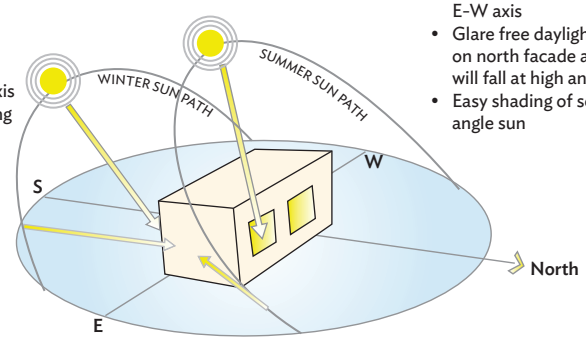
While the design of a building varies with its climate, location, and site conditions, the underlying principle to achieve energy efficiency remains largely the same—choosing a practically optimum orientation to minimize solar heat gain in summer, maximize daylight harvesting, and minimize heat loss in winter. In hot climates where no heating is required and other climates where cooling demand far exceeds heating demand, the priority is to minimize solar heat gain. It is desired that a building is shaped such that it is elongated in the east–west direction, i.e., the longer or larger facades of the building are oriented toward north–south. This is because glazing areas on east or west facades, which receive higher intensities of solar radiation than those on south or north facades, are more difficult to shade from direct sunlight due to the low angles of the sun. Where possible, surface areas and openings on east or west facades should be minimized.

In addition to exposure to solar radiation, prevailing wind direction is another important factor to consider when orienting a building. This is particularly relevant to hot-humid and warm-humid climates where the full potential of natural ventilation and cooling should be availed of. To do so, a building needs to be oriented at an angle to the prevailing wind direction to facilitate maximum airflow and cross-ventilation through the building. Often this direction does not necessarily coincide with the preferred sun orientation. Thus, it is not possible to simultaneously optimize both design parameters, which means a trade-off between them. In this case, a reasonable compromise should be made based on a detailed analysis of the situation. Possibilities for diverting the wind direction using vegetation and/or structural arrangements should be explored, such as the use of parapet walls within the external adjoining space. As a rule of thumb, usually, low-rise buildings would not receive much solar radiation and, therefore, could be oriented according to the prevailing wind direction to maximize the benefit of natural ventilation. For high-rise buildings, on the contrary, the priority should be given to best orienting the building to minimize solar radiation and heat gain. When there is a group of buildings on a site, they should be properly laid out such that minimal wind shadows would be created, and wind movements could be accentuated (Figure 22).

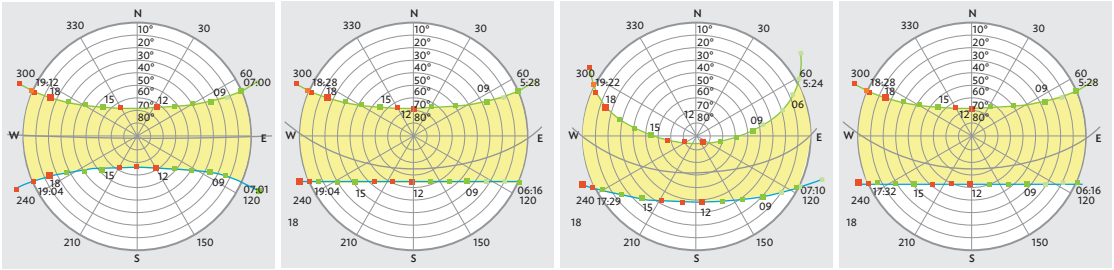
Figure 21: Illustration of a Building's Solar Exposure in Subtropical Climate in Northern Hemisphere and Sun Path Diagrams of Singapore, Manila, New Delhi, and Beijing

WINTER SUN
- Sun path at a low angle, south to E-W axis
- Solar radation will penetrate south-facing facades at a low angle during winter

SUMMER SUN
- Sun path at a high angle sun, north to E-W axis
- Glare free daylight is most easily available on north facade as minimal solar radation will fall at high angle
- Easy shading of south facade from high angle sun



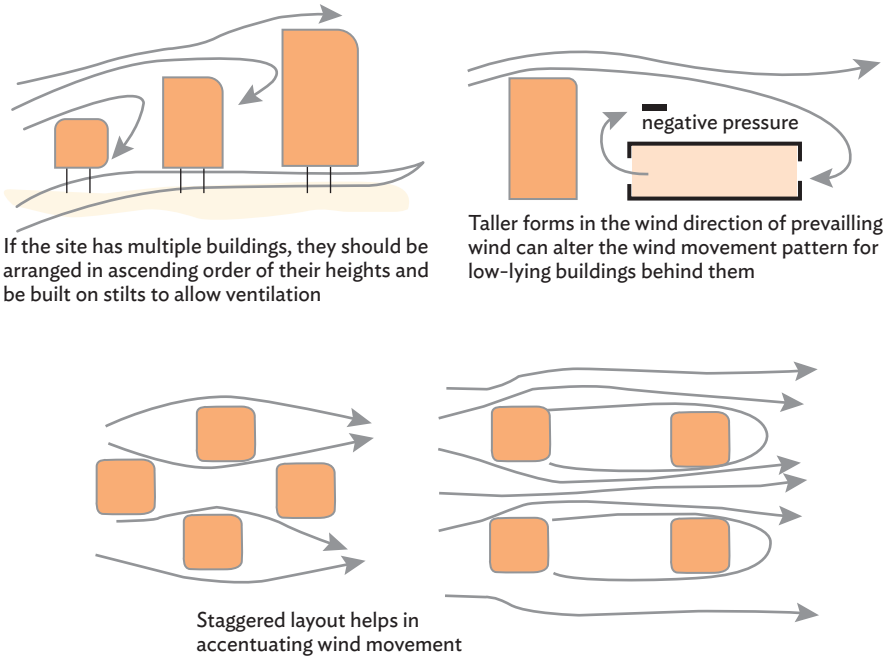
East and west facades continue to receive uniform, strong solar radiation at a low angle through the year.



Sources: NZEB Alliance. 2021d. Form and Orientation; GAISMA. 2021. Sunrise, Sunset, Dawn and Dusk Times Around the World.

From the perspective of reducing solar heat gain through building envelope, there are two important built form design parameters to consider: (i) the ratio of perimeter-to-area, and (ii) compactness (Lim and Kim 2018) surface-to-floor ratio, area-to-perimeter ratio, and volume ratio to evaluate building energy performance. Also, the paper focused on the relation between the air-conditioned room and non-air-conditioned room. This approach affects both the design stages of the floor plan and the main designing factors that decide which spaces would become air-conditioned spaces such as those mostly occupied by residents or non-air-conditioned space such as staircases and elevators. The heating load and cooling load were calculated using the new equation based on the location of non-air-conditioned spaces and envelope ratio facing the outdoor. Both the width-depth ratio and envelope ratio were analyzed using the IES-V.E (Integrated Environmental Solutions Virtue Environment. The perimeter-to-area ratio can be an indicator of radiative heat gain. For a given area, a higher value of the ratio corresponds with a longer boundary and increased exposure to solar radiation. Thus, a low ratio is desired for hot climates. The compactness is the three-dimensional extrapolation of the perimeter-to-area ratio. It is measured using the ratio of surface area to volume. For a given volume, the greater the surface area, the greater the potential solar radiation and heat gain through the surface. Therefore, it is desirable to design a compact shape to minimize unwanted solar heat gain (CLEAR 2004; Fairconditioning 2021a). For office buildings, a compact design may also bring the benefit of having less space requirements on distribution of horizontal and vertical building services, particularly for air-conditioning ductwork (CIBSE 2012).

Figure 22: Building Orientation and Prevailing Wind Direction



Source: Fairconditioning. 2021a. Form and Orientation.

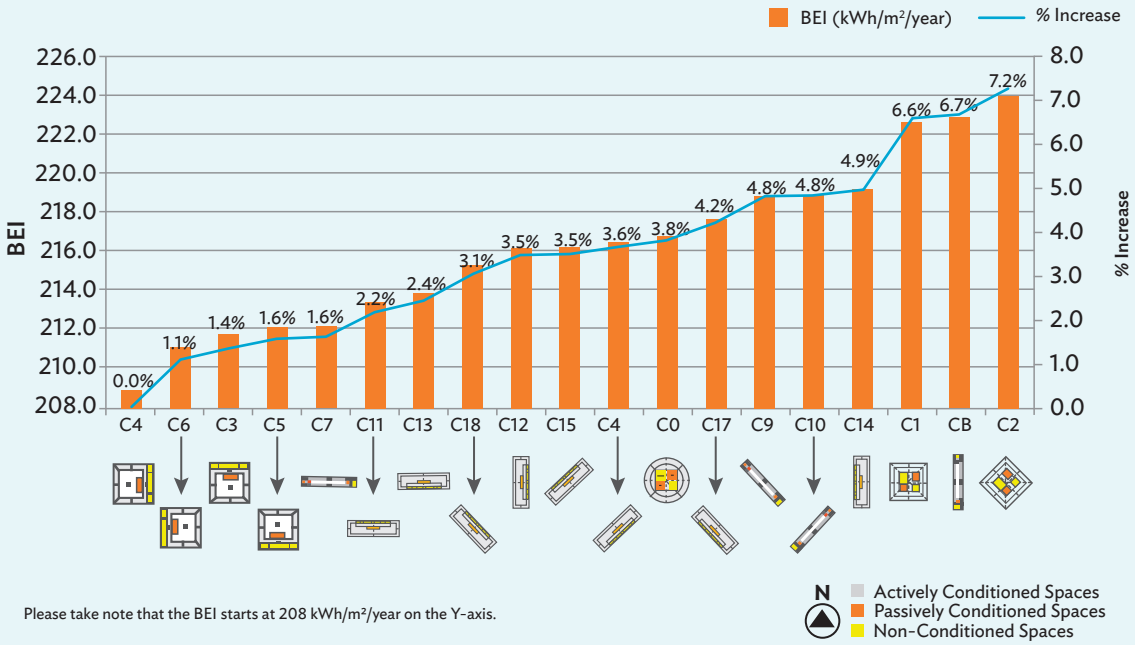
In theory, the most compact building shape would be a cube. In practice, this configuration is often not realistic or acceptable due to various reasons, such as planning regulations, functional requirements, site availability, topographical conditions, neighboring buildings, daylight access, or simply architectural aesthetics. From the perspective of energy use, a form design of high compactness may result in a deep plan, which may lead to a greater complexity of configuring building services. A deep plan also means a large portion of the floor area is placed far from the perimeter daylighting and thus may require continuous electric lighting (CIBSE 2012). Also, internal activities in this inner area may require mechanical ventilation and/or cooling, which otherwise would not necessarily be necessary if the inner area can be naturally ventilated. In contrast, a less compact design of built form may prioritize access to daylighting and natural ventilation by placing more portion of the floor area closer to the perimeter. While this may result in a suboptimal arrangement for solar exposure, there is the possibility that the reduced lighting load and cooling load may well offset the increased solar radiation and heat gain (CLEAR 2004). In addition, for office buildings, the view out and the location of the core (building services such as elevators, toilets, air-handling units, staircases, risers, etc.) are also important aspects that can have a substantial impact on form design and the energy performance of a building (Box 4). Therefore, similar to building orientation as earlier discussed, a trade-off across a range of design factors should be adequately analyzed to make an informed design decision.

Box 4: Impact of Built Form, Orientation, and Core Location on Energy Performance of Multistory Office Building in Malaysian Climate Zone

The selection of built form often decides where the location of service core can be placed, while the core location decides whether a mechanical system is required to ventilate spaces such as pantries and toilets. It is also possible to take advantage of the core location by using the core as a buffer zone to reduce the impact of solar radiation in the air-conditioned space of the building. Therefore, the selection of the core location would have a substantial impact on the main orientation of the building and the extent to which the air-conditioned spaces are exposed to direct solar heat gain.

Against this backdrop, a simulation-based study was conducted to investigate the interplay between built form, core location and orientation and its implication for energy performance of a multistory office building in Malaysia. The results showed that it was possible to save up to 7.2% energy based on the selection of built form, core location, and orientation (Box Figure 4.1). The most significant factor for lowering building energy consumption was the glazing area. Although the external facade's window-to-wall ratio of the office space was fixed at 70% for every scenario simulated, the absolute external glazing area differed by up to 48% between models because of different core locations.

Box Figure 4.1: Building Energy Index as a Function of Built Form, Core Location, and Orientation

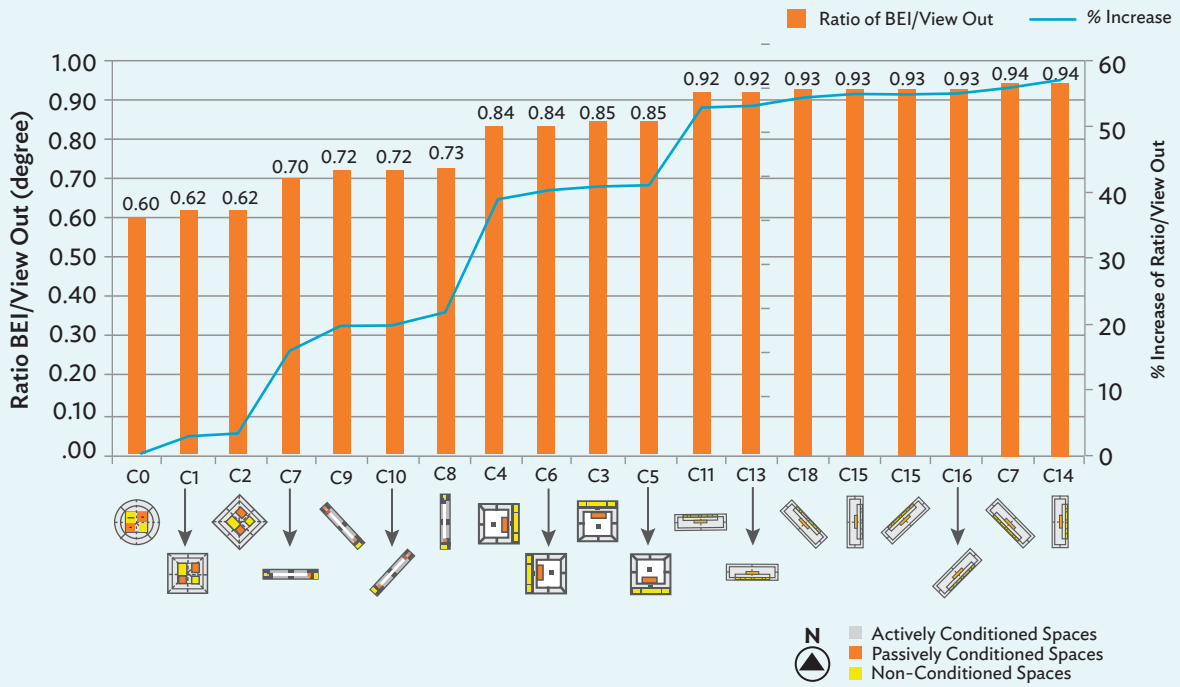


Please take note that the BEI starts at 208 kWh/m²/year on the Y-axis.

kWh = kilowatt-hour, m^2 = square meter.
Source: BSEEP Malaysia. 2017a. Building Energy Efficiency Technical Guideline for Passive Design.

The second significant factor was the ability to view out of the building. The view out was computed using the assumption of a person standing in the middle of the building looking out through the external facade. Internal partitions were assumed to be invisible or transparent, while external facade was opaque. A ratio of building energy index (BEI) in kilowatt-hour/square meter/year to view out in degrees was computed as the proxy of the energy cost for the view out of different built forms, core locations and orientations. This ratio indicated the amount of energy used for each degree of view out for each building model scenario. The lower the ratio, the less energy required for each degree of view out. The simulation results revealed that the energy penalty for increasing the view out reduced as the view out was increased (Box Figure 4.2).

Box Figure 4.2: Ratio of Building Energy Index to View Out as a Function of Built Form, Core Location, and Orientation



BEI = building energy index.
Source: BSEEP Malaysia. 2017a. Building Energy Efficiency Technical Guideline for Passive Design.

The orientation of the building was also shown to have a significant impact on the energy performance. The benefit of having a good orientation allowed for a higher glazing area and a better view out while reducing the BEI of the building in certain scenario. In short, having the glazing facing north and south resulted in a lower energy consumption than having the glazing facing east and west.

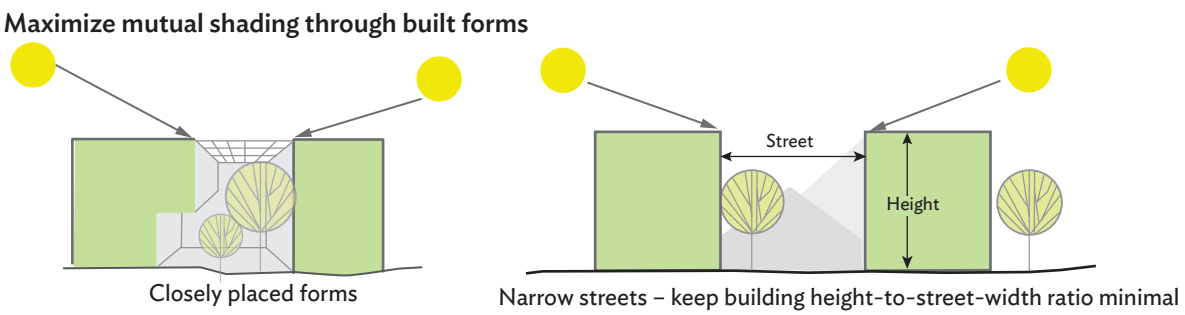
As key recommendations from the study, the selection of built form, core location and orientation for improved energy performance should have the following priorities:

- Choose a built form and core location that provides the least amount of glazing but maintains the necessary aesthetic appeal of the building and the view out.
- If the building is in a place that will benefit from having views in all directions, selection of a building with a 360° view out is an acceptable option due to the low ratio of BEI/view out as compared to other built forms, core locations and orientations.
- Expose glazing to the north and south but limit the exposure to the east and west. Whenever possible, locate the service core in the following order of preference: east, north–east, south–east, west, north–west, south–west, north, and south.

Source: BSEEP Malaysia. 2017a. Building Energy Efficiency Technical Guideline for Passive Design.

For building blocks such as buildings in a residential compound, there is a possibility to benefit from mutual shading to minimize the solar exposure of building elevations during summer (Figure 23). The effectiveness of mutual shading depends on a building's latitude and location with respect to the other buildings, the height of the context buildings, and the distance between the buildings (Bureau of Energy Efficiency 2014). The benefits of mutual shading in reducing solar exposure are possible if the buildings are closely placed to the east and west of the reference building. There is less shading effect from the buildings located south of the reference building, with minimal shading effect during peak summer. Except in tropical climates where the latitude is low, there is negligible shading from the buildings located north of a reference building.

Figure 23: Taking Advantage of Built Forms for Mutual Shading



Source: Fairconditioning. 2021a. Form and Orientation.

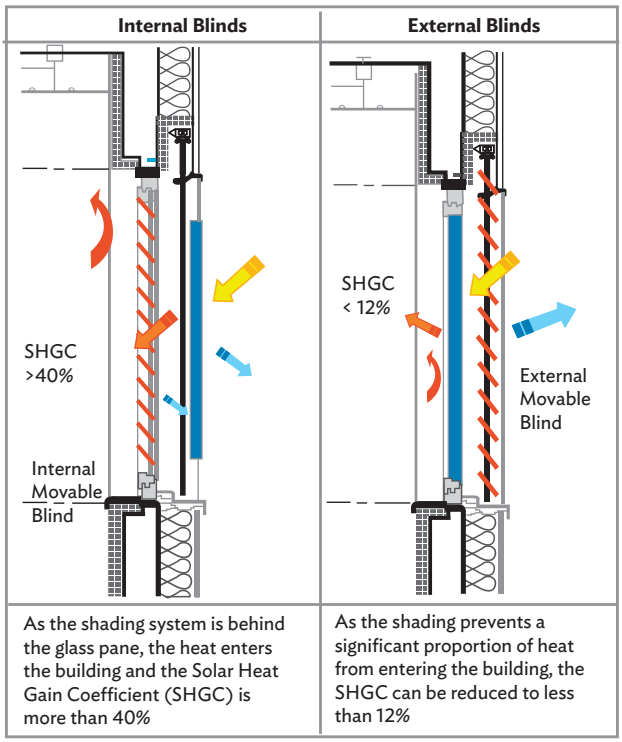
Shading

External shading, as an integral part of building envelope design, is a simple but effective method to intercept excessive solar radiation falling on the glazed surfaces and entering the building. With reduced solar heat gain, the need for mechanical ventilation and cooling to maintain a thermally comfortable indoor environment can be reduced, and considerable energy savings can be achieved. External shading plays a particularly critical role in tropical and subtropical climates where buildings are exposed to strong solar radiation for long periods during a year and the cooling load and associated energy cost are high.

Well-designed external shading devices have the potential to reduce solar heat gain through glazing by up to 80% (2030 PALETTE 2021c; Bureau of Energy Efficiency 2021b). This brings the potential benefit of cost-effectiveness. With well-designed external shading devices, low-cost single-glazing with a high solar heat gain coefficient (SHGC) may be used in lieu of high-cost, low-SHGC double-glazing, which otherwise would have been used.

External shading is much more effective than, and therefore greatly preferred over, internal shading, because the latter allows substantially more solar radiation and heat to be transmitted through the window into the building in spite of its role in blocking the glare of the sun (NZEB Alliance 2021h; The Society of Building Science Educators 2012). Depending on the reflectivity of the internal shade, some of this transmitted heat is reflected straight back out of the window, but the rest is absorbed by the shade, which is then heated up. The shade releases the heat in the form of long-wave radiation, which is trapped inside the room (BSEEP Malaysia 2017a). As shown in Figure 24, the SHGC of an internal movable blind can be as high as more than 40%, whereas that of an external movable blind can be as low as less than 12% (BEEP 2020b).

Figure 24: Comparison Between External Shading and Internal Shading



Source: Fairconditioning. 2021e. Shading.

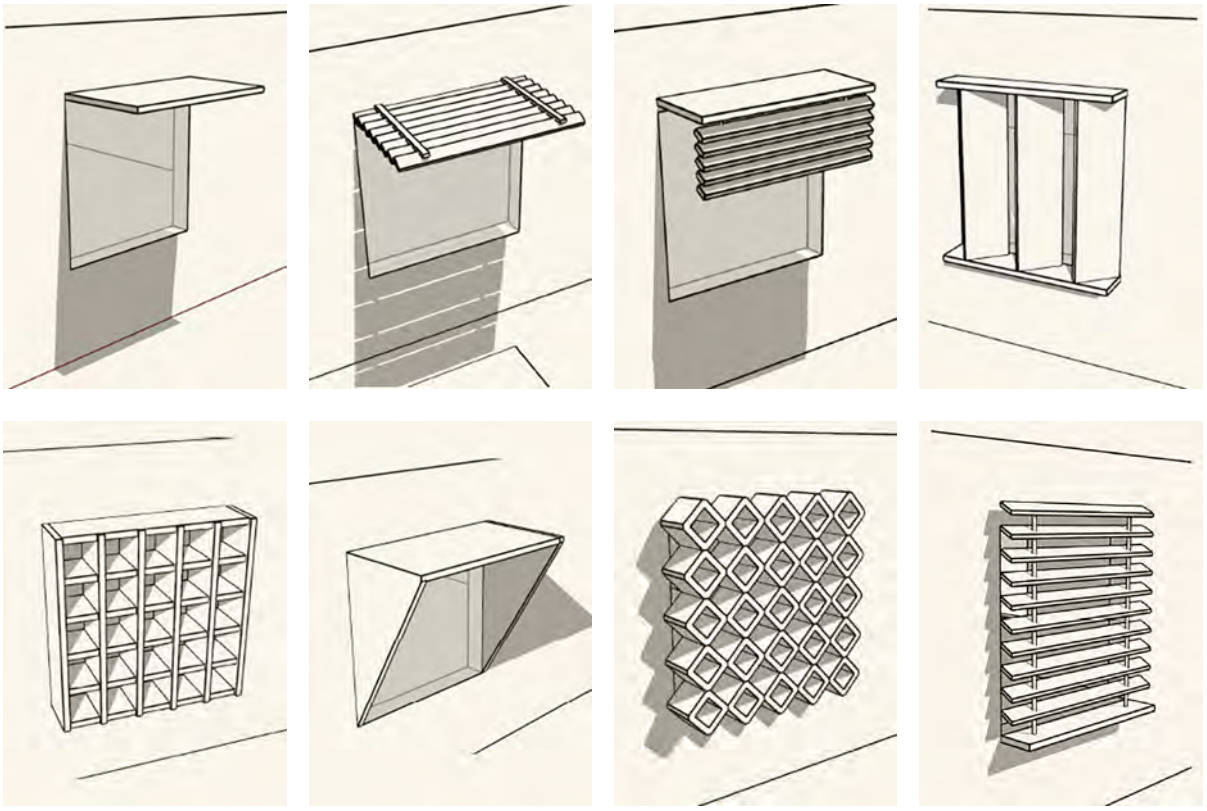
The orientation of an opening on a building facade is a key factor in the design of external shading devices. The impact of daily and seasonal variations in the sun path and the incident solar radiation is closely linked to the orientation. As the exposure of each facade of a building to the sun is different and varies with the sun's position (its altitude and azimuth), it is necessary to take a different approach to the design of shading for each orientation of a building. For a building located in the northern hemisphere, the south elevation receives both direct and diffused solar radiation and can be relatively easy to control. Shading devices are normally designed as horizontal projections above the windows, e.g., horizontal overhangs. The length of the projection is determined as a geometric function of the height of the window and the angle of elevation of the sun at solar noon. Such shading devices can be designed to eliminate sun penetration in the summer. For example, a vertical side fin of a triangular or rectangular shape on either side of the window can be used in combination with an overhang to cut off the direct solar radiation of the early morning (as the sun rises) and late evening (as the sun sets). Other typical shading devices for south elevation also include horizontal louvers in the horizontal plane, horizontal louvers in the vertical plane, a vertical panel parallel to the wall and hung from a horizontal overhang, large roof overhangs, deeply recessed windows, etc.

The necessity of shading for the north elevation depends largely upon the latitude of the building. When the latitude is low, e.g., in tropical Asian cities such as Singapore, Ho Chi Minh City, or Manila, the north elevation of the building is exposed to strong direct solar radiation for a long period throughout a year. Thus, proper shading is important, and the mentioned shading devices for the south elevation can also be used for the north elevation in these locations. With the increase in latitude, the north elevation's exposure to direct solar radiation reduces, and the angle of incidence of the sun's rays on the north elevation becomes less impactful. For example, the north elevation of a building in Hong Kong, China or Ha Noi is exposed to direct solar radiation for a much shorter period throughout the year, as

compared to the exposure in Singapore, Ho Chi Minh City, or Manila. At further northern latitudes, such as Beijing or Tashkent, the north elevation of a building receives direct solar radiation only in the summer months during the early morning and late evening hours. During these hours, the sun angle is so low that horizontal projections would be of little use as shading devices. Vertical side fins on the eastern and western sides of the window on the north elevation can be used to shade the window. Alternatively, since the impact of solar radiation and heat gain is limited in this circumstance, windows on the north elevation can go without shading devices (Bureau of Energy Efficiency 2021a).

As for the east and west elevations, they are exposed directly to strong solar radiation for the entire morning on the east face and the entire afternoon on the west face. The sun has low angles and penetrates deeper directly from the front of the window. This precludes shading using overhangs, as the overhangs will have to be too deep to be architecturally and structurally reasonable (The Society of Building Science Educators 2012; UN-Habitat 2018). More practical solutions for these orientations include multiple louvers, vertical fins, slanted vertical fins, eggcrates, eggcrates with horizontal louvers, and their variants. These shading devices are also effective on the near east and near west exposures, e.g., east–northeast, east–southeast, west–northwest, and west–southwest. Figure 25 illustrates some of the typical external shading devices.

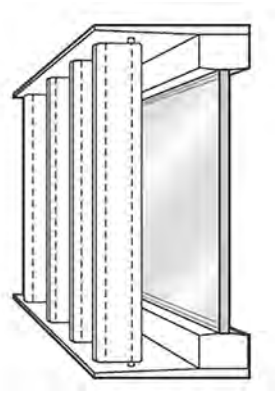
Figure 25: Schematics of Typical External Shading Devices



Source: UN-Habitat. 2018. Sun Shading Catalogue. Adequate Shading: Sizing Overhangs and Fins.

The shading devices illustrated are fixed ones, which have the advantages of simplicity, low cost, and low maintenance. A major disadvantage, however, is that the shading effect cannot be adjusted, and therefore the effectiveness can be limited. Movable shading devices are installed on the windows and glass facades of buildings to dynamically control the solar heat gain and the visual light transmission. Compared to fixed shading, movable shading devices have greater effectiveness against diffused radiation (BEEP 2020b). A typical example is rotating vertical fins, which are highly flexible and adjustable for daily and seasonal conditions and are most effective on east and west exposures (Figure 26). Other typical movable shading devices include rotating horizontal louvers, eggcrates with rotating horizontal louvers, shutters, solar screens, roller blinds, retractable awnings, etc. For movable external shading devices that are automatically controlled, it is desirable that manual adjustment by occupants be permitted. Also, it is important to have automatic retraction to prevent wind damage (CIBSE 2012).

Figure 26: (a) A Schematic of Rotating Vertical Fins; (b) Application of Rotating Vertical Fins at the Institute of Robotics and Mechatronics at German Aerospace Center



(a)



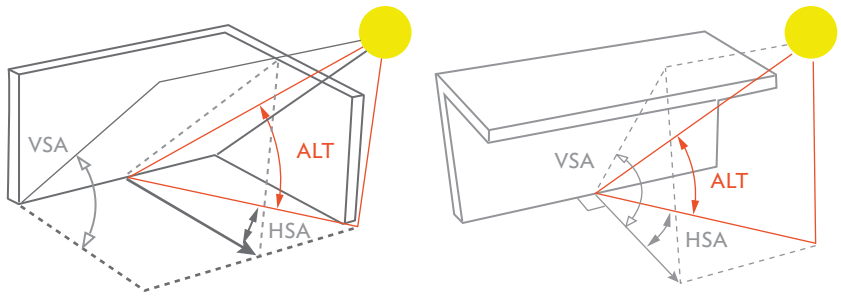
(b)

Sources: CIBSE. 2012. Guide F Energy Efficiency in Buildings; German Aerospace Center. 2021. Institute of Robotics and Mechatronics.

In designing a shading device for windows, it is important to understand the sun angle, which is critical to various aspects of design, including determining the basic building orientation and selecting appropriate shading devices. The key metrics are horizontal shadow angle (HSA) and vertical shadow angle (VSA). The HSA, which describes the performance of vertical shading devices such as vertical fins, is the angle between the solar azimuth and the normal of the windowpane, i.e., the orientation of the building facade under consideration. The VSA is required for designing horizontal shading devices such as overhangs. It is the angle between the horizontal plane of the building facade under consideration and a virtual tilted plane that contains the bottom edge of the window and the sun (Figure 27).

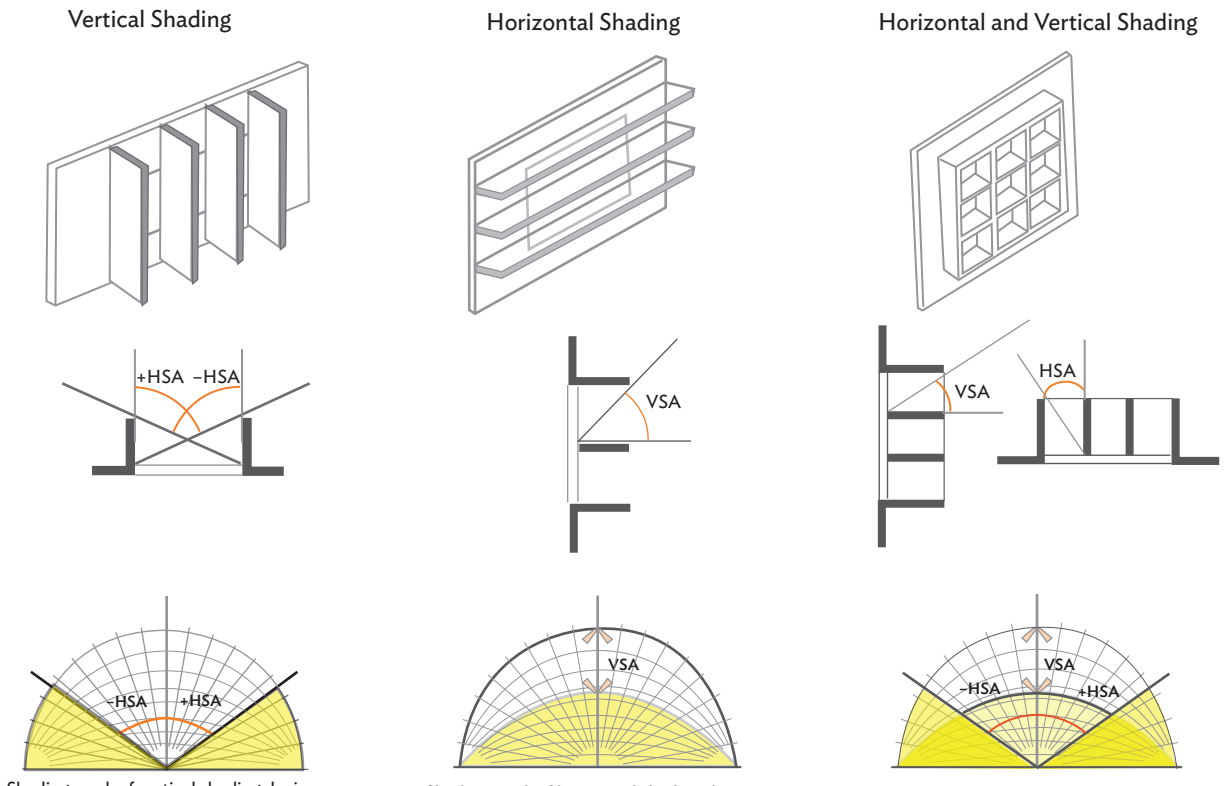
The latitude of a building and the orientation of its facade under consideration determine the period (both daily and annually) when shading is needed and the angle of solar radiation on the facade. A sun path diagram can be used to obtain the azimuth and altitude of the sun at each of the cut-off periods. And then the solar shading protractor can be used to determine the HSA and VSA, based on which a shading device satisfying performance specifications can be designed (Figure 28).

Figure 27: Horizontal Shadow Angle and Vertical Shadow Angle



ALT = altitude, HSA = horizontal shadow angle, VSA = vertical shadow angle.
Source: UN-Habitat. 2018. Sun Shading Catalogue. Adequate Shading: Sizing Overhangs and Fins.

Figure 28: Design of External Shading Devices



Shading mask of vertical shading device

Vertical shading devices protect from sun at sides of the elevation such as east and west side

Shading mask of horizontal shading device

Horizontal shading devices protect from sun at high angles and opposite to the wall to be shaded such as north and south sides

Shading mask of eggcrate shading device

Combination of horizontal and vertical shading devices protect from sun in all orientations

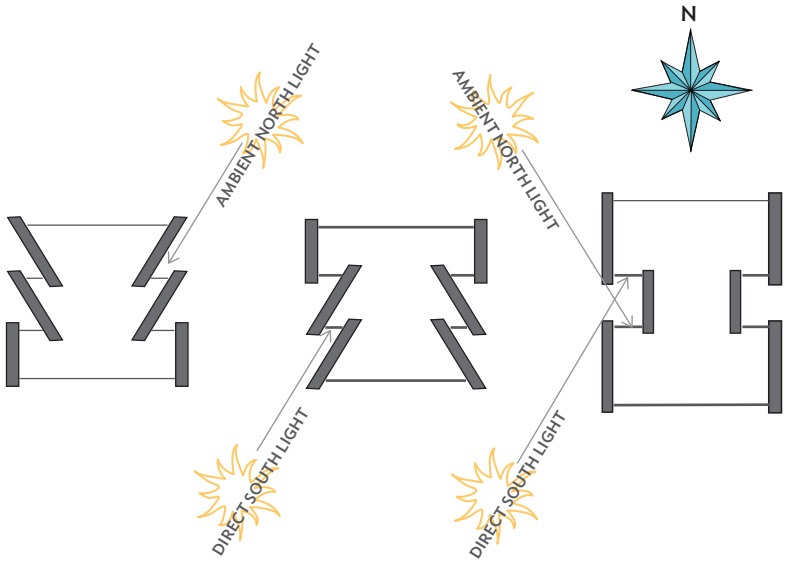
HSA = horizontal shadow angle, VSA = vertical shadow angle.
Source: NZEB Alliance. 2021h. Shading.

In general, it is recommended that the longer sides of a building be oriented north–south to minimize overall solar radiation and heat gain through the building envelope. The use of a large number of windows on the east and west facades should be avoided to the extent possible. East and west vertical fins, or eggcrates, should be angled to maximize the shading effect, which is important for buildings in tropical and subtropical climates. Exterior drop-down shades and adjustable horizontal louvers or blinds are also effective in blocking east–west sunlight. When external shading is not possible due to architectural, structural, aesthetic, or other reasons, it is necessary for the glazing to have a lower SHGC. Also, the building facade may be configured such that the windows are designed to avoid east and west orientation and thus solar heat gain (Figure 29).

Where possible, shading through landscaping and foliage should be availed of, especially for low buildings. To achieve desired shading effects, plant characteristics, such as foliage density, canopy height, and spread, need to be carefully considered (Fairconditioning 2021e). Deciduous trees or vines can be effective in screening the solar heat and glare in summer (and allowing solar penetration when passive solar gain is desired). High-branched canopy trees can be used to shade the roof, walls, and windows, whereas shrubs are appropriate for more localized shading of windows. Sometimes, using plants can also address the issue of reflected radiation from neighboring structures, water, or ground finishes (CIBSE 2012).

Other than using external shading devices, a building can be designed to provide shading for itself through different architectural forms. Typical examples include deep porches, covered verandas, recessed windows, and extended elements blended with envelope structural features (2030 PALETTE 2021a; Fairconditioning 2021e). In hot and humid climates, a good form of design is to both shed water and shade exterior walls and outdoor living spaces. In hot and dry climates, admitting cooler outdoor air through shaded outdoor living spaces or courtyards is a good strategy for natural ventilation (2030 PALETTE 2021b).

Figure 29: Orientation of Windows to Avoid Solar Heat Gains



Source: Society of Building Science Educators. 2012. Carbon Neutral Design Strategies.

Windows and Glazing

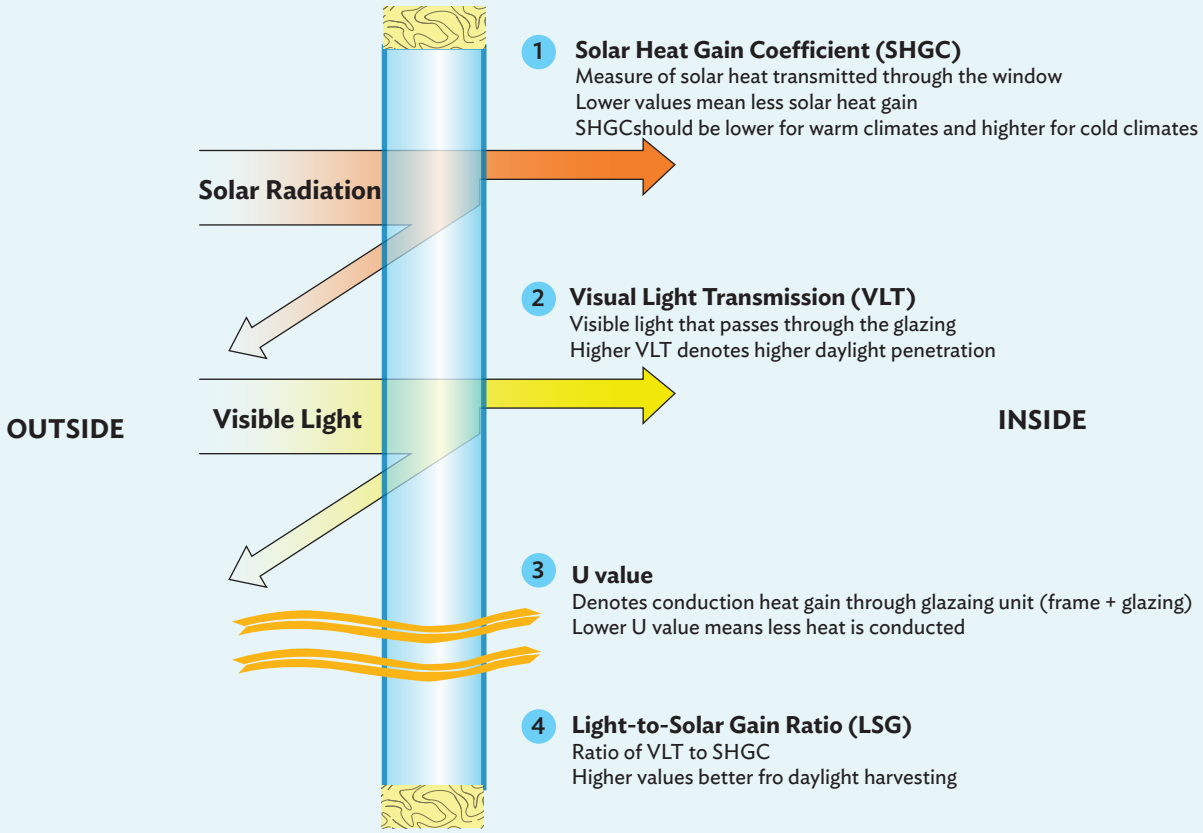
Windows comprise glass panes, structural frames, spacers, and sealants. With technological advances, a large variety of glass types, coatings, tints, and frames are available for use in window systems, providing opportunities to optimize selection and performance in different climates. Strategic decisions in building design require adequate interplay and collaboration between architects and building services engineers to appraise key factors that influence the design of the window and/or glazing system as an integral component of the building facade. Essentially, a good balance should be achieved across: (i) effective control of heat gains; (ii) providing daylight and avoiding the use of electric lighting at certain times; (iii) allowing for natural ventilation and avoiding the need for mechanical ventilation or cooling in some operating conditions; (iv) permitting some degree of occupant control over the local environment, which may reduce cooling demands; and (v) controlling glare and providing an adequate view out. For residential buildings, optimum window design and glazing specification can reduce energy consumption by 10%–50% below accepted practice in most climates. For commercial, institutional, and industrial buildings, well-designed window and/or glazing systems have the potential to reduce lighting and air-conditioning costs by 10%–40% (Whole-Building Design Guide 2016).

A window's ability to control solar heat gain and provide daylight to interior space depends mainly on its glass portion, namely glazing. Other than that, the type, shape, location, and functionality of a window are key factors in the utilization of natural ventilation, which reduces the need for mechanical ventilation or cooling. For example, long horizontal strip windows can ventilate a space more evenly, whereas tall windows with openings at the top and bottom can use induce local stack ventilation, with cool air supplied at the bottom and warm air exhausted at the top (Fairconditioning 2021f). Horizontal pivoting windows can produce effective ventilation because large open areas are created at a separation equivalent to the window height. By contrast, vertical pivoting windows are less efficient because the open area is uniformly distributed through the height of the window (CIBSE 2012). Coordination and integration with solar control strategies, particularly the use of shading devices, are important for the ventilation capacity and characteristics of windows. Further, the placement, orientation, and size of windows should be an integral part of the design of the built form and facade of a building.

Glazing plays a key role in determining a window's suitability in a specific climate and energy efficiency characteristics. A good glazing technology and its appropriate application may be more advantageous than the use of external shading devices. A good glazing technology can reduce solar heat gain from both direct and diffuse solar radiation, whereas external shading devices mainly block direct radiation with limited influence on heat gain from diffuse radiation (BSEEP Malaysia 2017a). Also, the control of solar heat gain is often coupled with the control of visible light transmittance, which, if well-designed and operated, may promote daylight harvesting. Apart from reducing the use of electric lighting, this may also generate the potential benefits of reducing the need for mechanical cooling and even allowing for a smaller air-conditioning system. As shown in Figure 31, the primary energy-related properties of glazing can be measured by the following metrics (Efficient Windows Collaborative 2021a; Efficient Windows Collaborative 2011; Efficient Windows Collaborative 2021b; Bureau of Energy Efficiency 2009; Whole-Building Design Guide 2016).

Solar heat gain coefficient. SHGC is the fraction of solar radiation admitted through a window or skylight, both directly transmitted, and absorbed and subsequently released inward. SHGC is expressed as a number between 0 and 1. The lower the SHGC value, the less solar heat is transmitted and the greater the shading ability. Key factors influencing SHGC include type of glass and number of panes, tints and coatings on the glazing, gas fill between glass panes, and solar shading (Bureau of Energy Efficiency 2013). SHGC can be expressed in terms of the glass alone or can refer to the entire window assembly. Whether a higher or lower SHGC is desirable depends on the climate, orientation, shading conditions, and other factors. In tropical and subtropical climates where cooling demand is high, the general preference is to use glazing with low SHGC values.

Figure 30: Schematic of Glazing Properties Relating to Energy Efficiency and Daylight Harvesting



Source: NZEB Alliance.2021c. Fenestration.

Visible light transmittance, also known as visible transmittance. Visible light transmittance (VLT) is an optical property that indicates the portion of incoming visible light transmitted through a window. It is a whole window rating and includes the impact of the window frame that does not transmit any visible light. While the theoretical value of VLT ranges from 0 to 1, most values in practice are between 0.3 and 0.7. The higher the value, the more light is transmitted, suggesting a greater opportunity for harvesting daylight. Key factors influencing VLT include the color of the glass, tints and coatings on the glazing, and the number of glass panes (Bureau of Energy Efficiency 2013). VLT affects building energy use by providing the opportunity to harvest daylight and reduce electric lighting as an integral part of internal heat gain. Thus, it indirectly helps reduce cooling loads.

Light-to-solar gain ratio. The light-to-solar gain (LSG) ratio is a measure of the ability of glazing to provide light without excessive solar heat gain. It is the ratio between the VLT of a glass and its SHGC. The higher the LSG is, the better it is for daylight harvesting.

Insulation value. The insulation value (U-value) indicates the rate of heat flow due to conduction through a window as a result of a temperature difference between the inside and outside. Measuring non-solar heat gain or loss, the U-value may be expressed for the glazing alone or for the entire window assembly, which includes the effect of the frame and the spacer materials. Thus, key factors influencing U-value include the coatings on the glazing, the size of the air gap between glass panes, gas fill between glass panes, and window frame construction

(Bureau of Energy Efficiency 2013). The lower the U-value, the greater a glazing or window's resistance to heat flow, and the better the insulation value. U-value can be in the unit of British thermal units (Btu)/hour (hr)·feet (ft)2·°F (US) or Watt/square meter (W)/m^2)·°K (European metric). The typical U-value ranges from a high of 1.25 for single-glazing in an aluminum frame to a low of 0.15 for low-emissivity-coated triple-glazing in an insulated frame. In a tropical climate, U-value has a relatively smaller influence on building energy consumption as compared to the VLT, SHGC, and LSG properties of glazing. For a tropical climate, it is recommended to select glazing based on VLT, SHGC, and LSG values, with the U-value as a secondary criterion of the selection process. This is because a good glazing selection based on VLT, SHGC, and LSG would typically come with an improved U-value, except for normal, single-tinted glazing. Thus, in a tropical climate, it is not economically justifiable to select glazing based solely on U-value (BSEEP Malaysia 2017a).

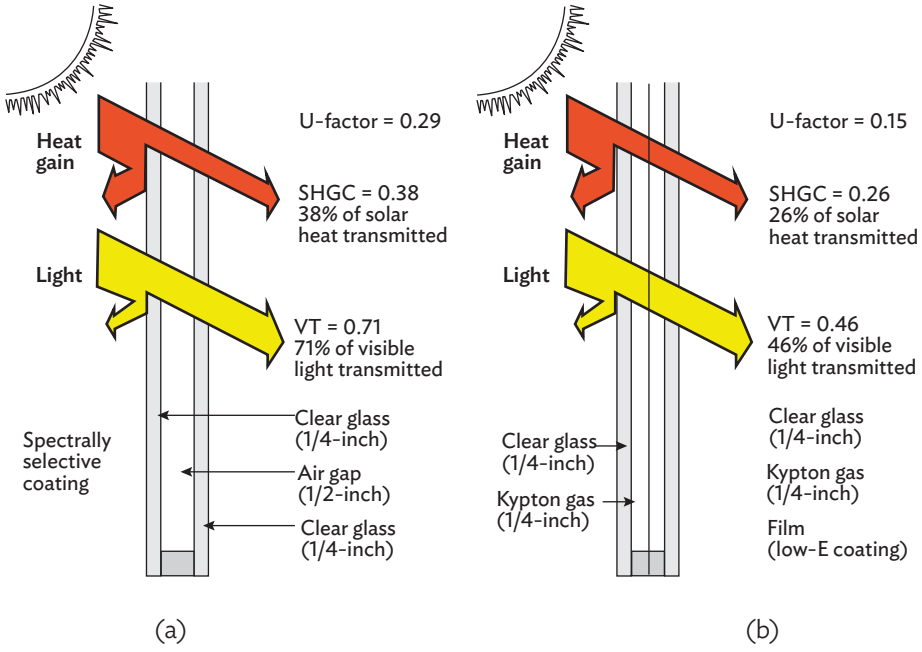
The properties of a given glass can be altered by tinting or by applying various coatings or films to it. Coatings, usually in the form of metal oxides, can be applied to glass during production. For example, reflective coating increases glass surface reflectivity, which can reduce solar heat gain substantially and control glare. This makes it suitable for large windows in hot climates. However, this is at the cost of a substantial reduction in visible transmittance, which disadvantages daylight harvesting (Efficient Windows Collaborative 2011). An increasingly popular type of coating is low-emittance (low-E) coatings, which are microscopically thin, virtually invisible, metal, or metallic oxide layers deposited on a window or skylight glazing surface to reduce radiant heat transfer through the glazing. Low-E coatings have been designed to allow for high solar gain, moderate solar gain, or low solar gain. The solar reflectance of low-E coatings can be manipulated to be spectrally selective so that the desirable wavelengths of the solar spectrum, such as the visible light spectrum, are transmitted and the others, such as short-wave and long-wave infrared as well as ultraviolet radiation, are reflected (US DOE Office of Energy Saver 2021c; Efficient Windows Collaborative 2021c; Efficient Windows Collaborative 2011).

There are two main categories of low-E coatings: sputtered low-E and pyrolytic low-E. Sputtered low-E coatings, also often referred to as soft coats, are designed to be placed inside a double-glazed insulated glass unit because they cannot be exposed and must be protected from contact and humidity. Pyrolytic low-E coatings are hard and durable enough to be exposed internally and are therefore also often referred to as hard coats or room-side coats. They can either be applied to single-pane glass or used in a double-glazed insulated glass unit. Comparatively, sputtered low-E coatings generally perform better than pyrolytic with respect to solar control and the reduction of heat transfer (Glassworks 2018; Efficient Windows Collaborative 2021a).

This spectral selectivity can also be achieved with high-performance tints. Tints are generally the result of colorants added to the glass during production. Some tints are also produced by adhering colored films to the glass following production (Whole-Building Design Guide 2016). Tinted glass is used to reduce glare from the outdoors and solar heat transmission through the glass. Tinted glass retains its transparency from the inside, although the brightness of the outward view is reduced, and the color is changed. As traditional bronze and gray tinted glass reduces the amount of daylight entering the room, a solution to applications where daylighting is desirable is to use clear glass with spectrally selective low-E coatings (Figures 31–33). Alternatively, high-performance tints with a relatively high VLT can be used in conjunction with low-E coatings (Efficient Windows Collaborative 2011).

In addition to the insulating capabilities of double glazing and low-E coatings, gas fills and additional glazing layers can further improve the insulating value of a glass unit. Triple-glazed and quadruple-glazed windows are designed to have their inner layers consisting either of glass or of suspended plastic films. Triple-glazed windows may have two glazing layers and one suspended plastic films, whereas quadruple-glazed ones may have two glazing layers and two suspended plastic film (Efficient Windows Collaborative 2021e). These inner layers bring down the U-value of the unit by dividing the inner air space into two or three chambers, which can be filled with insulating gas, such as 0.5-inch argon fill or 0.25-inch krypton fill. In addition to the U-value, solar heat gain can be effectively reduced. However, as a side effect of having these additional layers, there is some reduction in visible light transmission, as shown in Figure 31.

Figure 31: (a) Double-Glazing with Clear Glass and a Spectrally Selective Low-E Coating; (b) Triple-Glazing with Clear Glass and a Low-E Coating on Plastic Film



SHGC = solar heat gain coefficient, VT = visible transmittance.
Sources: Maven Double Glazing. 2017. Low-E Coatings.

In general, from the perspective of reducing solar heat gain, single-glazing with clear or tinted glass is not recommended due to its high SHGC. For cooling-dominated places such as ADB members in tropical and subtropical climates, the ideal type of glazing is double-glazed low-solar-gain low-E glass with argon gas fill (with or without a room-side low-E coating). For climates with both cooling and heating loads, such as ADB members in East Asia and Central West Asia, the ideal types of glazing include double-glazed moderate-solar-gain low-E glass with argon gas fill (with or without a room-side low-E coating), and triple-glazed low-solar-gain low-E glass. All these types provide reasonably high VLT values, which are good for daylight harvesting. Table 5 summarizes the performance characteristics of these types. The values are indicative of the glazing alone (center-of-glass). The choice of frame can make a substantial difference in performance.

Table 5: Ideal Glazing Types for Buildings in Climates That Mainly Require Cooling or Climates with Both Cooling and Heating Loads

Climate Zone	Type of Glazing	U-Value (Btu/hr·ft²·°F)	SHGC	VLT
Cooling-dominated climates	Double-glazed low-solar-gain low-E glass	0.24	26%	64%
	Double-glazed low-solar-gain low-E glass with a room side (fourth surface) low-E coating	0.20	27%	63%
Climates with both cooling and heating loads	Double-glazed medium-solar-gain low-E glass	0.25	42%	72%
	Double-glazed medium-solar-gain low-E glass with a room side (fourth surface) low-E coating	0.20	41%	70%
	Triple-glazed low-solar-gain low-E glass	0.15	24%	51%

Btu = British thermal unit, hr = hour, ft = foot, F = Fahrenheit, SHGC = solar heat gain coefficient, VT = visible transmittance.

Sources: Efficient Windows Collaborative. 2021c. Window Technologies: Glazing Types - Double Low-E Glazing; Efficient Windows Collaborative. 2021d. Window Technologies: Glazing Types - Double Low-E Glazing with Roomside (4th surface) Low-E; Efficient Windows Collaborative. 2021e. Window Technologies: Glazing Types - Triple Low-E Glazing.

In addition to these properties, heat gain or loss through a window caused by air leakage (infiltration and exfiltration) around the frame and sash and through gaps in movable window parts can have a considerable impact on building energy use. This effect is measured by the amount of air that passes through a unit area of window under given pressure conditions. Infiltration varies slightly with wind-driven and temperature-driven pressure changes. In tropical and subtropical climates, air leakage may lead to an increased cooling load. When outdoor humidity is high, air leakage may have an adverse impact on moisture mitigation and indoor air quality, thus causing greater needs for ventilation and dehumidification. All these will translate into more energy consumption for the air-conditioning system. Limiting air leakage is key to improving energy efficiency. Making windows and other components of the building envelope more airtight can save 5%–40% of cooling or heating energy (IEA 2013).

At the whole-building level, an important variable to be considered at the design stage is the window-to-wall ratio, which is also known as the glazing ratio. This ratio plays a key role in determining facade thermal properties and building energy performance because heat gain and loss through windows can be as much as 20 to 30 times that through walls (Fairconditioning 2021b). For cooling-dominated climates, a higher ratio implies more heat gain and, consequently, a higher cooling load and energy consumption of the air-conditioning system. Meanwhile, the high ratio may bring the benefits of better natural ventilation and daylight harvesting, which collectively contribute to lowering building energy consumption. If, however, a lower ratio is applied, the building is exposed to less solar radiation and heat gain. This is in favor of reducing cooling loads but goes against daylight harvesting and natural ventilation which may be desired. A lower ratio may also reduce the quality of the view. Either way, there are trade-offs, and therefore some compromises must be made. Moreover, the architecturally aesthetic value of a building often carries a substantial weight in deciding a building's facade design, especially in the case of commercial buildings. Therefore, the impact of the window-to-wall ratio needs to be carefully examined during the design stage to achieve a reasonable balance across these performance aspects. As a general recommendation, buildings in climates that are either cooling-dominated or have significant cooling demand during summer should avoid having a very high window-to-wall ratio. Usually, residential buildings have much lower window-to-wall ratios than nonresidential buildings, such as office buildings, commercial buildings, etc.

For example, in India, design guidelines for energy-efficient multistory residential buildings recommend that the window-to-wall ratio should be 10%–15% in bedrooms and 30% in living rooms for residential buildings in composite and hot-dry climates (Bureau of Energy Efficiency 2014), and 10% in bedrooms and 20% in living rooms for residential buildings in warm-humid climates (Bureau of Energy Efficiency 2016). In the PRC, the design standard for energy efficiency of residential buildings in hot-summer-and-warm-winter zones requires the window-to-wall ratio of a single facade to be no more than 0.4 for south–north orientation and no more than 0.3 for east–west

orientation (Ministry of Housing and Urban–Rural Development 2013). For nonresidential buildings such as office buildings and commercial buildings in the PRC, the applicable design standard imposes specific requirements on the window-to-wall ratio and energy-properties of glazing (Ministry of Housing and Urban–Rural Development 2015), as summarized in Table 6. In the Philippine Green Building Code, the window-to-wall ratio ranges from 10% to 90%, with each ratio value having a maximum SHGC and a minimum VLT of glazing. The higher the ratio, the lower the required SHGC (Department of Public Works and Highways 2015). IFC's greening building certification system, EDGE, sets a baseline window-to-wall ratio of 30% for residential buildings and 55% for nonresidential buildings, based on a study of the facades of building typologies across various regions (IFC 2019b).

Table 6: Window-to-Wall Ratio, U-value, and Solar Heat Gain Coefficient Requirements for Public Building in the People's Republic of China

Climate zone	Window-to-wall ratio (WWR)	U-value ($W/m^2 \cdot K$)	SHGC
Cold (typical cities: Beijing, Tianjin)	$0.40 < WWR \leq 0.70$	≤ 2.7	–
	$WWR > 0.70$	≤ 2.4	
Hot summer and cold winter (typical cities: Shanghai, Nanjing)	$0.40 < WWR \leq 0.70$	≤ 3.0	≤ 0.44
	$WWR > 0.70$	≤ 2.6	
Hot summer and warm winter (typical cities: Guangzhou, Shenzhen)	$0.40 < WWR \leq 0.70$	≤ 4.0	≤ 0.44
	$WWR > 0.70$	≤ 3.0	

SHGC = solar heat gain coefficient, Watt/square meter $(W)/m^2.°K$ (European metric).

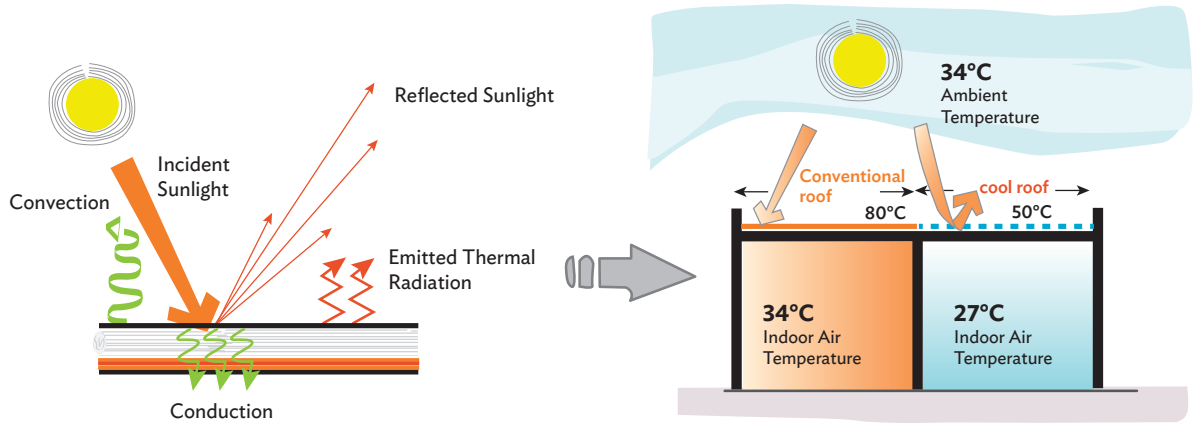
Source: Ministry of Housing and Urban-Rural Development. 2015. *Design Standard for Energy Efficiency of Public Buildings (GB 50189-2015)*.

Cool Roof

The roof of a building may receive up to four times more solar radiation per m^2 than the walls during summer (Bureau of Energy Efficiency 2014). The exposed roof surface can become very hot, with dark surfaces reaching temperatures as high as 80°C (Global Cool Cities Alliance 2012; Bureau of Energy Efficiency 2017). The excessive solar heat gains through the roof result in a high indoor air temperature, create thermal discomfort in the occupied space, and increase cooling demand to be met by the air-conditioning system or equipment.

A cool roof is one that strongly reflects solar energy and also cools itself by efficiently emitting some of the absorbed heat back into the atmosphere (Cool Roof Rating Council 2021). Under the same conditions, a cool roof could stay cooler by as much as 28°C to 36°C than a conventional dark roof (Global Cool Cities Alliance 2012; US DOE Office of Energy Saver 2021a). Accordingly, the amount of heat conducted into the building underneath the roof can be reduced substantially. As a result, the indoor environment can be kept cooler and more comfortable than otherwise. Meanwhile, for an air-conditioned building, a cooler indoor environment helps reduce the need for air-conditioning, save energy, and potentially provide an opportunity to downsize a new or replacement air-conditioning system or equipment. Beyond individual buildings, cool roofs contribute to alleviating the heat island effect in dense urban areas and also reducing peak electricity demand, which can help prevent power outages (Global Cool Cities Alliance 2012; NZEB Alliance 2021b; US DOE Office of Energy Saver 2021a; Cool Roof Rating Council 2021; Green Building Alliance 2021).

Figure 32: Schematic of Cool Roof Properties and Performance



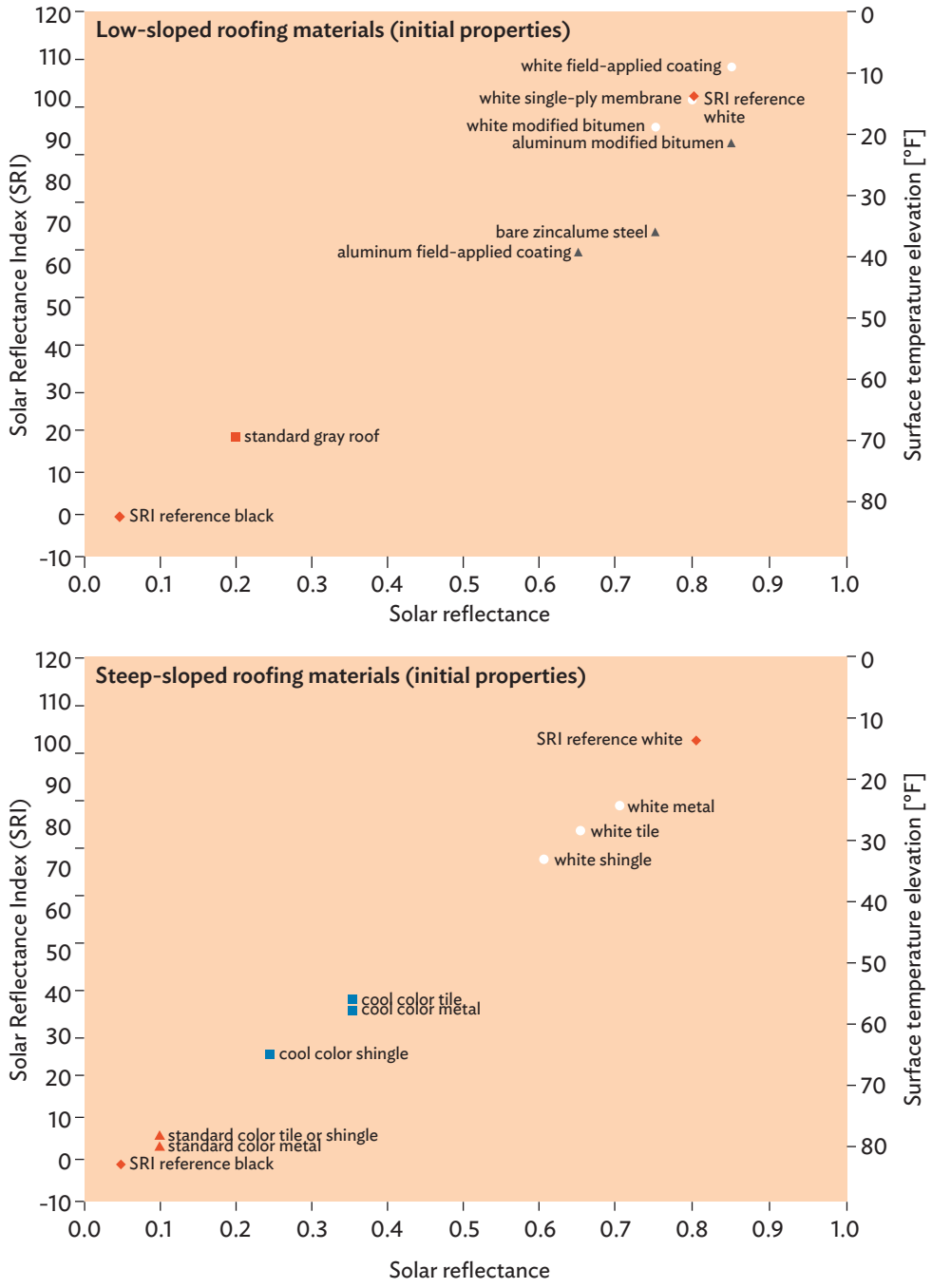
Source: NZEB Alliance.2021b. Cool Roofs.

The term "cool roof" refers to the outer layer or exterior surface of a roof, which acts as the key reflective surface. The two primary thermal properties characterizing a roof surface are solar reflectance and thermal emittance. Solar reflectance, also known as reflectivity, is the fraction of solar energy that is reflected by a roof's surface back to the sky, expressed with a number between 0 and 1. White surfaces have the highest solar reflectivity, while black surfaces have the lowest. The term "albedo" is often used interchangeably with solar reflectance. Surfaces with a high albedo or reflectance stay much cooler than those with a low albedo or reflectance. Thermal emittance, also known as infrared emittance or emissivity, is the relative ability of a roof surface material to radiate absorbed heat, expressed with a number between 0 and 1. High thermal emittance helps a surface cool by radiating heat to its surroundings. Nearly all nonmetallic surfaces have high thermal emittance, usually between 0.80 and 0.95. Uncoated metal has low thermal emittance. Radiant energy incident on a roof surface that is not reflected is absorbed by it. This absorbed heat is eventually radiated by the roof or transferred through conduction. Compared with traditional roofs, a cool roof can reduce the solar heat gain of a building by first reflecting a substantial amount of incoming radiation and then quickly reemitting the absorbed portion. As a result, the cool roof stays cooler.

Another important indicator to evaluate a roof's ability to shield the building beneath it from solar radiation, namely, the "coolness" of the roof, is the solar reflectance index (SRI), which incorporates both solar reflectance and thermal emittance in a single value. Developed by the Lawrence Berkeley National Laboratory (LBNL), SRI quantifies how hot a surface would get relative to standard black and standard white surfaces. It is defined such that a standard black (reflectance 0.05, emittance 0.90) is 0 and a standard white (reflectance 0.80, emittance 0.90) is 100. By internalizing the trade-off between reflectance and emittance into a single value, SRI helps simplify the comparison of roof products.

Cool roof options and materials available to a building depend mainly on the type of building and its roof structure. Broadly, roofs can be categorized into low-sloped and steep-sloped. The term "low-sloped roofs" typically refers to roofs with a profile of no more than 5 centimeters (cm) vertically over 30 cm horizontally, or a pitch no more than 2:12. Most commercial and high-rise residential buildings have low-sloped or even flat roofs with little visibility from the ground. This makes it relative easier and less costly to apply cool roofs, either at new construction or during routine retrofits or scheduled replacement of roofing covering. In contrast, roofs with a pitch higher than 2:12 are considered "steep-sloped," as in the case of many low residential buildings. As steep-sloped roofs can be more easily seen from the ground, often it is the aesthetic preference or concern, rather than the surface solar reflectance

Figure 33: Initial Solar Reflectance, Solar Reflectance Index, and Surface Temperature Elevation (surface temperature—outside air temperature) of Cool Roof Products for (a) Low-Sloped Roofs and (b) Steep-Sloped Roofs



Source: Lawrence Berkeley National Laboratory. 2009. Cool Roof Q & A.

of a roofing product that plays the decisive role in selecting the cool roof option. This explains why white roofing products do not gain popularity for residential roofs. There are, however, a wide range of roof materials using alternative cool colors, such as green, red, and gray, that can strongly reflect the invisible near-infrared solar radiation and make the roof cooler than conventional roofs but are not as cool as white roofing products.

Figures 34–36 show the initial solar reflectance, SRI, and surface temperature elevation (surface temperature minus outside air temperature on a summer afternoon) of some cool roof products for low-sloped roofs and steep-sloped roofs. This is followed by a more detailed introduction of various types of cool roofs (APEC Energy Working Group 2012; US DOE Office of Energy Saver 2021a; Designing Buildings 2020; Green Building Alliance 2021).

Coated roofs. A coated roof is coated with a paint-like finish to help enhance the roof's adhesion, durability, and longevity. Roof coatings can be divided into two categories: field-applied and factory-applied. Field-applied coatings are applied directly onto the roof surface, either on a new roof assembly or over an existing roof surface. Factory-applied coatings are applied at the factory prior to distribution. Cool coatings are best for low-sloped roofs and can be added to a variety of surfaces, including asphalt cap sheet, gravel, metal, and other single-ply materials. Typical cool roof reflective coatings include:

- White roof coatings, which are opaque and reflective, consist of polymeric materials and some types of white pigment.
- Pigmented coatings, which are made from similar materials and come in darker shades such as red, green, and blue. These coatings are less efficient than white coatings and are more commonly used for aesthetic purposes in residential buildings.
- Aluminum roof coatings, which are made from resin containing flakes of aluminum leaf. These coatings provide the visual effect of an aluminum sheet, masking the material layer underneath while providing effective solar reflectance and thermal emittance.
- Elastomeric roof coatings, which are acrylic-based materials, help protect roofs from extreme weather conditions. These coatings can be applied directly to an existing roof, depending on the condition of its surface.

Single-ply membranes. Single-ply membranes are prefabricated sheets rolled onto a low-sloped or steep-sloped roof. They can be firmly set on the roof and attached with mechanical fasteners and adhered with chemical adhesives, or they can be loosely laid and weighted down with ballast or pavers. These membranes serve to protect the structure from extreme weather and can provide insulation as well. They are often made from felt, fiberglass, polyester, or other materials and can be covered with pigments to increase solar reflectance. Generally, there are four main types of single-ply membrane for cool roofs, including (i) ethylene propylene diene monomer (EPDM) rubber; (ii) chlorosulfonated polyethylene (CSPE), also known as Hypalon; (iii) polyvinyl chloride (PVC) polymers; and (iv) thermoplastic olefin (TPO). The first and second are thermosets that cannot be hot air welded and must be sealed using tape or contact cement. The third and fourth are thermoplastics consisting of compounded plastic polymers, to which heat can be applied for melding.

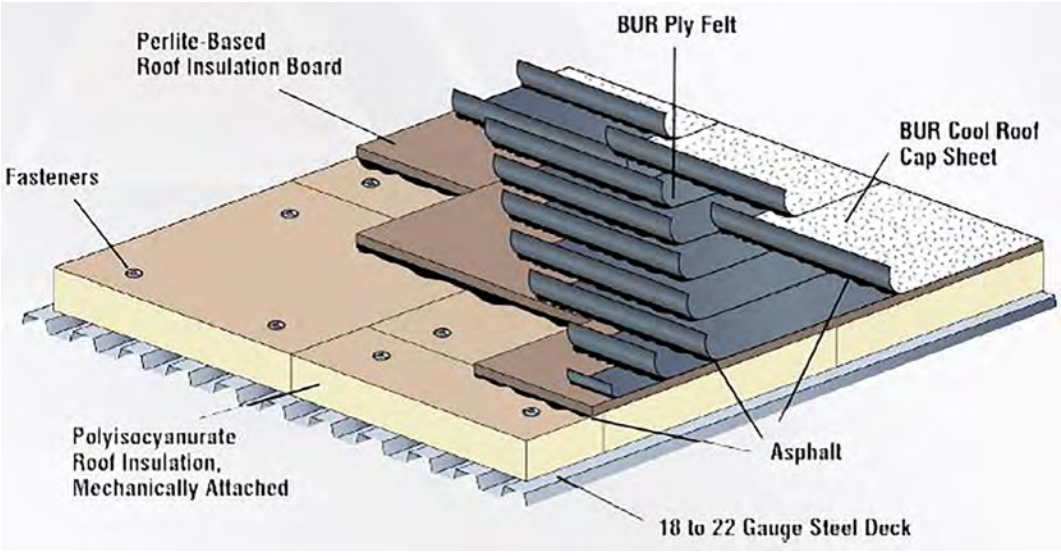
Shingles and tiles. Roof shingles and tiles are roofing products based on the same concept, which is to put together individual elements to form a roof. These elements are normally flat rectangular shapes laid in rows without the side edges overlapping. With available products made of various materials, shingles and tiles are commonly used for residential buildings and increasingly for commercial buildings. A typical example is asphalt shingle that is surfaced with light-colored or cool-colored granules, if a darker color is preferred. It is also possible to field-coat previously installed asphalt shingle roofs to make them cool. Other shingle-based products include polymer shingles that are factory-colored with light-colored or cool-colored pigments and wood singles and shakes, which are naturally cool-colored materials. As for using tiles as cool roofs, concrete tiles can be integrally colored with pigments, surface-colored with a slurry coating, which mixes pigment with white cement, or with a pigmented polymer coating.

Unglazed clay tiles in a natural cool color or clay tiles with a factory-fired light- or cool-colored glaze can provide the desired coolness. Alternatively, glazed clay tiles can also be retrofitted with a field-applied light- or cool-colored polymer coating. An advantage of roofing products made of shingles and tiles is their heavy thermal mass owing to their dense and earthen composition. This may yield energy savings on top of what can be achieved by their solar reflectance and thermal emittance properties.

Metal roofs. Cool metal roofing is a family of energy-efficient roofing products comprising unpainted metal, factory-painted metal, and metal that is factory-surfaced with mineral granules. It is available in a wide variety of finishes, colors, textures, and profiles to suit different built forms and structures. Mill-finish metal roofing has high solar reflectance, but poor thermal emittance. Metal roofing with oven-cured, pre-painted organic coatings with special cool pigmentation can offer high solar reflectance and high infrared emittance even with darker colors. Emissivity as high as 90% can be achieved for painted and granular-coated roofing. Metal roofing can be broadly categorized into structural and nonstructural. Structural metal roofing is attached directly to purlins or lathe boards without requiring underneath support. It can be further categorized into low-slope and steep-slope products. Low-slope structural metal roofing consists of interlocking panels or overlapping panels, which can have a painted, mill-finish, or clear acrylic finish. Steep-slope structural metal roofing is available in both vertical and horizontal profiles. Nonstructural metal roof panels require a solid substrate beneath them, typically plywood, oriented strand board, or a metal roof deck. It has a variety of styles, including vertical standing seams and horizontal panels, which are often shaped to resemble the look of asphalt shingles, wood shakes, slate, and tiles, or to fit unique curvatures.

Built-up roofs. A built-up roofing system is made from multiple layers that commonly include a base sheet, fabric reinforcement layers, and a protective surface layer (Figure 34). Cooling options for built-up roofs can vary by building type. One method is to embed thermally reflective materials into asphalt or coal tar. Another method is to cap the built-up roof with mineral-surfaced sheets consisting of reflective mineral granules or applied reflective coatings. Built-up roofs mostly appear light gray or tan and have a solar reflectance of 0.15 to 0.25.

Figure 34: Schematic of a Built-Up Roofing System



Source: Asphalt Roofing Manufacturers Association. 2017. Multi-Ply Built-Up Roofing.

Modified bitumen. Modified bitumen is bitumen (asphalt or tar) modified with plastic, layered with reinforcing fabrics, and then topped with a surfacing material. The radiative properties of modified bitumen are determined largely by the surfacing material. So, the cooling performance of modified bitumen roofing is realized using a cap sheet with a factory-applied reflective mineral surface or reflective coating. Modified bitumen is similar to built-up roofing but with a higher degree of elasticity. It is suitable for both warm and cold temperatures. Modified bitumen roofing can be installed in four main ways, i.e., torch-applied, hot-mopped, cold-applied, or with self-adhesives. The tough and tenacious properties of the modified bitumen blend, coupled with high-tensile polyester and/or fiberglass reinforcements, provide strong resistance to foot traffic, punctures, dropped tools, hailstorms, and other potential damages. This makes these products ideal for buildings with high-traffic roofs, such as those with mechanical systems installed on the rooftop. Modified bitumen sheet membranes can also be used to surface a built-up roof to produce a hybrid roof.

Foam roofs. A foam roof, topped with a foam-like substance for insulation purposes, is an affordable cool roof technique with a long history of applications. The foam is generally made from two liquid chemicals that mix to react and expand to form a solid, flexible, and lightweight piece that adheres to the roof. Foam roofs can be field-applied or factory-applied. Field-applied foam roofs, similar to field-applied coatings, are sprayed on in liquid form and harden as they set on top of the roof. Factory-applied foam roofs are formed into rigid panels and coated with a reflective coating.

In general, cool roofs are cost-competitive with conventional roofing options, having a short payback period based on the benefit of energy savings (Global Cool Cities Alliance 2012; Natural Resources Defense Council 2020). Usually, in the case of new buildings or existing buildings for which the roof surfaces need to be replaced anyway, the costs of cool roof options would be similar to or only slightly more than similar traditional non-cool alternatives. This means the cost premiums for cool roofs are limited or, at times, none (Bureau of Energy Efficiency 2017; Global Cool Cities Alliance 2012). For a traditional roof that is in good condition and not due to be retrofitted or replaced, converting it into a cool roof would incur a higher incremental cost than converting a roof scheduled to be re-roofed anyway (US DOE Office of Energy Saver 2021a). The costs of conversion depend on the existing roof's surface and condition. During a cool roof's service lifetime, the recurring maintenance cost is usually similar to that of traditional non-cool roofs. It is, however, worth noting that cool roofs tend to have an extended lifetime because they maintain a lower average temperature, which slows heat-related degradation of roofing materials (Akbari 2005; Global Cool Cities Alliance 2012). For example, a coated cool metal roof could have higher durability and work in good condition for a longer period of time as compared to a similar coated dark metal roof (Global Cool Cities Alliance 2012). This benefit contributes to enhancing the cost-competitiveness of cool roofs. Table 7 presents the new installation cost premiums for cool roof options as alternatives to some common traditional roof types and technologies.

Table 7: Solar Reflectance and Cost Premiums of Cool Roof Options for Some Common Traditional Roof Types

Traditional Roof Types	Traditional Roof Options	Non-cool Roof Solar Reflectance	Applicable Cool Roof Options	Cool Roof Solar Reflectance	Cost Premium ($ per square foot)
Asphalt shingle	Black or dark brown with conventional pigments	0.05–0.15	"White" (actually light gray) or cool color shingle	0.25	0.00–0.75
Built-up roof	Dark gravel	0.10–0.15	White gravel	0.30–0.50	0.00
	aluminum coating	0.25–0.60	White smooth coating	0.75–0.85	0.50–1.50
Clay tile	Dark color with conventional pigments	0.20	Unglazed red tile (terracotta)	0.40	0.00
			Colored with cool pigments	0.40–0.60	0.00
			White tile	0.70	0.00
Concrete tile	Dark color with conventional pigments	0.05–0.35	Colored with cool pigments	0.30–0.50	0.00
			White tile	0.70	0.00
Liquid applied coating	Smooth black	0.05	Smooth white	0.70–0.85	0.00
Metal roof	Unpainted corrugated	0.30–0.50	White painted	0.55–0.70	0.00–1.00
	Dark-painted corrugated	0.05–0.10	Colored with cool pigments	0.40–0.70	0.00
Modified bitumen	With mineral surface cap sheet	0.10–0.20	White coating over a mineral surface	0.60–0.75	0.50
Single-ply membrane	Black (PVC or EPDM)	0.05	White (PVC or EPDM)	0.70–0.80	0.10–0.15
			Colored with cool pigments	0.40–0.60	0.00
Wood shake	Dark color with conventional pigments	0.35–0.50	Left bare	0.40–0.55	0.00

Source: Global Cool Cities Alliance. 2012. A Practical Guide to Cool Roofs and Cool Pavements; Hewitt, V., E. Mackres, and K. Shickman. 2014. Cool Policies for Cool Cities.

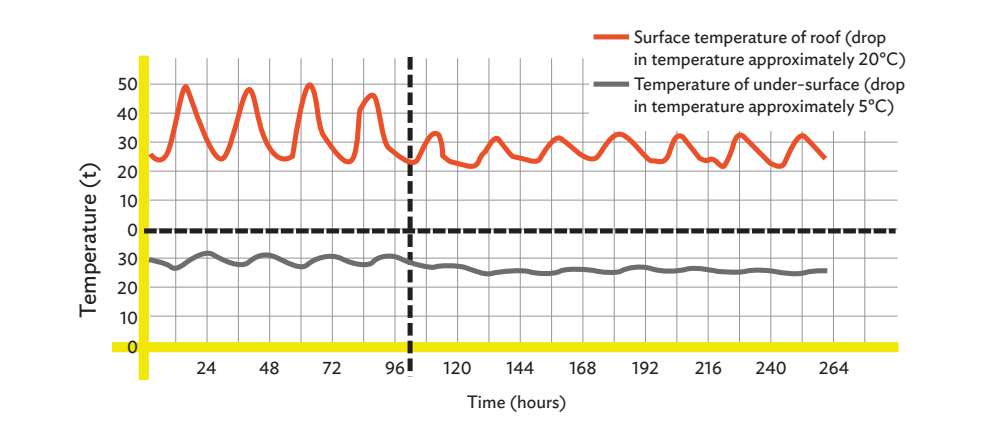
Box 5: Case Study of Cool Roof Application for Office Buildings in Hyderabad, India

A demonstration project to quantify and record the benefits of cool roofs was carried out at two office buildings in Hyderabad, India. The study team included the International Institute of Information Technology and Lawrence Berkeley National Laboratory (LBNL), supported by the United States Agency for International Development (USAID) and SPM Thermoshield.

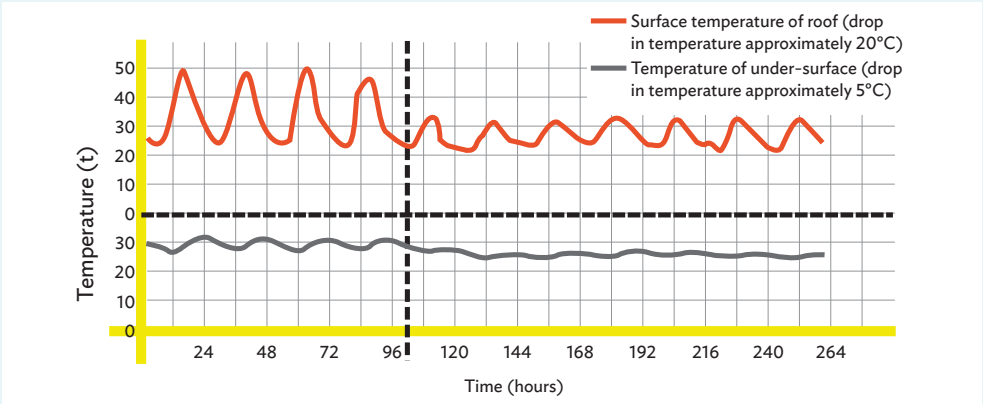
The complex for the application included two office buildings that were nearly identical. This setup facilitated the investigation by ensuring identical parametric values for floor area, number of floors, roofing material and system, occupancy and schedules, and cooling systems. Each building had two stories, with a roof area of approximately 700 square meters (m^2). For one building, its roof was painted black. For the other building, a white reflective cool roof coating was applied to its roof.

Weather towers, temperature sensors, current transducers, and data loggers were deployed to continuously monitor the weather condition (outdoor temperature, relative humidity), building temperatures (heat flux through the roof, surface temperature, roof underside temperature, indoor air temperature), and energy use (whole-building electricity use, cooling energy use). Results showed that the application of a cool roof reduced the average daily roof surface temperature by 20°C (Box Figure 5.1) and the cooling energy use by 15% to 20% during hot summer days (Box Figure 5.2).

Box Figure 5.1: Surface and Under-Surface Temperatures of Roof Assembly Before and After Cool Roof Coating Application



Box Figure 5.2: Heat Flux and Cooling Energy Use Before and After Cool Roof Coating Application



Source: Bureau of Energy Efficiency. 2017. Cool Roofs for Cool Delhi.

Ventilative Cooling

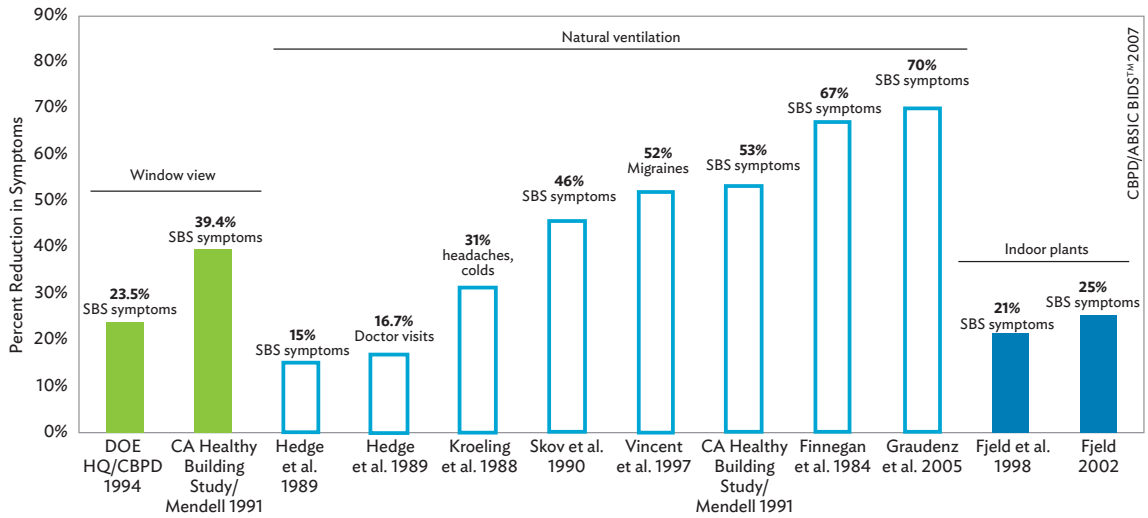
Natural Ventilation

Natural ventilation can serve a range of purposes in buildings, from delivering fresh air to maintain indoor air quality to ventilative cooling to limit temperatures in the summer. In naturally ventilated buildings, the driving force for air movement can be generated by a range of techniques that harness the potential of the stack effect, using air passages at different heights, and wind effects. As it involves no energy for driving airflow, natural ventilation is also known as passive ventilation. The complexity of building designs employing natural ventilation can vary substantially, depending upon specific application contexts, from simple designs of manually opened windows to sophisticated automated mixed-mode systems to those involving induced airflow through technologies such as passive downdraught evaporative cooling.

A major reason to take advantage of natural ventilation and ventilative cooling is the potential for lower energy consumption, CO_2 emissions, and operational costs compared with mechanical ventilation. Studies have found that buildings using mixed-mode ventilation and air-conditioning are major CO_2 emitters. In these buildings, CO_2 emissions resulting from fans and pumps required to transport conditioned air accounted for up to 50% of the emissions associated with space cooling and heating. Also, as the built form of air-conditioned buildings tends to be a deep plan, artificial lighting is more commonly used than buildings of other forms, thereby causing more energy consumption and CO_2 emissions.

In addition to energy savings and emission reduction, there are a range of other motives for choosing natural ventilation over other options. Naturally ventilated buildings tend to create an indoor environment more comfortable and desirable to occupants than mechanically ventilated and/or air-conditioned buildings. Usually, a lower prevalence of sick building syndrome (SBS) is reported by occupants of naturally ventilated buildings (Figure 35). Besides, naturally ventilated buildings, if carefully designed, can cost less to construct and maintain than buildings that are more heavily mechanically serviced. Maintenance is generally infrequent and of a relatively straightforward and unspecialized nature.

Figure 35: Reduction in Sick Building Syndrome Resulting from Access to the Natural Environment—Window View, Natural Ventilation, and Indoor Plants



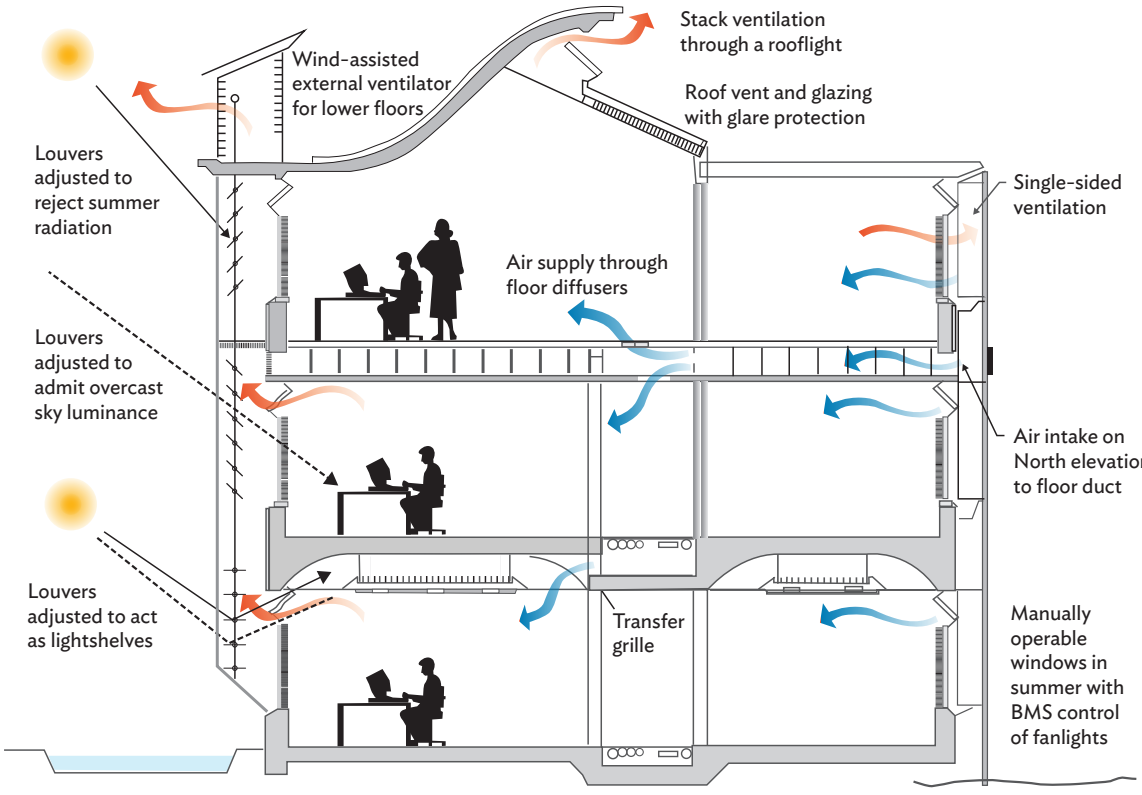
CA = California, CBPD = Center for Building Performance and Diagnostics, DOE = Department of Energy Headquarters, SBS = sick building syndrome.

Source: Kellert, S.R., J. Heerwagen, and M. Mador. 2008. Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life. Wiley.

Heat gains, especially in nondomestic buildings located in urban heat islands, are a critical factor in the success of design strategies for natural ventilation. It is also important to identify, at an early stage, and minimize, to the extent possible, other external environmental conditions that may constrain the use of natural ventilation, such as high levels of ambient noise and air pollution. Their presence may require windows to be closed and the operation of a mechanical ventilation system, resulting in higher energy consumption and CO_2 emissions. Further, controls of natural ventilation need to be ergonomically efficient and rapidly responsive to occupants' needs.

The most important aspects of natural ventilation are the form and layout of the buildings, which can enhance airflow. The airflow path defines different ventilation modes, such as background ventilation, single-sided ventilation, cross-ventilation, stack ventilation, and sub-slab distribution. While sometimes mechanical equipment and devices are added to enhance ventilation system performance and control, these systems are invariably conceived as variants of the basic modes of ventilation strategies. Figure 36 provides an illustration.

Figure 36: Illustration of Various Natural Ventilation Strategies



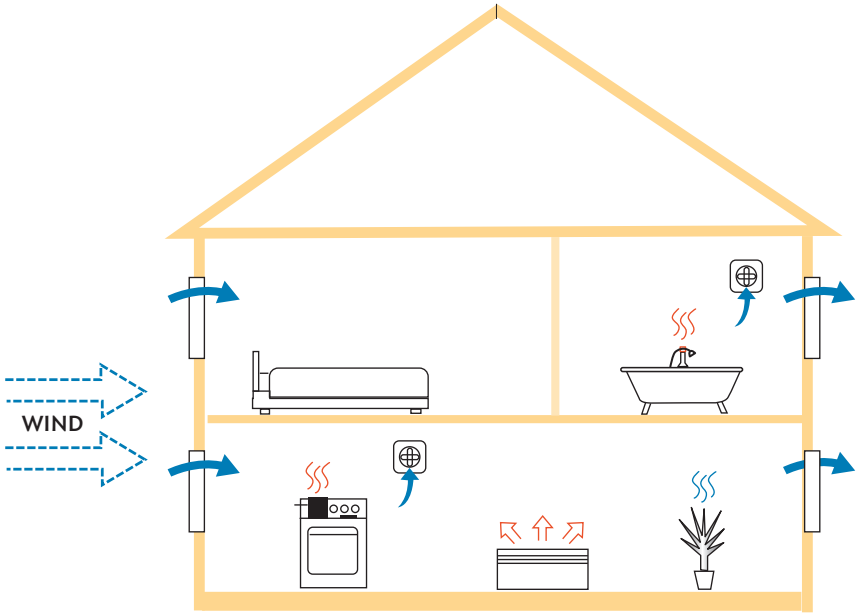
bms = building management system.

Source: Pennycook, K. 2009. *The Illustrated Guide to Ventilation: BG 2/2009*, Bracknell, Berkshirem, UK: Building Services Research and Information Association (BSRIA).

Background Ventilation

Background ventilation, also known as trickle ventilation, serves to provide the necessary minimum fresh air rate to satisfy the minimum ventilation requirements during room occupation, particularly in winter, but without increasing heat loss (Figure 37). At higher airspeeds, trickle ventilation can also provide external airflow for ventilative cooling outside of the occupation period.

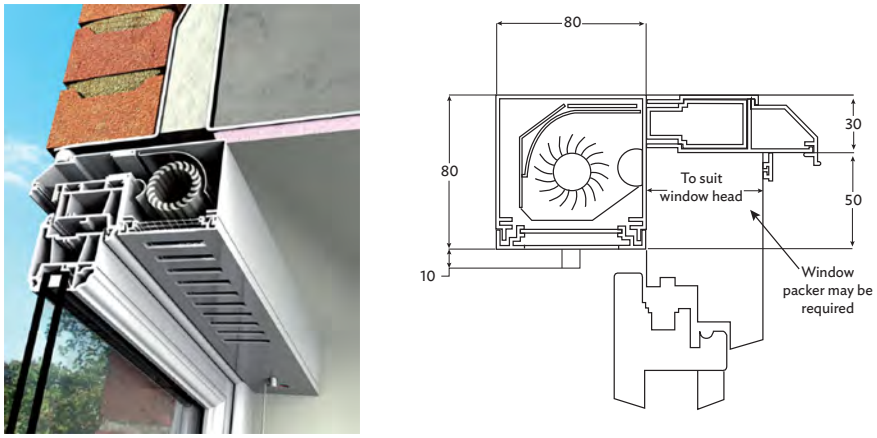
Figure 37: Background (Trickle) Ventilation



Source: Joinery Developments. 2010. Background Ventilation.

To minimize cold draughts, trickle vents are usually controllable and should be placed at a high level, typically 1.75 meters above floor level, and designed to promote rapid mixing within the room. Installation locations of trickle vents vary—they may be mounted between window lintel and frame, be surface-mounted at the window frame or sash, or be glazed in. Trickle vents may be passive, with the airflow driven by pressure drop, or be equipped with a fan serving as as an exhaust vent. Technical challenges that should be considered in designing and operating trickle vents include the prevention of excessive airflow in cases of high wind pressure, reasonable U-values to address heat loss, noise protection, and fire resistance. Figure 38 provides an example of a commercially available trickle vent.

Figure 38: Trickle Exhaust Vent with Fan

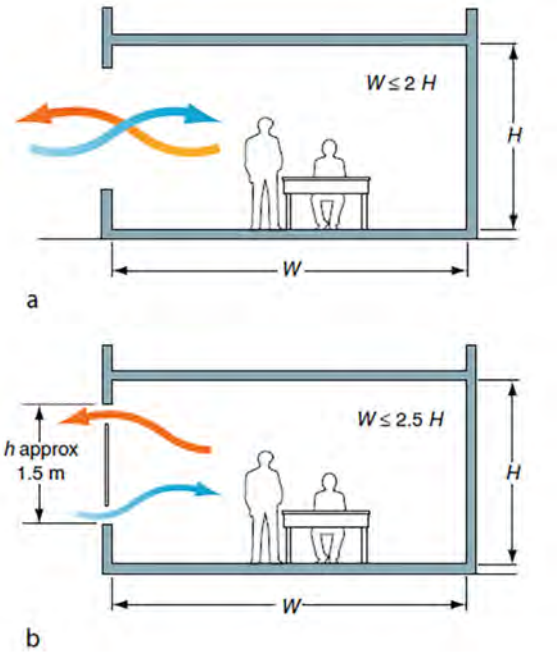


Source: Titon UK. 2021. Vent-Trex Over-Head Extract Fan and Trickle Ventilator.

Single-Sided Ventilation

Single-sided ventilation typically serves single rooms and uses vents on only one side of the enclosure (Figure 39). It is often found in many multi-room buildings with opening windows on one side of the room and a closed internal door on the other side.

Figure 39: Single-Sided Ventilation (a) Single-Sided Single-Opening; (b) Single-Sided Double-Opening



H = height, m = meter, W = width.

Source: Yang, T. and D.J. Clements-Croome. 2013. Natural Ventilation in Built Environment. In V. Loftness and D. Haase, eds. *Sustainable Built Environments*. Springer.

Compared to other natural ventilation strategies, a single-sided ventilation with a single opening is less attractive due to lower ventilation rates and smaller distances of ventilating air penetrating into the room. It is mainly driven by wind turbulence, which generates reversing flows in and out of the room. When the single opening is tall, the exchange of air can also be driven by stack effects generated by temperature differences.

In the case of double openings, the driving force of air exchange can be enhanced by room-scale stack effects. The stack-induced airflow is a function of the vertical separation of the openings and the inside and outside temperature differences. Compared to a single opening, there is an increased probability of pressure differences occurring between two openings, thus improving ventilation effectiveness to some extent. In winter, to minimize cold drafts for occupants at the perimeter, care should be exercised to position the inlets within the room.

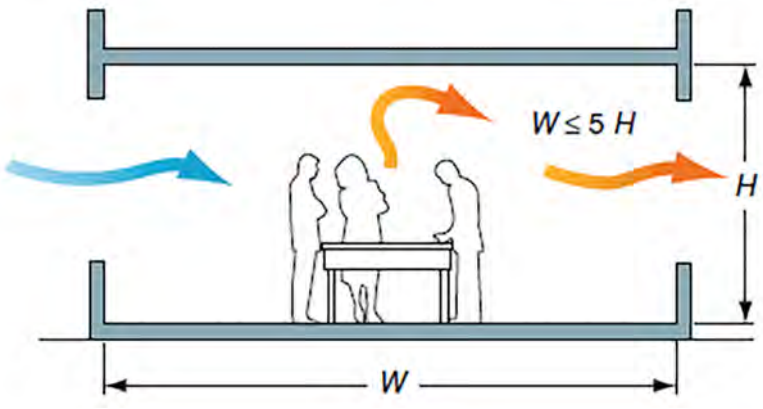
Single-sided ventilation should only be used when the building form or location limits ventilation to one facade. As a rule of thumb, the limiting depth for effective ventilation is about two times the floor-to-ceiling height for single openings, and 2.5 times the floor-to-ceiling height for double openings, respectively. When heat gain is low, single-sided ventilation could be effective over a depth of up to 10 meters and may be incorporated into open-plan offices.

Cross-Ventilation

Cross-ventilation is usually driven by wind-generated pressure differences, inducing positive pressures on windward surfaces and negative pressures on leeward surfaces (Figure 40). Airflow characteristics are determined by the combined effect of wind and temperature differences. The floor depth in the direction of ventilation must be limited to effectively prevent heat and pollutant buildup in the space during ventilation. As a rule of thumb, the limiting depth for effective ventilation is about five times the floor-to-ceiling height, implying a relatively narrow plan depth for the building.

An effective measure to improve wind-driven natural ventilation, such as cross-ventilation, is to use windcatchers, which are vertical building-integrated structures, often roof-mounted, that induce outdoor fresh air into indoor space by harnessing the pressure difference over the building and across the device openings. Major components of a windcatcher include a louvered terminal, a base, and damper assemblies that enable automatic or manual adjustment of the ventilation. With compartmentalized vertical vents, the pressure difference across the segments facing the wind drives outdoor air into the room, and the suction created by the negative pressure on the leeward segments draws indoor air out of the room (Figure 41).

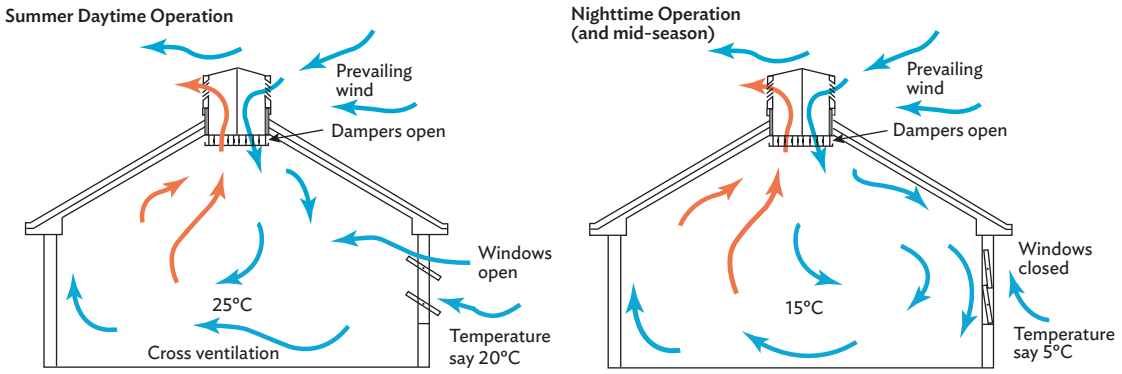
Figure 40: Cross-Ventilation



H = height, W = width.

Source: Yang, T. and D.J. Clements-Croome. 2013. Natural Ventilation in Built Environment. In V. Loftness and D. Haase, eds. *Sustainable Built Environments*. Springer.

Figure 41: Windcatcher Operation During Daytime and Nighttime

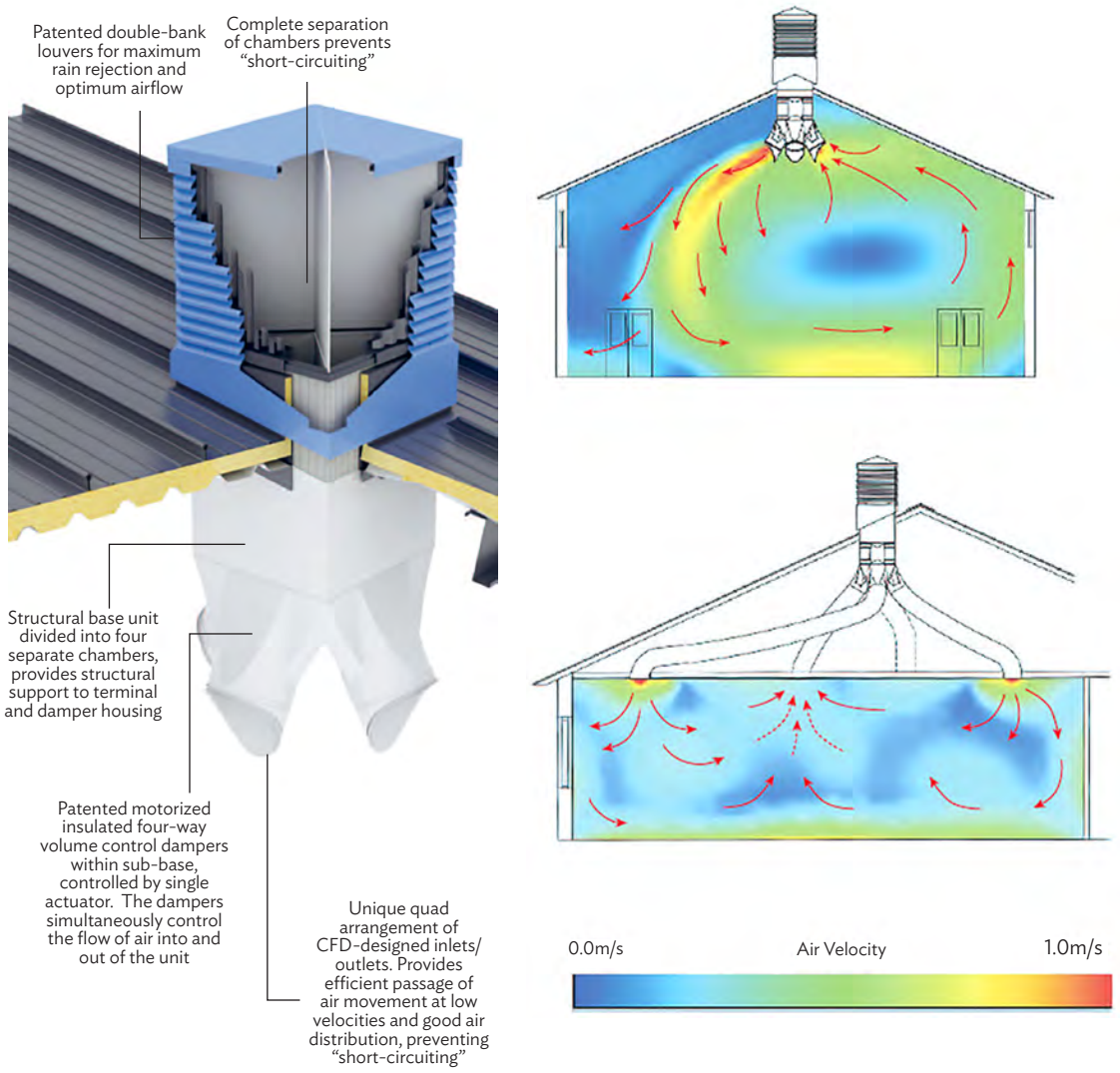


Source: Delta Pyramax. 2021. Windcatcher: Feature.

Roof-mounted windcatchers are particularly suitable for schools, libraries, and health and community centers—all of which require low operational and maintenance costs. The performance of windcatchers depends upon the positioning and alignment of windcatchers, the shape of louvers, the size of louvered area, the height of louvers relative to roof level, the resistance of dampers, and the airflow driving forces (pressure difference and temperature difference) in the context of prevailing wind conditions. Other factors such as acoustic liners, which might be required in applications in areas of heavy local traffic, and the airflow network within the ventilated room, which is affected by room layout and heat gains, should also be considered.

Figure 42 shows the Airscoop terminal manufactured by Passivent, UK, which is a roof-mounted windcatcher particularly designed for large or deep-plan spaces where direct perimeter ventilation through the building facade is limited or not possible. Each unit of the Airscoop terminal is divided into four separate internal ducts so that prevailing wind from any direction can be captured and channeled down through the windward chambers. The cooler and denser outdoor fresh air flows down into the building, while the warmer and lighter stale air from inside is displaced upward and out via the leeward chambers. The complete separation of chambers provides improved distribution and mixing of air and prevents short-circuiting of inward and outward airflows around the unit. To cater to the needs of buildings with intermediate ceilings, such as offices and classrooms, the inlets and outlets of an Airscoop unit can be connected via flexible ductwork to four diffusers mounted to the ceiling of the ventilated space. This flexibility enables the ceiling diffusers to be positioned for maximum ventilation and air distribution benefits in relation to space utilization.

Figure 42: Roof-Mounted Windcatcher—Airscoop Terminal



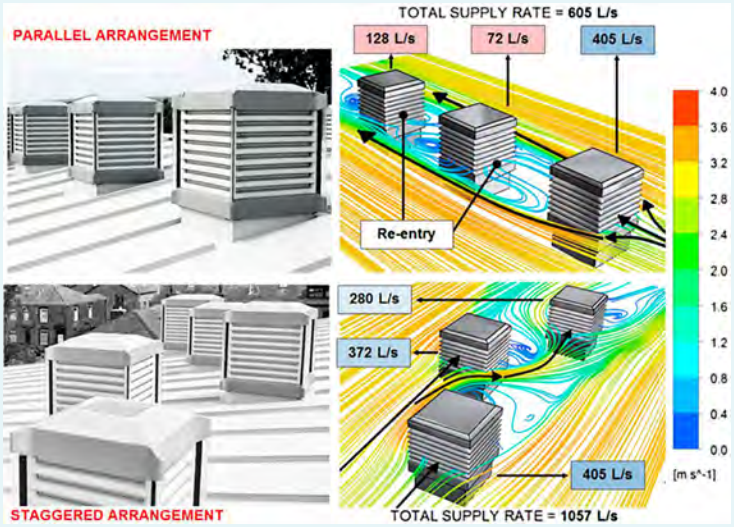
CFD = computational fluid dynamics, m/s = meter per second.

Source: Passivent. 2018. Roof Ventilation Terminals.

Box 6: Effects of Arrangement and Spacing of Windcatchers on Ventilation Performance

The layout and spacing of windcatchers have substantial impacts on ventilation performance in terms of indoor airflow distribution, ventilation rate, and carbon dioxide (CO_2) concentration. Calautit, O'Connor, and Hughes (2014) conducted a computational fluid dynamics (CFD) analysis to numerically investigate the effects of spacing and arrangement of multiple windcatchers located on the same building (Box Figure 6.1). The CFD model of an isolated windcatcher as the benchmark was validated using experimental wind tunnel measurements. A total of six different cases, consisting of two different arrangements with three different spacing lengths between windcatchers, were simulated.

Box Figure 6.1: Parallel and Staggered Arrangements of Roof-Mounted Windcatchers



Source: Calautit, J.K., D. O'Connor, and B.R. Hughes. 2014. Determining the Optimum Spacing and Arrangement for Commercial Wind Towers for Ventilation Performance. Building and Environment. 82. pp. 274–287. .

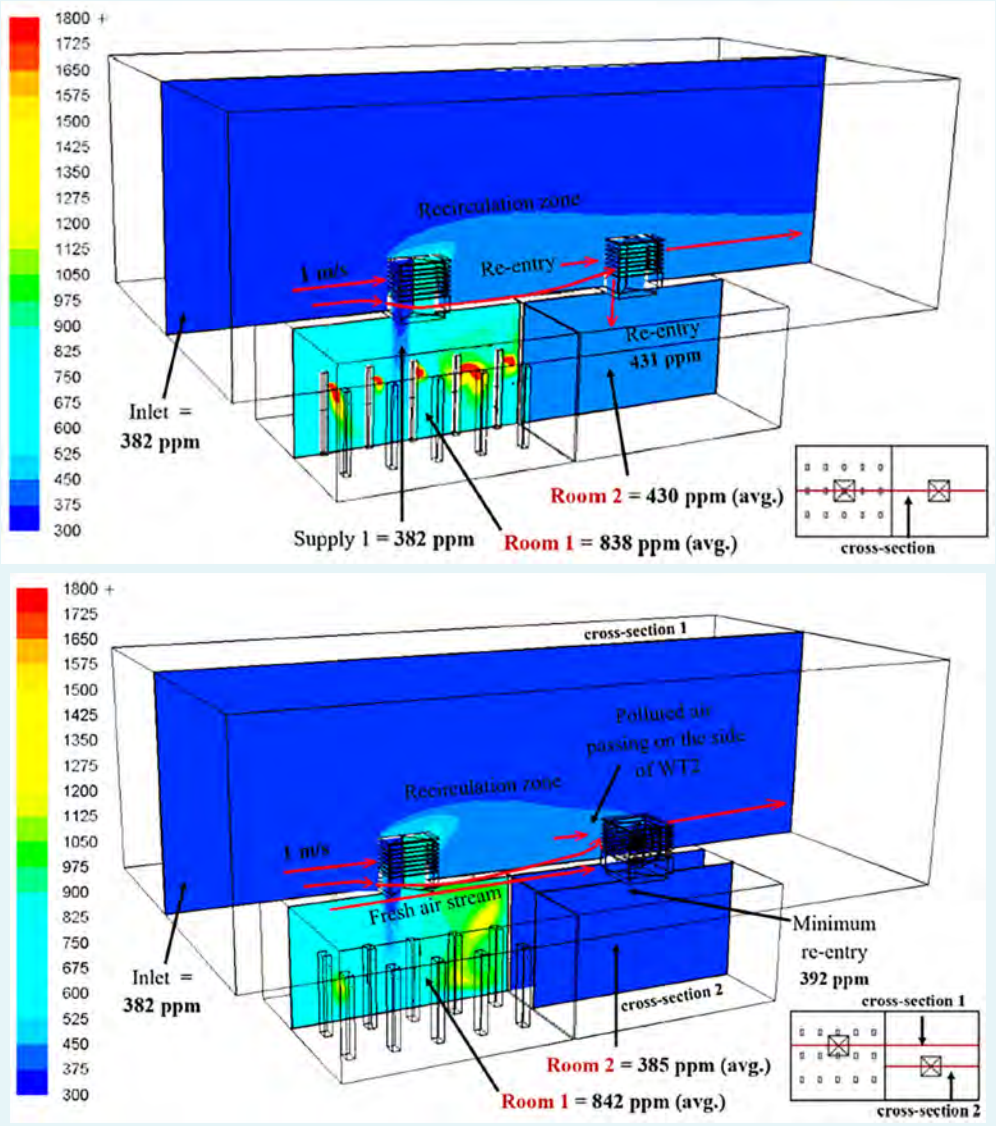
It was found that a parallel arrangement of windcatchers was not effective for ventilating an occupied volume, regardless of the spacing between two windcatchers, when the incident wind direction was parallel to the arrangement. The maximum supply rate for the leeward windcatcher in parallel arrangement at a spacing of 5 meters was just over 50% of the British regulation rate of 10 liters per second per occupant (L/s/occupant) and 40% of the supply rate of an isolated windcatcher as the benchmark. Decreasing the spacing between the parallel windcatchers to 3 meters further reduced the supply rate to 2.4 L/s/occupant, and the device was observed to be operating in reverse—airflow entering from a leeward opening. As the angle of wind increased, an improvement in air supply rates was seen. For a staggered arrangement, the leeward windcatcher was able to supply the recommended ventilation rates at all tested spacing lengths.

The average indoor CO_2 concentration of the ventilated space with the leeward windcatcher was substantially higher in the parallel arrangement than the staggered arrangement at a zero-degree wind angle. As shown in Box Figure 6.2, with the parallel arrangement, the average CO_2 concentration was 28–50 parts per million (ppm) higher than the outdoor concentration. With the staggered arrangement, which effectively minimized the reentry of pollutants, the indoor CO_2 concentration was brought down to just 1–3 ppm above the outdoor level.

continued on next page

Box 6 *continued*

Box Figure 6.2: Contours of Carbon Dioxide Concentration (ppm) Inside the Occupied and Unoccupied Room Ventilated with Parallel (above) and Staggered (below) Arrangements with Spacing of 5 Meters



ppm = parts per million.

Source: Calautit, J.K., D. O'Connor, and B.R. Hughes. 2014. Determining the Optimum Spacing and Arrangement for Commercial Wind Towers for Ventilation Performance. Building and Environment. 82. pp. 274–287.

Source: Compiled by authors.

Box 7: Case Study of Cross-Ventilation—Bayalpata Hospital, Achham, Nepal

Bayalpata Hospital is in the mountains of northern Nepal. Through three phases of expansion, the previously obsolete and overrun medical facility was transformed into a model of sustainable rural health care. Now, with a built area of 4,225 square meters (m^2) spreading across a 7.5-acre hilltop in Achham, Nepal, this medical complex comprises five medical buildings that provide the functions of outpatient, inpatient, and antenatal units, along with emergency facilities for 70 beds, operation theaters, a pharmacy, a radiology lab, and other laboratory spaces. It also has an administration block with offices and a 60-seat canteen. Fourteen single-family houses and an eight-bedroom dormitory provide accommodation to the hospital's staff and their families (Box Figure 7.1).

Box Figure 7.1: View of Bayalpata Hospital, Achham, Nepal



Source: Sharon Davis Design. 2019. Bayalpata Hospital.

The design and construction of the hospital responded closely to the local site and climatic conditions. Its architecture maintains a vernacular and modest scale through setbacks, gabled roofs, and low-cost heat-storing materials. The low-rise, one- and two-story structures of the complex are organized around landscaped courtyards. Built from on-site materials and with low-tech construction methods, the complex managed to minimize the cost-prohibitive transportation of building materials in this mountainous region, thus contributing to low-carbon design from a life cycle perspective.

Box Figure 7.2: Courtyards of Bayalpata Hospital



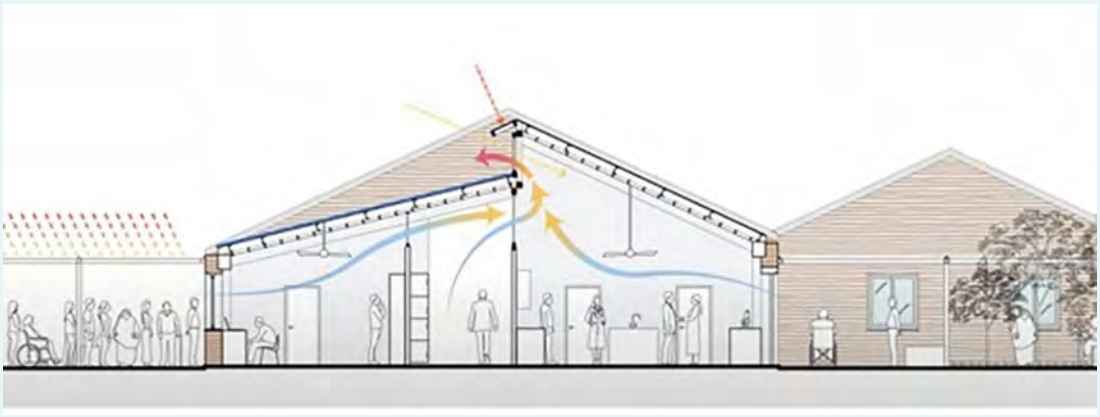
Source: Transsolar Energietechnik. 2021. Bayalpata Regional Hospital, Achham, Nepal.

continued on next page

Box 7 *continued*

Except for the operating theater and laboratories, all the other spaces of the complex are cooled and heated passively. The structures of the complex consist of massive, rammed earth walls with insulated roofs. Materials with thermal mass retain daytime heat gain in winter, while keeping the interiors cool by preventing overheating during summer. Cross-breezes through courtyards, assisted by clerestory ventilation and ceiling fans, facilitate natural ventilation, and improve indoor thermal comfort conditions with minimal energy consumption (Box Figure 7.3). For electricity, a grid-connected, 100-kilowatt photovoltaic system installed across all south-facing roofs is the major source of electricity supply to the hospital. A solar-powered water heating system installed can heat up to 3,300 liters of water per day for both medical and domestic use. Electricity for artificial lighting is reduced by harvesting daylighting throughout all clinical areas, which is realized through tall, narrow windows, south-facing glazed clerestories, and skylights in the buildings.

Box Figure 7.3: Ventilation Strategy of Bayalpata Hospital



Source: NZEB Alliance. 2021a. Bayalpata Hospital Achham, Nepal.

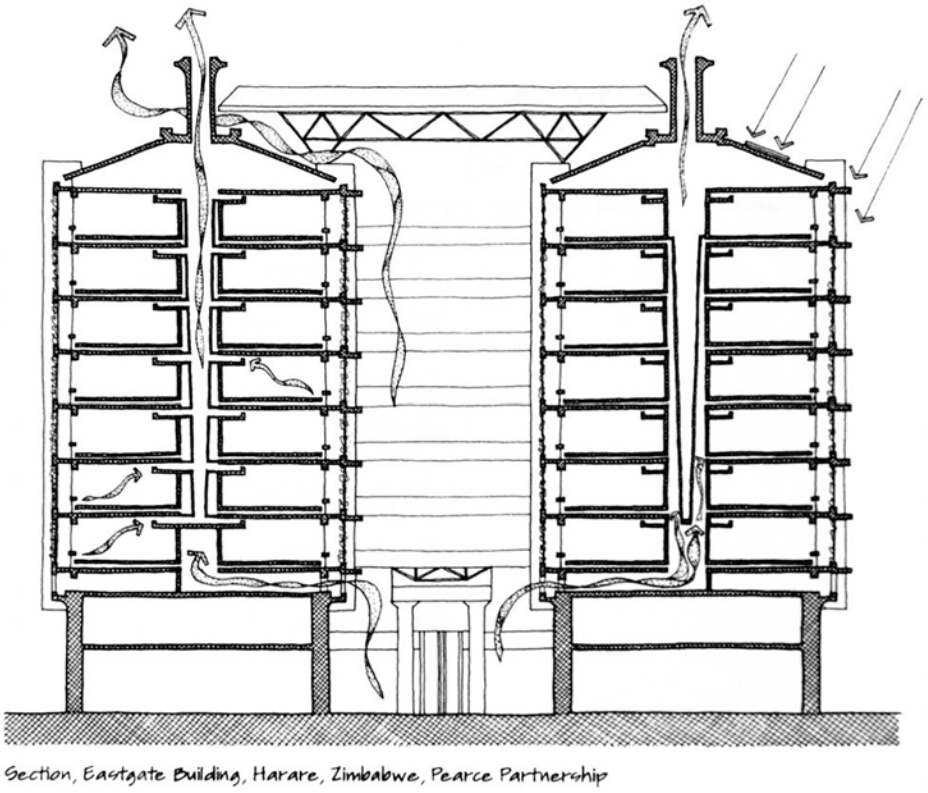
Source: NZEB Alliance.2021a. Bayalpata Hospital Achham, Nepal; Sharon Davis Design. 2019. Bayalpata Hospital; Transsolar Energietechnik. 2021. Bayalpata Regional Hospital, Achham, Nepal.

Stack Ventilation

For buildings with deeper floor plans, stack ventilation provides a solution. This is achieved via purposefully designed and built vertical ducts, shafts, solar chimneys, internal atria, etc. These various types of vertical spatial continuity within the building provide passage for air at higher temperatures, thereby generating pressure differences that give rise to the stack effect. Warmer and less dense indoor air rises and is exhausted via high-level vents. The upward air movement produces a negative indoor pressure at the bottom and a positive indoor pressure at the top. Thus, it is important to ensure that the roof vents are always positioned in a negative pressure zone with regard to wind-induced pressure. This can be achieved through designing the roof profile so that the vents are in a negative pressure zone for all wind directions (the Venturi effect), installing a single vent system, that turns to face away from the wind, or installing an automatically controlled multi-vent system that opens and closes outlets depending upon wind directions so that the opened ones are always in a negative pressure zone.

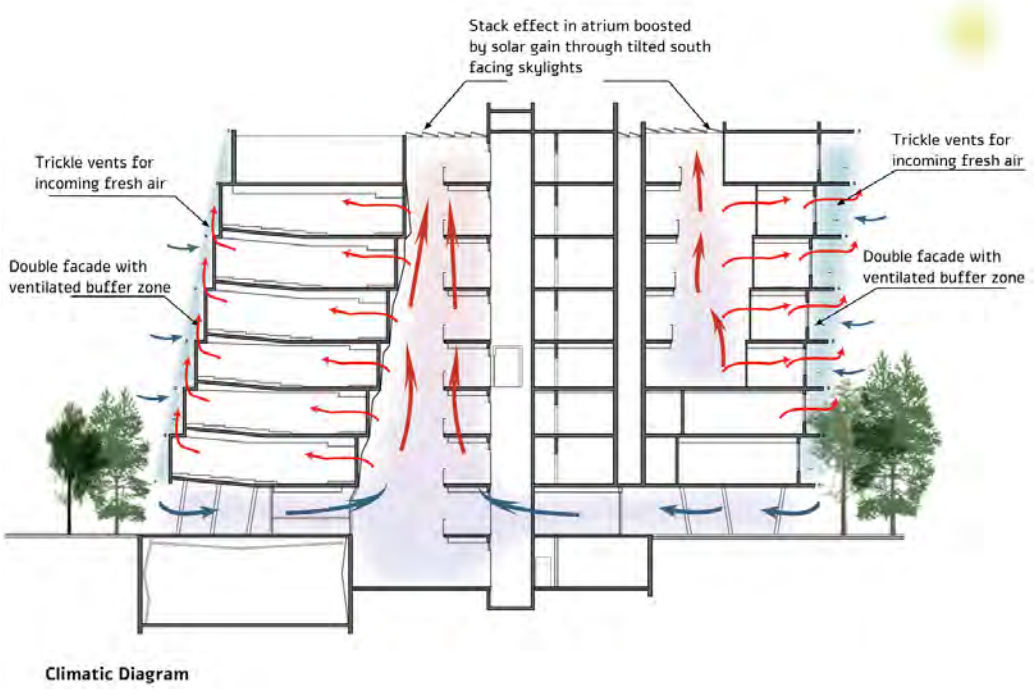
Figure 43 and Figure 44 illustrate how stack ventilation works. In Figure 43, ventilation shafts, stack towers, and an atrium are used, which are simple architectural features to enhance ventilation. Figure 44 is based on solar-induced ventilation. The double facade system not only promotes access to daylight, but also causes a higher pressure difference between the lower inlets and higher outlets of the air, creating a special form of solar chimney. The heat gain from solar radiation through south-facing tilted skylights strengthens the stack effect in the atrium.

Figure 43: Stack Ventilation Using Atrium, Shafts, and Towers



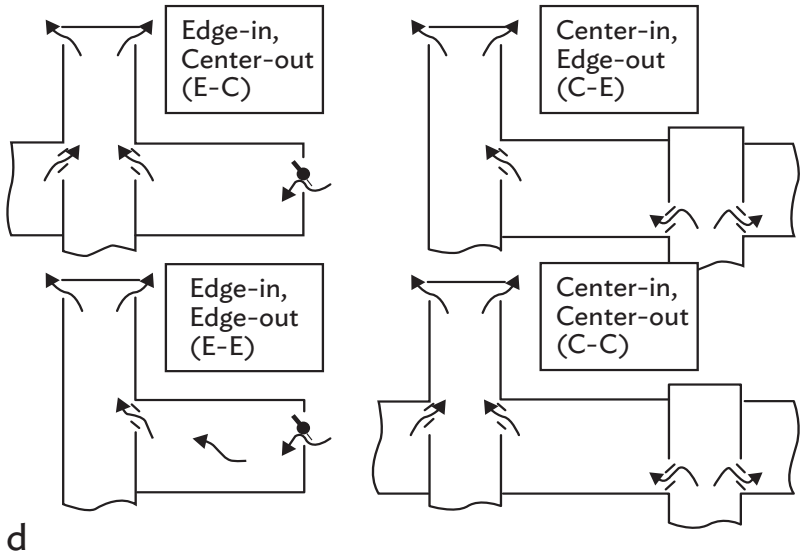
Source: Linquip. 2020. Stack Ventilation: A Comprehensive Overview of the Principles and Applications.

Figure 44: Solar-Induced Ventilation



Source: Oh, E., 2015. o2a's Proposed Tel Aviv University Building Controls Natural Light and Wind for a Sustainable Solution.

Figure 45: Different Forms of Stack Ventilation



Source: Kevin J.L. 2007. Architectural Design of an Advanced Naturally Ventilated Building Form. *Energy and Buildings*. 39 (2). pp. 166–181.

Depending upon the locations where air flows in to and out of a building, stack ventilation can be categorized into four forms: (i) edge-in, center-out; (ii) edge-in, edge-out; (iii) center-in, edge-out; and (iv) center-in, center-out (Figure 46). The edge-in forms are susceptible to local air pollution, noise, and security concerns associated with natural ventilation design for buildings in urban areas. These issues can be mitigated by the center-in forms, which enable the external facade of the buildings to be sealed. With edge-in forms, the use of operable windows can enhance the airflow throughout the building during summer and can also allow outside air to be preheated by perimeter heating elements in the building. The edge-in, center-out form allows for natural ventilation design for deep-plan buildings. With center-in forms, the central stack, while being the air supply route, can also introduce daylight into a deep-plan building. The center-in, edge-out location locates the exhaust stacks at the perimeter of the building and therefore allows more flexible internal space planning.

Box 8: Case Studies of Stack Ventilation

CASE 1: BSKYB BROADCAST CENTER, LONDON, UNITED KINGDOM

The BSkyB broadcast center located in West London, houses the world's first naturally ventilated television studios (Box Figure 8.1). The building has 13 giant ventilation chimneys, including nine lining the building's eastern elevation and another four mounted to the west facade. The construction of concrete boxes within boxes provides a solution to eliminate external noise as well as naturally ventilate the studios to remove excessive heat generated by studio lights. Fresh air is supplied through acoustically lined tunnels built in between the underside of the studio's concrete floor and the floor of the surrounding box from street level (Box Figure 8.2). This construction form allows large air paths to minimize resistance to air movement as well as eliminate all influxes of noise.

To prevent a common stack ventilation problem—air cooling in the flue and dropping back into a room—the flues are lined and insulated on the inside. In an intermediate mode, the ventilation system will run on extract only to pull the air up the chimney and warm it. When the right flue surface temperature is reached, the air's natural buoyancy will take over, and the system then automatically switches to natural ventilation mode.

At the south end of the building, a glazed atrium houses a series of meeting rooms, a café, and breakout spaces. The office areas (8 meters in depth) on the west elevation are ventilated using single-side natural ventilation. The offices (15 meters in depth) on the eastern side utilize three atrium-line chimneys in the center of the building to help draw air across the floor plates. Access to daylight through these atria is an additional benefit of the design.

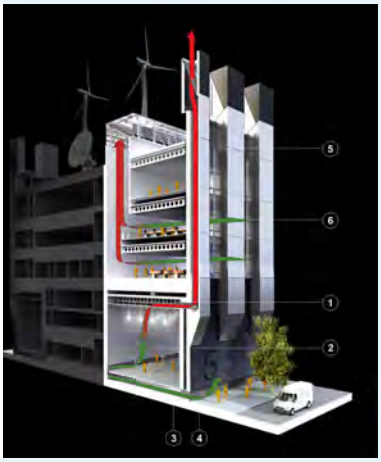
Box Figure 8.1: BSkyB Broadcast Center



Source: ARUP Associates. 2013. BskyB Sky Studios.

Box Figure 8.2: Natural Ventilation Flow within BSkyB Television Studios

1. Waste heat from the studio lights rises through the studio ventilation chimneys.
2. As waste heat rises, a small negative pressure is set up in the studios.
3. This pressure drop overcomes the resistance of the sound attenuators, drawing in fresh cool air from the exterior.
4. Exterior intake grilles
5. When external conditions are inappropriate for natural ventilation, mechanical ventilation and cooling of the studio spaces can be implemented using the same chimneys.
6. Office natural ventilation chimney follows similar principles



Source: ARUP Associates. 2013. BskyB Sky Studios.

Box 8 *continued*

CASE 2: COMMERZBANK, FRANKFURT, GERMANY

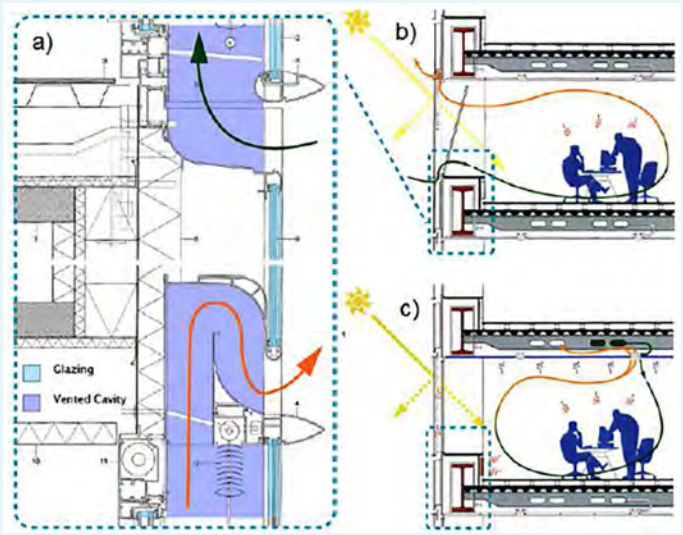
The Commerzbank in Frankfurt, Germany, is a successful example of a sustainable skyscraper integrating natural ventilation, daylight, and exterior views (Box Figure 8.3). The building's triangular-shaped plan provides a rigid structural support with high-rise functional cores at each corner of this triangle. The layout of the floor levels creates a helix with 4-story-high cutouts, creating space for landscaped terraces, called sky gardens. The center atrium of the buildings provides light from the glass roof at the atrium's top, as well as from the sky garden facades to the office areas. Sky gardens rotate around the facade and allow for ventilation through the atrium, which is divided into sections. Daylight is brought directly into the center of the building. Offices facing the center are provided with daylight and outdoor views through these green, natural spaces. The outer shell of the facade has slotted openings through which the outside air flows into the cavities between the layers and then enters rooms through open windows. This way, the wind pressure is brought down to appropriate levels to provide a natural ventilation of airflow. During winter, exterior vents are closed to allow heat to build up in the cavity spaces and improve the thermal insulation properties of the windows (Box Figure 8.4).

Box Figure 8.3: Commerzbank, Frankfurt, Germany



Source: Urban Systems Design. 2021. Commerzbank HQ Frankfurt, Germany.

Box Figure 8.4: Ventilation System of Commerzbank, Frankfurt (a) Double Skin facade (vented cavity); (b) Passive Heating, Cooling, and Ventilation System; (c) Active Heating, Cooling, and Ventilation System



Source: Penić, M., N. Vatin, and V. Murgul. 2014. Double Skin Facades in Energy Efficient Design. *Applied Mechanics and Materials*. 680. pp. 534–538.

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Box 8 *continued*

CASE 3: QUEEN'S BUILDING, DE MONTFORT UNIVERSITY, UNITED KINGDOM

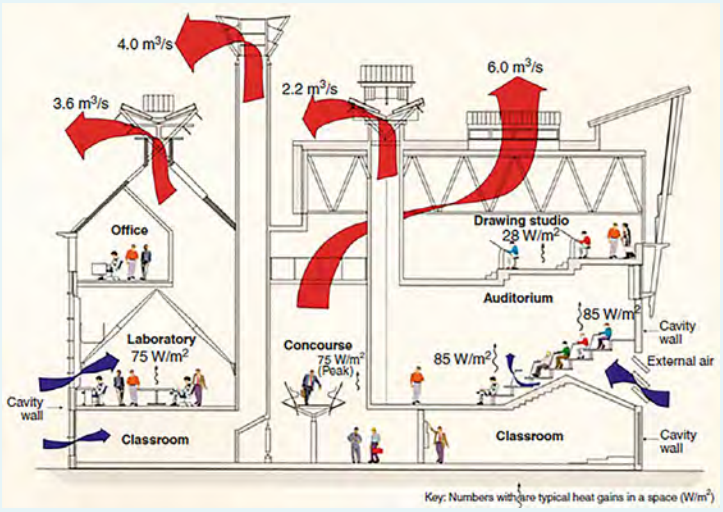
The Queen's Building at De Montfort University was built in 1993 (Box Figure 8.5). It was awarded Green Building of the Year 1995 by *The Independent*, and since then it has been serving as a demonstration project to showcase innovative technologies and demonstrate ways of achieving significant carbon reductions in modern buildings through refurbishment. The building features large ventilation chimneys, heavy thermal mass, a shallow floor plan, operable windows, and large ceiling heights to facilitate natural ventilation and daylighting. This traditional brick building has wide insulation-filled cavity walls and concrete slabs in the ceilings, which serve as a buffer for the indoor environment when outdoor temperatures vary drastically. Glazed ventilators also help to provide as much natural lighting as possible. In the auditoria, fresh air enters through louvers in the north facade by means of plenums below the raked wooden floor and wall inlets, which are controlled by the building energy management system (Box Figure 8.6).

Box Figure 8.5: The Queen's Building, De Montfort University



Source: Royal Academy of Engineering 2010. *Engineering a Low Carbon Built Environment: The Discipline of Building Engineering Physics*.

Box Figure 8.6: Natural Ventilation Strategies of the Queen's Building



Source: Yang, T. and D.J. Clements-Croome. 2013. Natural Ventilation in Built Environment. In V. Loftness and D. Haase, eds. *Sustainable Built Environments*. Springer.

CASE 4: THE SMART GHAR-III PROJECT (GREEN HOMES AT AFFORDABLE RATE), RAJKOT, INDIA

The Pradhan Mantri Awas Yojana (PMAY)—Housing for All (Urban)—was the Government of India's flagship program to address the housing shortage and fulfill housing demand for the urban poor. This mission target was 12 million affordable, eco-friendly houses between 2015 and 2022, supported by central financial assistance and subsidies through the states and union territories with different implementing mechanisms. The targeted construction was estimated to account for almost 11% of the predicted urban residential built-up area, housing 20%–30% of the urban population in 2022 (Chetia et al. 2020).

Rajkot, a mid-sized city in the Indian State of Gujarat, is the site of one project under the PMAY Untenable Slum Redevelopment program. The city falls in the composite climate zone with peak summer daytime temperatures reaching 41°C–43°C. Indoor temperatures on a typical summer day can reach 38°C and remain above 30°C for more than 6,200 hours per year. The project, named Smart GHAR III for "Green Homes at an Affordable Rate," comprises 11 residential towers and 1,176 dwelling units, each of which has a built-up area of 33.6 m^2. Each tower has seven stories with stilt parking.

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Box 8 *continued*

Box Figure 8.7: The Smart GHAR-III Project in Rajkot, India

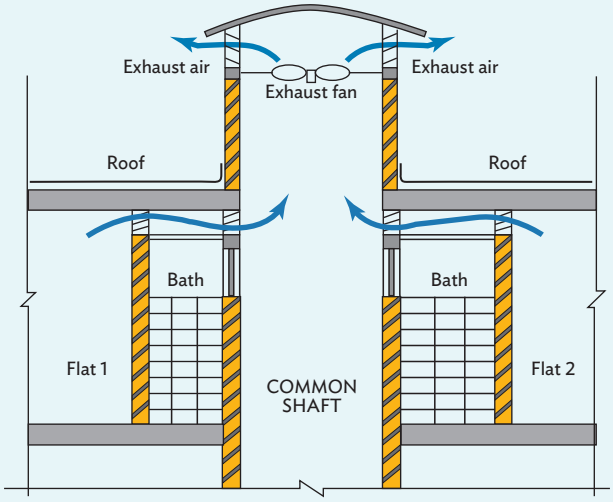




Source: Swiss Agency for Development and Cooperation. 2018. *Thermally Comfortable and Climate-Friendly Affordable Housing in India: The Smart GHAR III Project*.

One of the key design strategies to achieve indoor thermal comfort was to maximize the potential of natural ventilation for cooling. Although the wind speed in Rajkot is good, the design and layout of the residential towers and dwelling units are such that wind flow might not reach all flats as desired, and there would exist situations where very low or even no natural ventilation is available. This issue is addressed by using the existing service shafts between flats and exhaust fans to improve the natural ventilation. Adequate negative pressure is created in the shaft to improve air circulation and increase the air change rate in the flats. In addition to the assisted ventilation, the design strategies also include the use of a highly reflective china mosaic finish for roofing, tall and partially glazed casement windows, and lightweight concrete block walls with a low U-value. The window-to-wall ratio is low. Collectively, these measures effectively reduce heat gain through the building envelope.

Box Figure 8.8: Concept Sketch of Assisted Ventilation Through Common Shaft Between Flats



Source: WWF. 2021. Rajkot – Efficient Cooling is Key.

By adopting the above design strategies, the peak summer indoor temperature is reduced by more than 5°C compared to conventional housing in the same climate. The number of thermal discomfort hours per year drops from 6,200 to 2,500 (Gruner and Zinecker 2020). This improvement also helps to avoid or significantly reduce the need for air-conditioning units installed by the tenants, which leads to electricity savings, CO_2 emission reductions, and reduced energy bills. This project provides a good demonstration that careful design and appropriate building materials can achieve energy efficiency and thermal comfort in low-cost housing with a reduced climate impact (Swiss Agency for Development and Cooperation 2018).

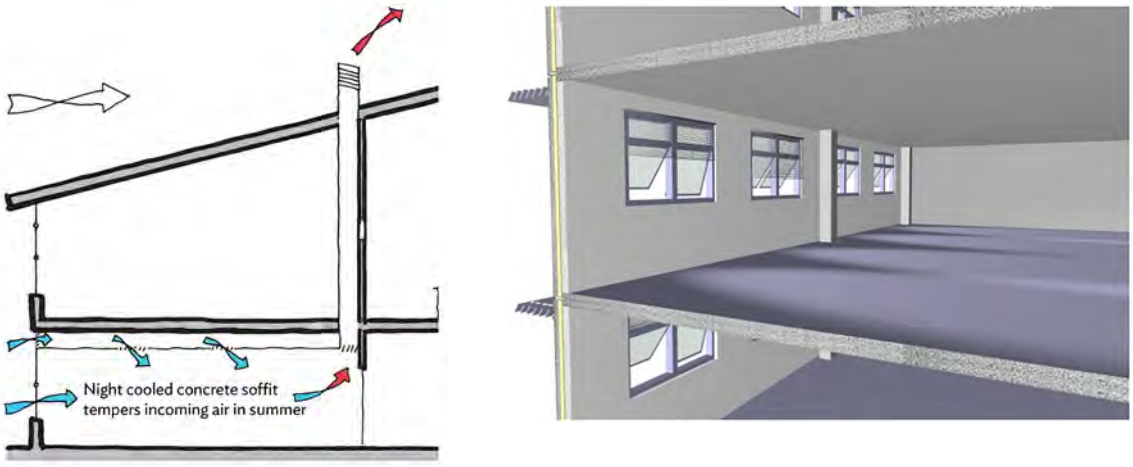
Source: Compiled by authors.

Night Ventilation

The motive for night ventilation is to avail of free night cooling benefits made possible by removing excess heat stored in the building structure through natural or mechanical ventilation during the nighttime (Figure 46). A key factor in night ventilation is to ensure good thermal contact between the ventilating air and the thermally massive building structure, e.g., the underside of floor slabs. During the day, the exposed floor slabs provide radiant cooling by absorbing the internal heat gains. During the night, the absorbed heat gains are dissipated as the exposed slabs are cooled by ventilating air. On the following day, the slabs can absorb more heat than they would otherwise, thereby significantly reducing or even avoiding the need for mechanical cooling and improving the indoor airflow and thermal conditions of the building. In this process, the thermal capacity of the slabs (and other thermal mass as part of the building structure) serves as a reservoir for incidental heat gains.

When mechanical ventilation must be used, the design of night ventilation needs to take account of the energy consumed by fans to transport the air through the building structure. It is important to use low-energy mechanical ventilation systems to avoid fan energy consumption exceeding the energy savings brought by the night cooling. It is also essential that the controls of night ventilation ensure that the summer night purge is undertaken during the coolest part of the night. In general, a well-insulated building with sufficient thermal mass exposed to night ventilation under good control strategies can reduce peak daytime temperatures by 2^0C to 3^0C. However, it should be noted that there is a risk of overcooling and subsequent reheating or thermal discomfort of the space on the following day. This needs to be controlled carefully. In addition, urban heat island effects in large cities present challenges to the effectiveness of night ventilation, as the nighttime air temperature is not low enough to cool down the exposed building thermal mass.

Figure 46: Night Ventilation Concept (left) and Exposed Slab (right)



Sources: Passivent. 2021. Night cooling; European Concrete Platform. 2009. *General Guidelines for Using Thermal Mass in Concrete Buildings*.

Mixed-Mode Ventilation

As natural ventilation is passive, it is likely that a purely natural ventilation system may not perform as expected, due to unavailable or suboptimal natural driving forces, such as wind for wind-driven systems, or pressure and temperature differences for stack ventilation systems. Therefore, it is necessary to use mechanical ventilation to complement natural ventilation and improve ventilation performance. This leads to mixed-mode ventilation. There are three distinct approaches to mixed-mode ventilation, including contingency design, concurrent mixed-mode design, and zoned design.

Contingency design. This approach provides for the future addition or removal of mechanical ventilation or cooling systems. For example, a naturally ventilated building may be planned for the ease of adding mechanical ventilation and/or air-conditioning. Equally, an air-conditioned building may be planned so that natural ventilation, or a combination of natural and mechanical systems, could easily be used when such a need arises. This approach is particularly useful in situations where the occupancy and/or activities in the building may change.

Concurrent mixed-mode. This approach has both natural and mechanical ventilation systems present. If well-designed and operated, the combination of the two systems can achieve desirable performance at a cost less than what otherwise would have been required by a full air-conditioning system.

Zoned design. This approach uses different systems, or combinations of systems, in parts of the building where the requirements for ventilation and cooling vary because of planning, location, occupancy, and/or usage. Zoning is particularly efficient where problems can be grouped. For example, parts of a building may be similarly poorly located for passive cooling but have heat gains from solar radiation, extensive equipment use, and high occupancy. In this situation, local air-conditioning may provide a solution.

It is important to ensure that natural and mechanical systems are properly designed and operated to avoid clashes, wasteful, and inefficient operation. In general, the strategies to achieve this include the following three ways.

Concurrent operation. An intrinsically efficient mechanical ventilation system, with or without cooling, operates in parallel with the natural ventilation system. With some care, this can be an effective and energy-efficient solution. For example, in a building designed for high thermal stability, the use of background mechanical ventilation, coupled with efficient fans, night ventilation, and heat recovery, may be able to maintain a steady indoor thermal environment in a cost-effective manner. While the use of mechanical ventilation reduces the need to open windows, openable windows can provide natural ventilation when required and can enhance indoor air quality and the thermal comfort of occupants. Moreover, the availability of natural ventilation helps to avoid over-sizing of the mechanical system and save costs.

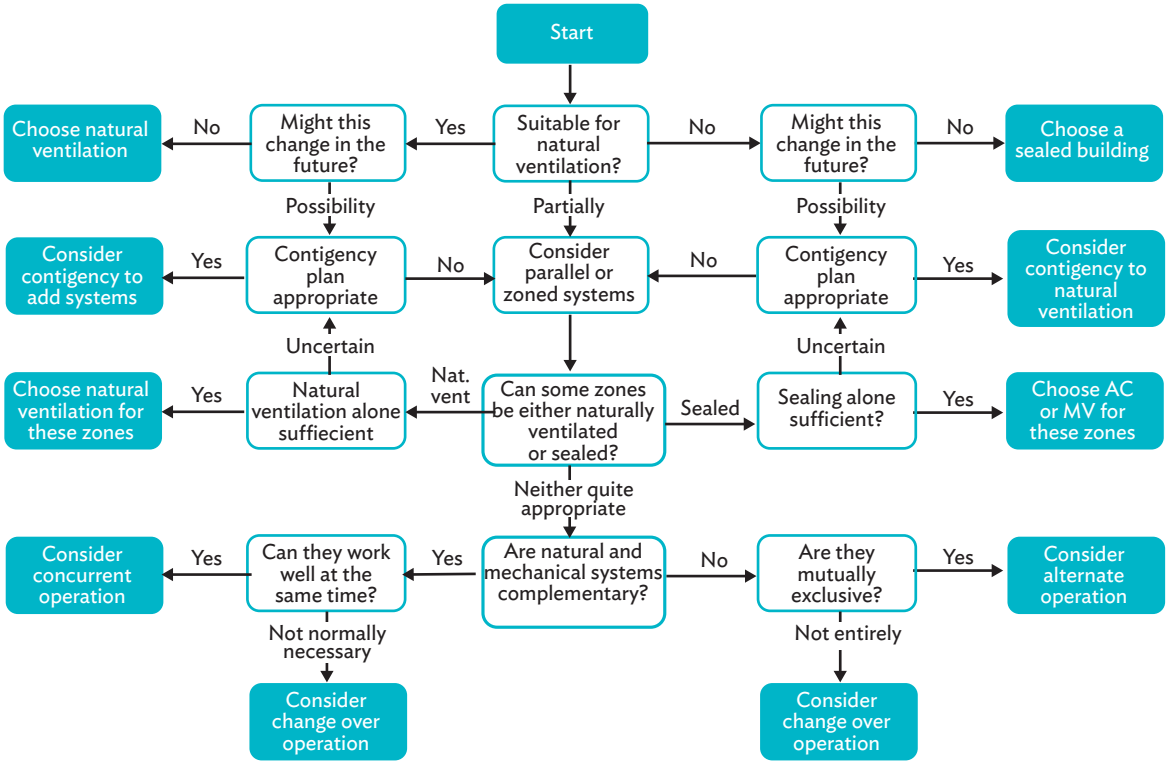
Changeover operation. In a building, natural and mechanical ventilation systems are both available and can operate together in different ways depending upon weather, time, occupancy, activities, etc. The underlying principle is that the use of natural ventilation is maximized to the extent reasonably possible, with the mechanical system used only as and when necessary. That is, natural and mechanical ventilation systems do not necessarily operate at the same time. For example, night ventilation in a building may be assisted by the mechanical system to enhance the cooling effect of the building structure. The night cooling effect may be further enhanced by mechanical refrigeration and cooling. Another example is local changeover, e.g., when windows are opened, mechanical cooling such as fan coils or chilled panels are switched off automatically.

Alternate operation. This is similar to the changeover operation but based on a longer-term operation and management choice. For example, when mechanical cooling is operated during the summer season, occupants are asked not to open windows when the cooling is running, e.g., during the daytime. Another example is that the system

is operated to cater to the specific needs of occupancy and use, e.g., full air-conditioning with closed windows. When there is a change of occupancy and use at the end of tenancy, the system operation may be changed to full natural ventilation or a hybrid operation.

Figure 47 presents a flowchart for selecting an appropriate mixed-mode strategy in various application contexts.

Figure 47: Selecting Mixed-Mode Strategies



AC = air-conditioning, MV = mechanical ventilation.
Source: CIBSE. 2012. Guide F Energy Efficiency in Buildings.

Box 9: High-Performance Air Systems

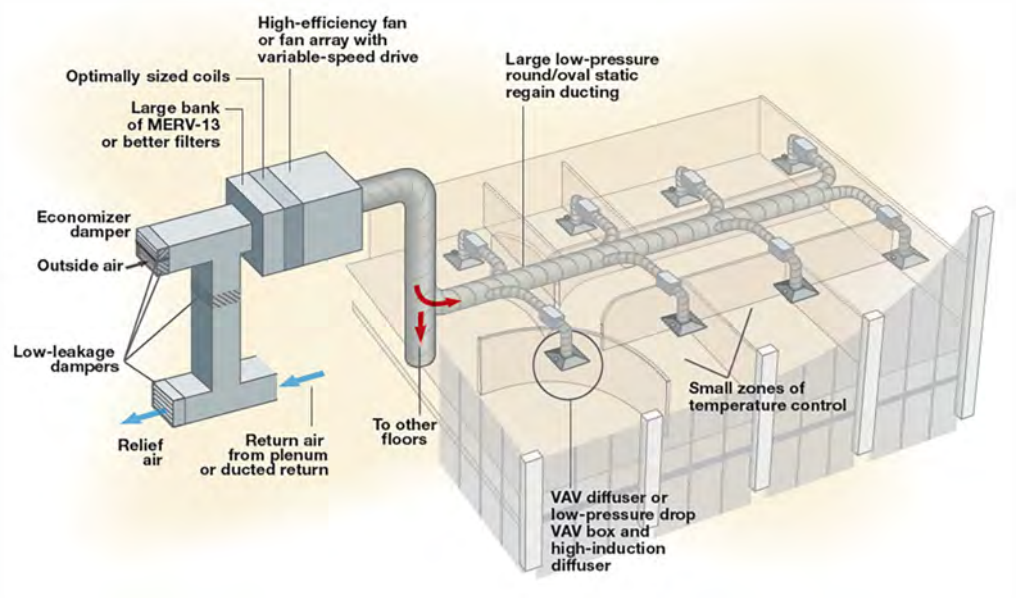
A high-performance air system (HPAS) is a variable-air-volume (VAV) system that optimizes energy efficiency, comfort, and indoor air quality, incorporating ventilation, cooling, and heating in a single ducted delivery system (Box Figure 9.1). HPASs perform significantly better than minimally code-compliant VAV systems by integrating the strategies and best practices of rightsizing, optimal zoning, free cooling, and coil cleaning using ultraviolet germicidal lamps. Also, HPASs minimize static-pressure drop, system leakage, and system effects.

Key strategies and technologies of HPASs include VAV, small temperature control zones, high-efficiency fans, economizers, air-to-air energy recovery, low leakage dampers and ducts, spiral or oval static regain ducting, low-pressure-drop components, variable flow compressors, and diagnostic sensors for system performance monitoring. All these contribute to energy savings. Advanced control technologies further increase energy savings through building-automation strategies such as demand-controlled ventilation, supply-air-temperature reset, and static-pressure reset.

An HPAS's high energy efficiency leads to low life cycle costs. Cooling energy cost savings are significant, as free cooling requires less cooling. Fan energy savings are also significant due to a lower system design static-pressure and optimal fan sizing. Additional energy savings come from on-and-off control via scheduling, the use of high-efficiency motors and variable-frequency drives, and demand-controlled ventilation. Continuous automated monitoring systems can lower life cycle costs by identifying operational events that could affect building performance. In addition to saving energy, the benefits also include higher worker productivity and an improved ability to lease the space. These benefits contribute to lowering life cycle costs.

Compared to ductless systems, other benefits of an HPAS include a low risk of refrigerant leakage (centralization of refrigerant in an equipment room or rooftop unit), improved comfort, flexibility, and efficiency (small temperature control zones), improved indoor air quality (use of minimum efficiency reporting value-13 or better filters), reduced noise (fans in a central location away from occupied spaces), higher adaptability (moving diffusers is easier than moving fan coil units), and safe and easy maintenance (no scheduled maintenance in occupied spaces).

Box Figure 9.1: Schematic of a High-Performance Air System



MERV = minimum efficiency reporting value, VAV = variable air volume.

Source: Air Movement and Control Association. 2017. *Introducing High Performance Air Systems*; Cowie, J. HPAC Engineering. 2017. The Case for High-Performance Variable-Air-Volume (VAV) Systems; Graham, C.I. 2016. High-Performance HVAC.

Box 10: Case Study of Mixed Ventilation and Microclimatic Envelope

Parkview Green FangCaoDi is one of the largest sustainable architecture projects in the People's Republic of China (PRC). This LEED Platinum and China 3-Star certified project, with a gross floor area of 200,000 square meters, comprises four buildings that include a luxury hotel, a retail mall, grade-A commercial office space, and a basement carpark. All buildings are designed with atria spaces, sky gardens, terraces, and link bridges to fit within a pyramidal glazed envelope (Box Figure 10.1). The four multistory buildings are separated by 24 meters to take advantage of natural light in the atrium. Offices are planned with a maximum 15-meter depth from facade to core and a clear floor-to-ceiling height of 2.9 meters for optimal daylight to reduce energy for lighting.

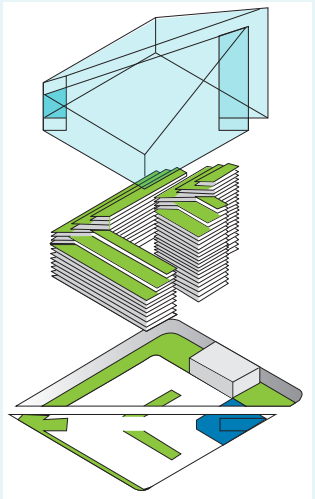
Box Figure 10.1: Parkview Green FangCaoDi, Beijing



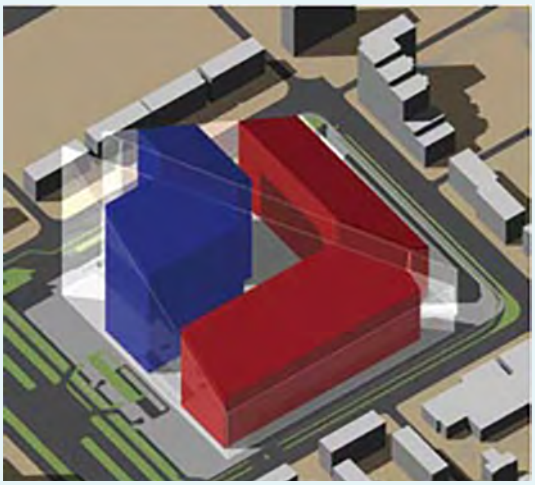
Integrated Design Associates. 2021. Parkview Green (FangCaoDi).



Building.com.hk. 2011. *Parkview Green Beijing: Microclimatic Envelope*.



Building.com.hk. 2011. *Parkview Green Beijing: Microclimatic Envelope.*



Building.com.hk. 2011. *Parkview Green Beijing: Microclimatic Envelope.*

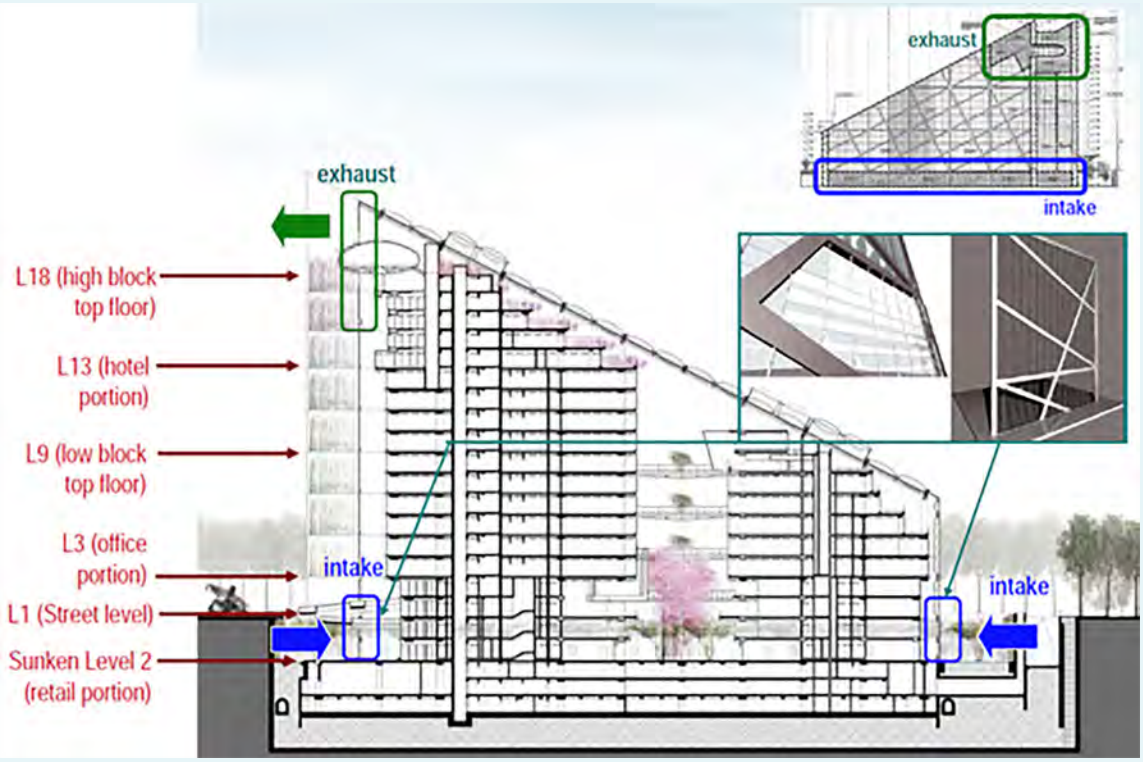
The project aimed to set the standard for a new paradigm of sustainable building in the PRC through a series of specific objectives, including sustainable and environmentally friendly occupied areas, low natural resource consumption and energy efficiency, minimal social and environmental impact on surrounding building occupants, cost-effective green technologies, maximized use of hybrid ventilation, low environmental impact, and good indoor environmental quality, among others.

continued on next page

Box 10 *continued*

At the heart of the set of design strategies to achieve these objectives is the pyramidal envelope, which is made up of a layer of single-glazing for walls and air-filled ethylene tetrafluoroethylene (ETFE) cushions for the roof, all supported by a steel structure that wraps the entire development. Within the envelope, the buildings are encased and shielded from the outer environment. This created an air buffer zone—the microclimate within the zone is relatively uniform and easily controllable. As a weather protection layer, the buffer zone controls the microclimate by way of thermal insulation formed in the airspace between the outer skin and the buildings. Also, as a passive breathing apparatus, the buffer zone regulates the enclosed environment in response to the extreme seasonal temperature variations in Beijing. It limits the need for air-conditioning in hot summers and reduces heat loss during freezing winters.

Box Figure 10.2: Section View, Ventilation Intake, and Air Exhaust of Parkview Green FangCaoDi



ARUP. 2008. Integrated Building Environmental Design—Beijing Parkview Green.

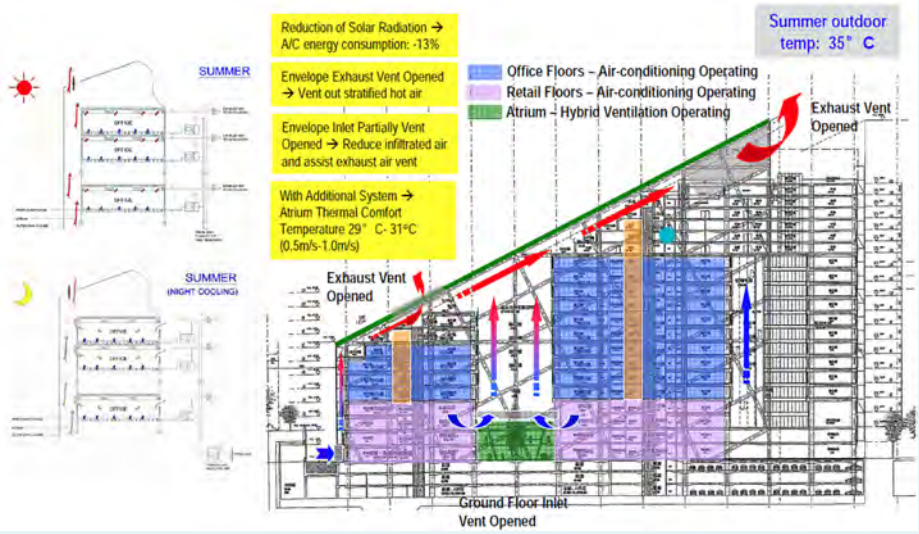
The pyramidal form of the envelope lends itself to natural air movement through the heat stack effect (Box Figure 10.2). Fresh air is drawn in at the base of the building as heated air rises through the atrium and into the roof void. The ETFE roof is set at a constant distance of 3 meters from the inner buildings to maintain air passage. Cool fresh air or warm air heated by solar radiation is being fed into the internal areas of the four buildings as required to regulate the temperature inside the office space. Operable windows and ETFE cushions are built into the microclimatic envelope for natural ventilation. These operable vents are computer-controlled and designed to work under different prevailing wind and environmental conditions. With the microclimatic envelope maintaining the atrium several degrees warmer in winter and cooler in summer, space cooling and heating loads and therefore the energy consumption of the HVAC system of the project are reduced substantially. The design and operation of the microclimatic envelope design are illustrated in box

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Box 10 *continued*

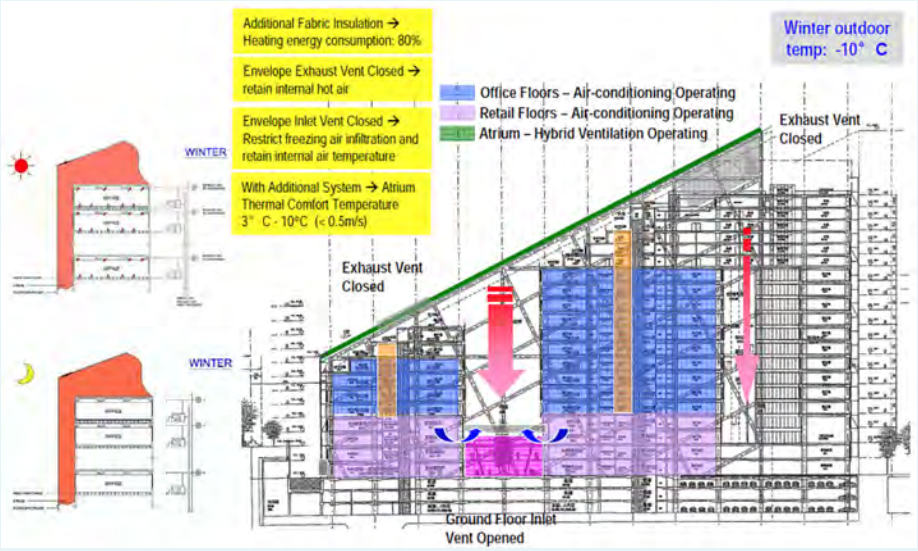
figure 10.3.

Box Figure 10.3: Microclimatic Envelope Design (Summer Season) of Parkview Green FangCaoDi



ARUP. 2008. Integrated Building Environmental Design—Beijing Parkview Green.

Box Figure 10.4: Microclimatic Envelope Design (Winter Season) of Parkview Green FangCaoDi



Source: ARUP. 2008. Integrated Building Environmental Design—Beijing Parkview Green; Integrated Design Associates 2021; The Skyscraper Center. 2016. Parkview Green FangCaoDi.

Low-Energy Cooling Technologies

Heat Recovery Ventilation

The principle of heat recovery is simple. Heat energy that would otherwise be released into the environment and therefore wasted is recovered for useful purposes. The recovered heat can take the form of sensible heat (temperature), latent heat (moisture), or a combination of both. Air-to-air heat recovery in ventilation and air-conditioning systems is the process of recovering heat and/or moisture between supply and return airstreams at different temperatures and humidities. The enthalpy of the supply air is decreased by the heat recovery device during warm or hot weather and increased during cold weather. This process helps to ensure the desired level of thermal comfort and indoor air quality while maintaining low operational energy costs and improving overall system efficiency. In some applications, heat recovery measures can reduce the system capacity and, thus, the overall capital cost of the building services. It is advisable to integrate heat recovery into the system at the design stage, as retrofitting the system at a later stage will be less cost-effective.

The key to the technical and economic feasibility of heat recovery is that the otherwise-wasted, recoverable heat should be of sufficient amount to justify the added complications of system design and operation. Additional power consumption by fans to overcome the additional air resistance of heat exchangers is a key factor to consider. As long as the ventilation and air-conditioning systems are in operation, additional fan power consumption is needed. However, the amount of recoverable heat may vary substantially throughout a year and sometimes need to be bypassed. Therefore, it is important to ensure the total energy savings from heat recovery exceeds the additional power consumption. Sometimes, under certain weather conditions, temperature differences between supply and return air streams may be reversed. In such a situation, reversed energy transfer should be avoided. In some applications, such as high moisture content in return air or full fresh air supply without recirculation, possible cross-contamination between air streams is an important design consideration.

Ideally, an air-to-air heat exchanger should function well to allow temperature-driven heat transfer and partial pressure-driven moisture transfer between supply and return air streams. It should provide optimal energy recovery performance to minimize pressure drop, at reasonable dimensions, weight, and cost. The ideal heat exchanger should also be able to minimize cross-stream transfer of air, particulates, and contaminants. In real-world applications, the main types of heat recovery devices include plate heat exchangers, run-around coils, heat pipes, and heat wheels.

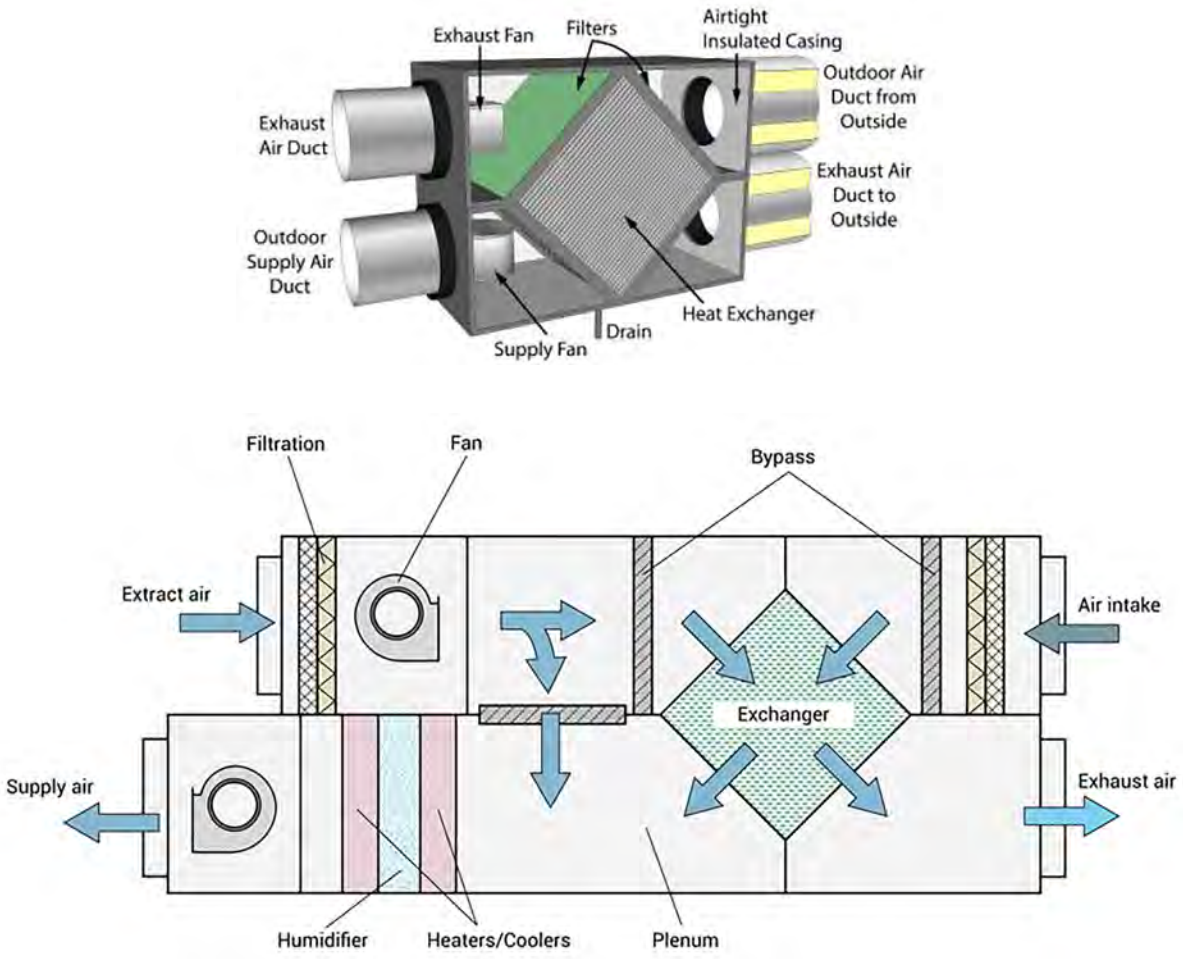
Plate Heat Exchangers

A plate heat exchanger contains a box with a series of parallel plates constructed from aluminum, steel alloys, or polymers, which allow the return air from the conditioned space to bypass the supply air for heat transfer. The plates are formed with spacers or separators constructed into the plates or with external separators. Plate spacing usually ranges from 0.1 to 0.5 inches, depending on the design and applications. The air streams are divided by the plates and have no contact with each other. Heat is transferred directly from the warm air stream through the separating plates into the cool air stream. Normally, only sensible heat is transferred. When water vapor permeable materials are used, such as microporous polymeric membranes, moisture may also be transferred, therefore enabling both sensible and latent heat (enthalpy) exchange.

Plate heat exchangers have only a primary heat transfer surface area separating the air streams and are not subject to the additional secondary resistance inherent in some other exchanger types, e.g., pumping liquid, in run-around systems or transporting a heat transfer medium. Almost any airflow direction and pattern of the supply and exhaust air streams can be handled by plate exchangers. In real applications, crossflow exchangers are the most commonly used configuration, due to design, construction, and cost factors. Sometimes additional counterflow patterns can be applied

to increase heat transfer effectiveness. As simple static devices, plate heat exchangers require no motive power and are therefore easy to commission and maintain. There is no or little leakage between air streams. Thus, the risk of cross-contamination is low. Normally, the efficiency of plate heat exchangers is in the range of 30% to 70%.

Figure 48: Schematics of a Plate Heat Exchanger and an Air-Handling Unit with a Plate Heat Exchanger



Source: Airtècnics. 2021. Air Handling Unit; BC Housing. 2015. *Heat Recovery Ventilation Guide for Multi-Unit Residential Buildings*.

Run-Around Coils

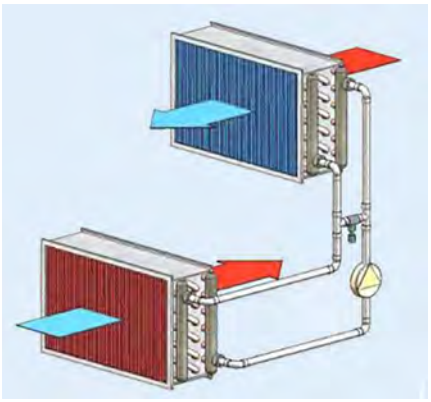
Run-around coils, also called coil energy recovery loops, are composed of extended surface, finned-tube copper coils located in the supply and return air streams of a building. The coils are connected in a closed loop by pipework, through which an intermediate heat transfer fluid is pumped and circulated. Typically, the fluid is water or an antifreeze solution. Sensible heat transfer takes place between air streams indirectly, via the fluid. Latent heat, i.e., moisture, cannot be transferred between air streams.

Run-around coils are particularly well-suited to applications where the supply and return air units are set up separately from one another due to layout constraints or strict hygienic requirements. The complete separation of supply and return air streams avoids the mass transfer of bacteria, contaminants, odors, etc. The high flexibility of

the loop configuration also allows simultaneous heat transfer involving multiple sources and uses in a single loop. Another advantage of run-around coils is their seasonal reversibility, which makes it possible to precool in the summer and preheat in the winter.

When assessing the technical and economic feasibility of run-around coils, additional air resistance, pumping energy consumption, temperature conditions, and frost protection are important factors to be considered. The typical efficiency of run-around coils ranges from 45% to 65%, depending on the number and spacing of coil rows and the prevailing temperatures.

Figure 49: Run-Around Coils



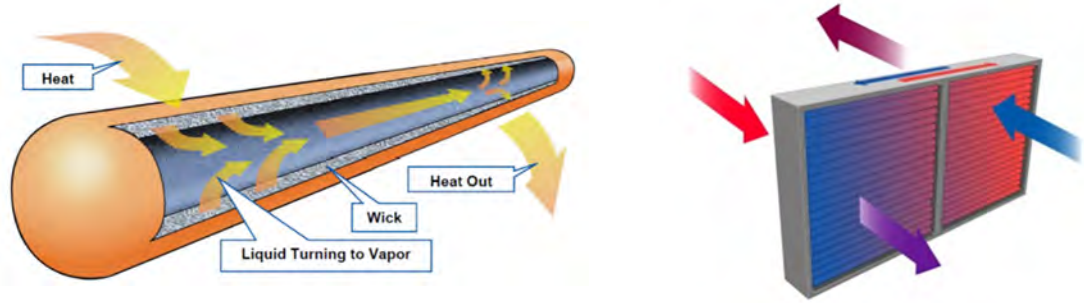


Sources: Robatherm. 2014. *Run Around Coils Heat Recovery Systems for High Efficient Heat Recovery*; The Renewable Energy Hub. 2021. Types of Heat Recovery System.

Heat Pipes

Heat pipes use a closed fluid cycle within a sealed tube to provide a reversible heat recovery system. A heat pipe has a condensation at one end and an evaporation section on the other end. Hot air flowing over the evaporation section transfers heat to the working fluid, which then vaporizes. A vapor pressure gradient drives the vapor to the condensation section, where the vapor condenses and releases the latent heat of vaporization. The condensed working fluid flows back to the evaporation section for re-vaporization. This way, the working fluid keeps operating in a closed-loop evaporation and condensation cycle, as long as there is a temperature difference as the driving force.

Figure 50: (a) Schematic of a Heat Pipe; (b) Heat Pipe Assembly



(a) (b)

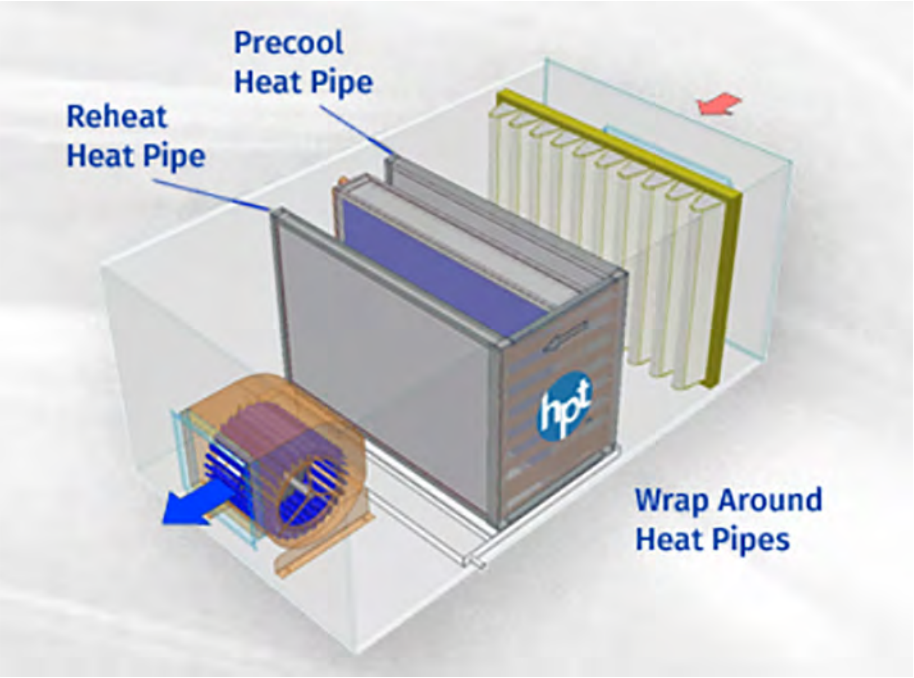
Source: Serck. 2019. Heat Pipes; Dynamic Air. 2012. Energy Recovery Heat Pipes | 5 Advantages of Using Heat Pipes for Air-To-Air Energy Recovery..

For ventilation and air-conditioning applications, heat pipe heat exchangers can be used to retrofit an existing system for improved energy recovery and dehumidification. During summer, the hot supply air stream is precooled by a heat pipe heat exchanger before it enters the cooling coil. This allows more dehumidification along with cooling by the cooling coil. Therefore, the peak demand and total energy consumption of the system can be reduced. For new installations, using heat pipes can have the benefit of reducing the air-conditioning system. During winter, the process is reversed. The warm return or exhaust air stream from the conditioned space transfers heat to the cold supply air stream indirectly via the heat pipe heat exchangers. This process preheats the supply air before it enters the heating coil.

Heat pipes can also be designed specifically for dehumidification of the supply air. As shown in Figure 51, air passing through the evaporator coil is cooled to a low temperature, resulting in significant moisture removal. The "over-cooled" air is then reheated to a desirable temperature by the reheat heat pipe section, using the heat transferred from the precool heat pipe. This entire process of precooling and reheating is accomplished passively, without mechanical active parts or the input of additional energy. This offers the ability to remove considerably more moisture than regular systems.

The working fluid is critical to the operational performance of a heat pipe. Its key characteristics should include high latent heat of vaporization, high surface tension, low liquid viscosity, and thermal stability under operating conditions. For ventilation and air-conditioning applications, normally this fluid is commercial refrigerant. Copper or aluminum are typical materials for heat pipe tubes and fins. Supply and exhaust air ductwork need to be adjacent to install the heat pipes and allow heat transfer through them. Typically, the efficiency of heat pipes is in the range of 50% to 65%.

Figure 51: Wrap Around Dehumidifier Heat Pipes (HPT 2021)



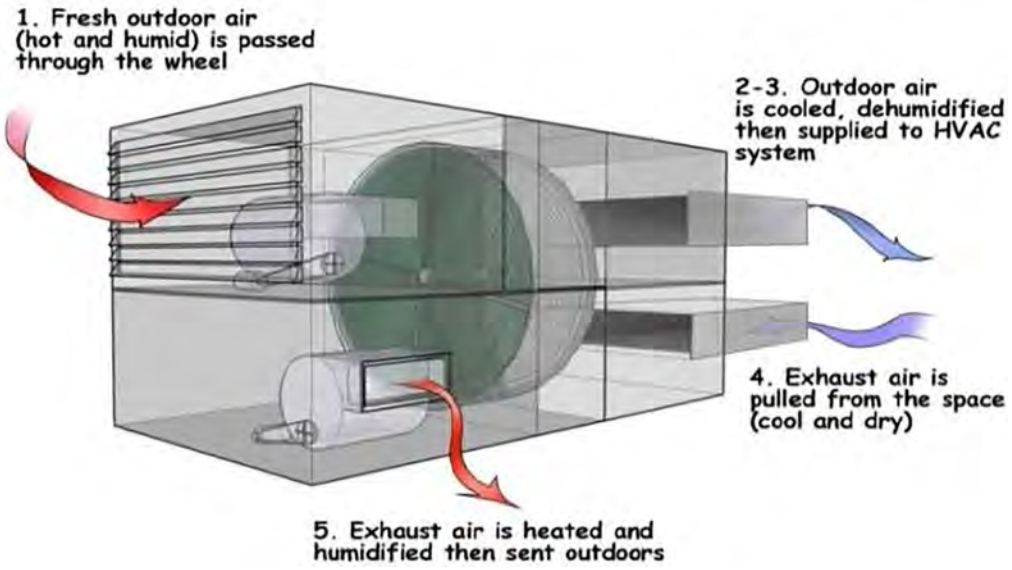
Source: Advance Heat Pipe Pte. Ltd.

Thermal Wheel

Compared to these heat recovery devices, a thermal wheel, also known as a rotary air-to-air heat exchanger, usually has a higher heat recovery efficiency, which can reach 60% to 85%, depending on the medium construction of the wheel.

A thermal wheel has a revolving cylinder filled with an air-permeable and heat-absorbing medium that has a large internal surface area. The wheel rotates slowly while adjacent supply and exhaust air streams from an air-handling unit flow through half of the wheel in a counterflow arrangement. Sensible heat is transferred from the hot air stream to the medium for temporary storage and subsequent release to the cold air stream (O'Connor, Calautit, and Hughes 2016). During summer, the hot supply air is precooled by this setup. During winter, the cold supply air is preheated. Figure 52 shows the schematic of a thermal wheel operating for precooling outdoor air during summer.

Figure 52: Schematic of the Operation of a Thermal Wheel



HVAC = heating, ventilation, and air-conditioning.

Source: Gawad, A.F.A. et al. 2015. Computational and Artificial Intelligence Study of the Parameters Affecting the Performance of Heat Recovery Wheels. *American Journal of Energy Engineering*. 3 (4). p. 79.

Depending on the heat transfer medium, a thermal wheel can also recover both sensible and latent heat, i.e., total heat. When a hygroscopic medium is used, latent heat is transferred as the medium adsorbs water vapor from the higher-humidity air stream and desorbs moisture into the lower-humidity air stream. This process is driven by the vapor pressure difference between the air stream and medium. Simultaneously, sensible heat transfer also occurs.

Air temperature, dew point, and contaminants are key factors that influence the choice of materials for the casing, rotor structure, and medium of a thermal wheel. Common choices include metal, mineral, or synthetic materials. Aluminum, steel, and polymers are the usual structural, casing, and rotor materials for normal ventilation and air-conditioning systems. The operation of a thermal wheel can be regulated by controlling the amount of air bypassing the wheel and varying the rotational speed of the wheel. There is the possibility of cross-contamination from the exhaust air to the supply air, which can normally be mitigated using a purge section.

It should be noted that thermal wheels are different from desiccant wheels, which are for the specific purpose of dehumidifying the supply air stream. Often, desiccant wheels and thermal wheels are used in series within a system for heat recovery and dehumidification. Section 4.3.4 of this handbook discusses applications of desiccant wheels.

Evaporative Cooling

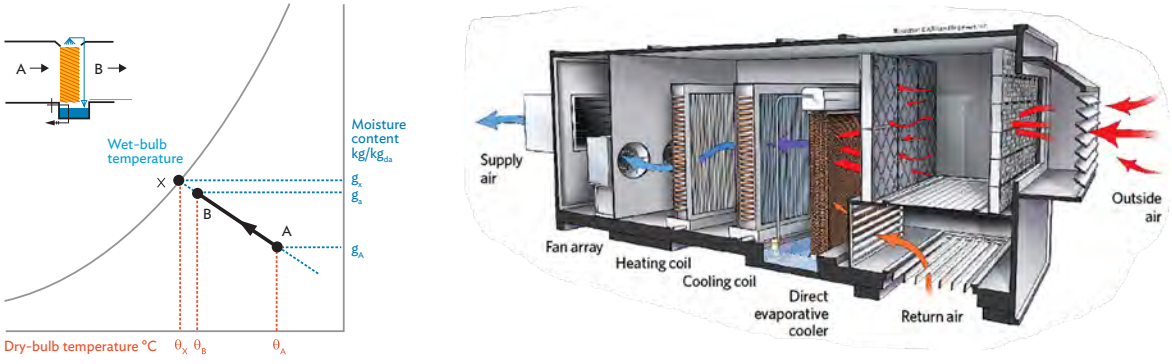
Climatic conditions may often provide a source of "renewable" energy to provide a cooling effect. In dry and high-temperature climates, air systems using evaporative cooling can be an energy-efficient, cost-effective, simple, and environmentally friendly solution as a good supplement to conventional mechanical vapor-compression cooling systems (Heidarinejad et al. 2009; ASHRAE 2017).

Evaporative cooling works under the basic principle that water evaporated in non-saturated air will produce a drop in dry-bulb temperature and an associated rise in moisture content. When the warm ambient inlet air comes into contact with water added to the inlet air, it transfers some of its heat to the liquid water and evaporates some of the water. The process of heat transfer from inlet air to water cools the inlet air. The increase in water vapor content means a higher relative humidity in the air. An additional benefit of this process is that the water can clean the inlet air stream of airborne particulates and soluble gases (ASHRAE 2016). Theoretically, the inlet air can be cooled up to 98% of the difference between its ambient dry-bulb and wet-bulb temperatures. Thus, the most cooling can be achieved in hot and/or dry weather. The primary disadvantage of evaporative cooling is the large quantity of water consumption, which is a major component of system operating costs. There are two types of evaporative cooling: direct evaporation and indirect evaporation. Both direct and indirect systems have significant potential to save energy by eliminating the need for mechanical cooling, or by reducing the operating hours of chillers.

For direct evaporative cooling, moisture is added directly to the supply air stream to allow the latent heat of evaporation to cool the air. The dry-bulb temperature of the air is lowered, whereas the wet-bulb temperature remains unchanged. The relative humidity of the air has increased. This process is shown in the psychrometric chart in Figure 53.

In real applications, instead of directly adding water to the air, a wetted element is used as the cooling medium. A typical method is to expose the supply air to a thin film of water on the extended surface of honeycomb-like wetted media made of cellulose paper, which is also referred to as an evaporative cooling panel or pad. Water is

Figure 53: (a) Psychrometric Process for Direct Evaporative Cooling; (b) Air-Handling Unit with Direct Evaporative Cooling



(a) (b)

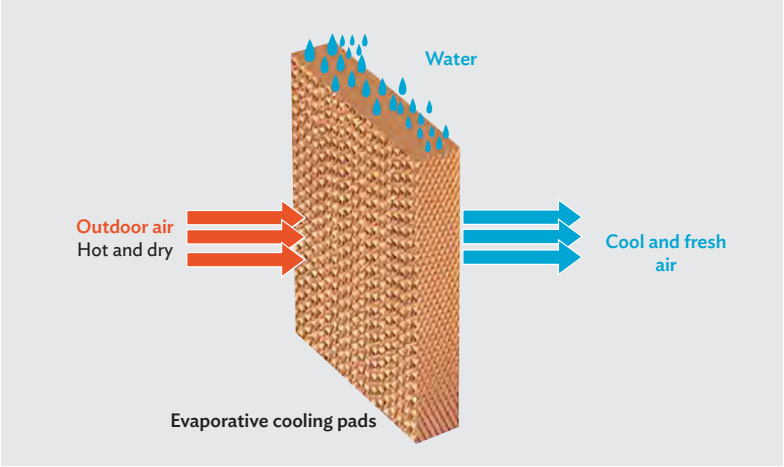
kg = kilogram.

Sources: Dwyer, T. 2018. Module 135: Direct Evaporative Cooling for Comfort Applications; Falconer, J. 2017. Making The Case For Evaporative Cooling.

supplied through a manifold at the top of the pad and allowed to trickle down as air flows through the pad. Water used for this purpose may or may not require treatment, depending on its quality and the pad's specifications. An alternative method is termed fogging, which is to add moisture to the supply air by spraying fine droplets of water (Figure 54). High-pressure fogging systems can be designed to produce droplets of variable sizes, depending on the desired evaporation time and ambient conditions. Typically, the water used by fogging systems is of higher quality than that used by wetted media systems.

With direct evaporative cooling, the humidity of the supply air and that of the conditioned space will increase. From the perspective of thermal comfort and indoor air quality, a high relative humidity may still be acceptable so long as the dry-bulb temperature is within a reasonable range. Usually, the relative humidity should not exceed 70%. In many applications, a high relative humidity may not be desired and therefore needs to be mitigated.

Figure 54: (a) Evaporative Cooling Pads; (b) Fogging System



(a)



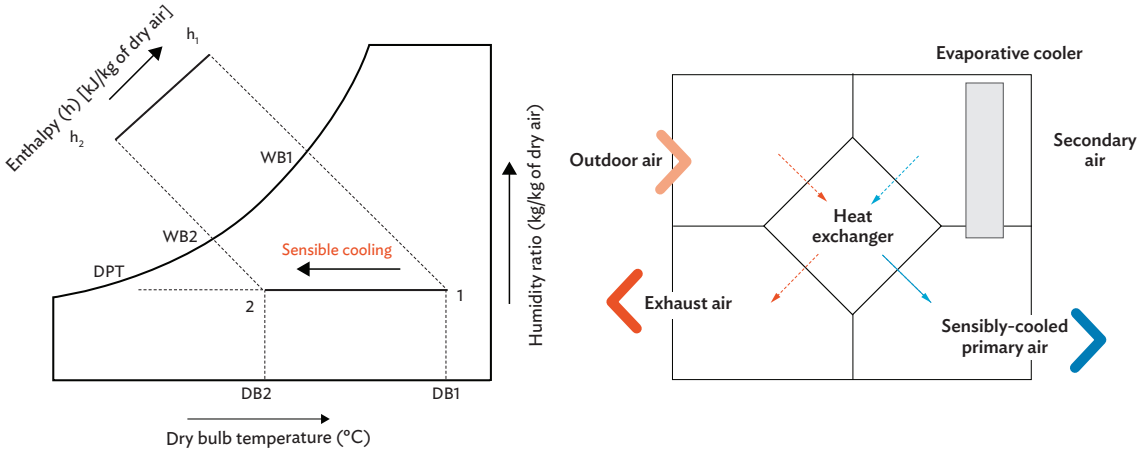
(b)

Sources: DRI. 2021. Indirect-Direct(2/3 Stage) Evaporative Coolers; CAREL. 2021. Evaporative Cooling.

One way is to mix the cooled and humidified supply air with outdoor air that has bypassed the evaporative cooler. Another method, which is more popular, is to use indirect evaporative cooling. A secondary air stream, which can be either return air from the conditioned space or outdoor air, is first evaporatively cooled and then used to precool, through a heat exchanger, the incoming outdoor air to reduce its dry-bulb temperature without directly affecting its moisture content. The wet-bulb temperature of the supply air is reduced. This offers the benefit of allowing the supply air (with a reduced wet-bulb temperature) to be further cooled, through direct evaporation, to a lower dry-bulb temperature than what is possible by only direct evaporative cooling of the ambient air, without first using indirect cooling (ASHRAE 2016). There are, however, disadvantages to indirect evaporative cooling. When humidity is high, indirect evaporative cooling cannot reduce the dry-bulb temperature as low as what is possible with conventional chillers. Compared with direct cooling, the additional capital cost of an indirect heat exchanger is required for indirect evaporative cooling. Also, indirect evaporative cooling has a higher total parasitic load than chillers and direct evaporative cooling, due to electricity consumption for pushing air through the direct evaporative cooling sections and the heat exchanger (ASHRAE 2016). Indirect evaporative cooling has an efficiency of 60%–70%, whereas direct evaporative cooling can reach an efficiency of 85% (Sarbu and Sebarchievici 2017b). Figure 55 shows the psychrometric path, a schematic of a simple heat exchanger, and an air-handling unit with indirect evaporative cooling.

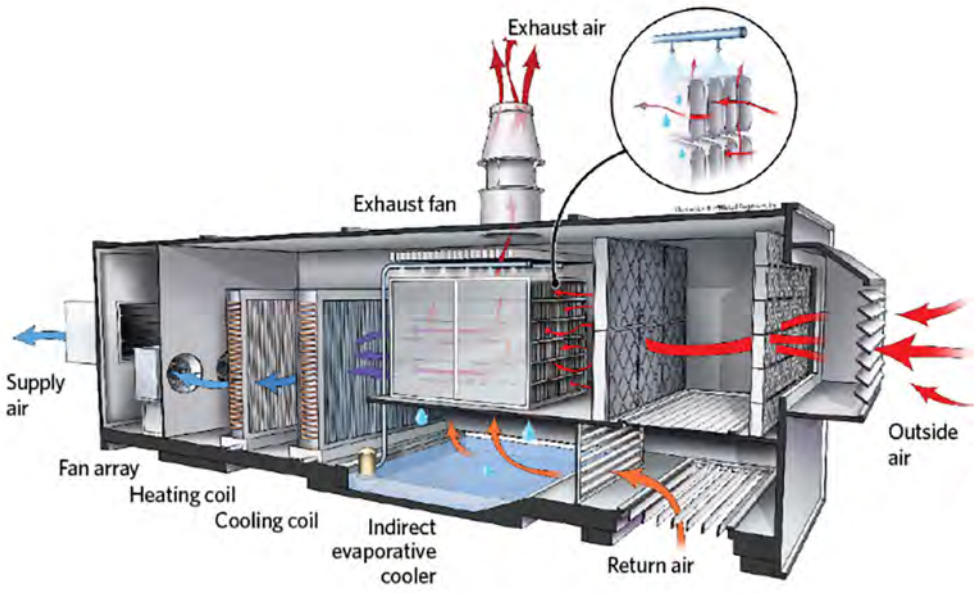
Evaporative cooling is often used in conjunction with a conventional mechanical cooling system. It can also be combined with desiccant dehumidification to create a hybrid system to cope with both sensible and latent cooling loads in the conditioned space.

Figure 55: (a) Psychrometric Process for Indirect Evaporative Cooling; (b) Schematic of Indirect Heat Exchanger; (c) Air-Handling Unit with Direct Evaporative Cooling



continued on next page

Figure 55 *continued*



(c)

DPT = dew point temperature, h = enthalpy, kg = kilogram, KJ = kilojoule, WB = wet bulb.

Source: Sarbu, I. and C. Sebarchievici. 2017. Solar Thermal-Driven Cooling Systems. In I. Sarbu and C. Sebarchievici, eds. Solar Heating and Cooling; Dwyer, T. 2017. Module 109: Evaporative Cooling for Building Environmental Systems; Falconer, J. 2017. Making The Case For Evaporative Cooling. Systems – Fundamentals, Experiments and Applications. Academic Press. pp. 241–313.

Sorption Cooling

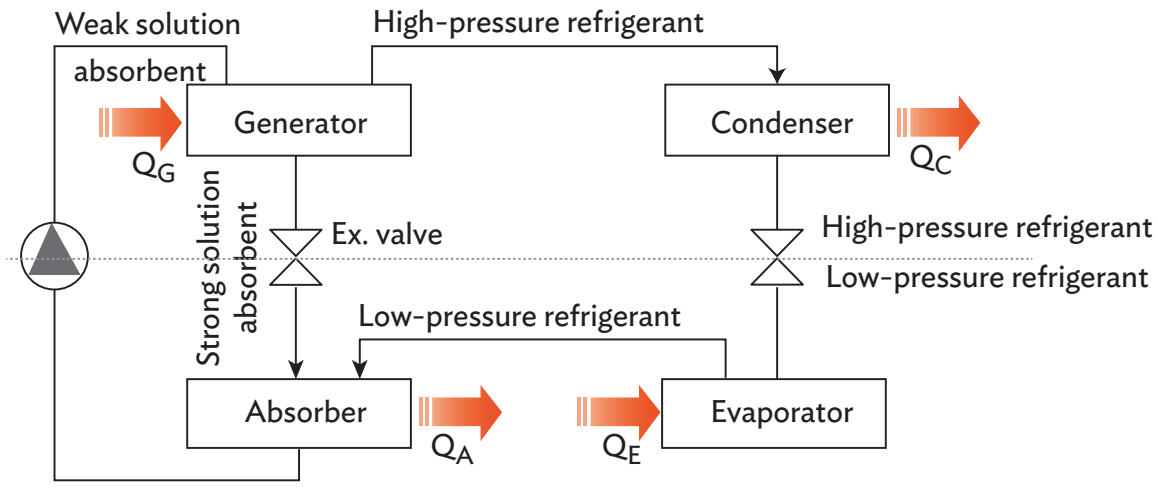
Sorption technologies are typically used in thermal-driven cooling systems. There are two types of sorption systems, i.e., open ones, and closed ones. Open sorption systems, also called desiccant cooling systems, are used for air dehumidification. Open systems are introduced in a separate section. This section focuses on closed sorption systems for refrigeration and cooling purposes, including absorption systems and adsorption systems. Closed systems use chemical or physical attraction between a pair of substances, called the sorption working pair, to produce the refrigeration effect. The working pair is isolated from the ambient, hence the term "closed." For the absorption cooling system, the common working pairs are water-lithium bromide (LiBr) and ammonia-water. For the adsorption cooling system, the common working pairs are water-zeolite, water-silica gel, ammonia-calcium chloride ($CaCl_2$), etc.

Absorption Cooling

As a thermal-driven cooling system, absorption cooling has the advantage of being able to utilize low-grade heat, such as solar thermal heat and industry waste heat. Like conventional vapor compression-based cooling systems, the cooling effect of absorption cooling systems also comes from the evaporation of a liquid refrigerant. The difference between the two systems is the way in which the refrigerant vapor is pressurized. In conventional vapor-compression cooling systems, the refrigerant vapor is pressurized by mechanical compression. In absorption cooling systems, the refrigerant vapor is pressurized by the solution circulating under two pressure conditions. This is realized through operating the absorption cooling system with a binary working fluid, i.e., a working pair that contains the refrigerant and the absorbent. The refrigerant has a lower boiling temperature than the absorbent. The equilibrium concentration of the working pair varies with temperature and pressure.

Figure 56 presents a schematic diagram of a typical absorption cooling system. The system consists of four components, including an absorber, where sorption takes place; a generator, where desorption takes place; a condenser; and an evaporator. The system operation involves two circulation loops, i.e., a solution loop and a refrigerant loop. In the solution loop, the solution flows through the generation (desorption), throttling (expansion valve), absorption, and pumping processes. In the refrigerant loop, the refrigerant flows through the generation (desorption), condensation, throttling (expansion valve), evaporation, and absorption processes. The two loops are not separate but connected by the absorption and generation (desorption) processes.

Figure 56: Schematic of a Basic Absorption Cooling Cycle



Source: Maidment, G.G. and A. Paurine. 2012. Solar Cooling and Refrigeration Systems. In A. Sayigh, ed. *Comprehensive Renewable Energy*. Elsevier. pp. 481–494. .

High-pressure liquid refrigerant leaving the condenser flows through an expansion valve for throttling, which reduces its pressure, and then flows into the evaporator. In the evaporator, the low-pressure refrigerant evaporates and removes heat from the cooling load (air or water). The resultant low-pressure refrigerant vapor is then sent to the absorber, where it is absorbed into a strong solution absorbent, and the sorption heat is released to the ambient. The evaporation and absorption processes have the same pressure. The weak solution with a high percentage of refrigerant leaving the absorber is recirculated to the generator, where it is boiled into a strong solution absorbent. At the same time, the refrigerant vapor is boiled off. This process is under high pressure and requires heat, which can be supplied via solar thermal energy or industrial waste heat. After this step, the strong solution is passed back to the absorber via an expansion valve, and the high-pressure refrigerant vapor is sent to the condenser for condensation. The generation and condensation processes have the same pressure. Essentially, the solution loop acts as a thermal-driven compressor to regenerate the high-pressure refrigerant vapor, which is analogous to the electric compressor used in a conventional system. Therefore, from an energy-saving perspective, the attractiveness of an absorption cooling system is the very low electricity consumption required for the solution loop and the ability to use low-grade heat sources for the desorption process in the generator, such as solar heat and waste heat. The condensation and evaporation processes work under the same principle as a conventional system.

The performance of absorption cooling is substantially dependent on the properties of its working pair. Typical working pairs for absorption cooling systems include water-LiBr and ammonia-water. In a water-LiBr solution, water is the refrigerant and the water-LiBr solution is the absorbent. In an ammonia-water solution, ammonia is the refrigerant, and the ammonia-water solution is the absorbent. Systems using water-LiBr solutions are often

used for air-conditioning, whereas systems using ammonia-water solutions are more suitable for refrigeration in industrial applications. The operation of water-LiBr-based absorption systems is subject to limits on the evaporating temperature and the absorber temperature due to the freezing of the water and the solidification of the LiBr-rich solution. While this is not an issue for ammonia-water systems, the toxicity of ammonia is a concern, and ammonia is often used for systems with large capacities. Table 8 compares the advantages and disadvantages of the two working pairs.

Table 8: Comparison Between Water-LiBr and Ammonia-Water as Working Pairs for Absorption Systems

Working pair	Advantages	Disadvantages
Water-LiBr	• High coefficient of performance • Low operation pressures • Environmentally friendly and innoxious	• Risk of congelation • Need for a device for anticrystallization • Relatively expensive (LiBr)
Ammonia-water	• Evaporative at temperatures below 0°C	• Toxic and harmful to health (ammonia) • Need for rectifier for refrigerant purification • Operation at high pressures

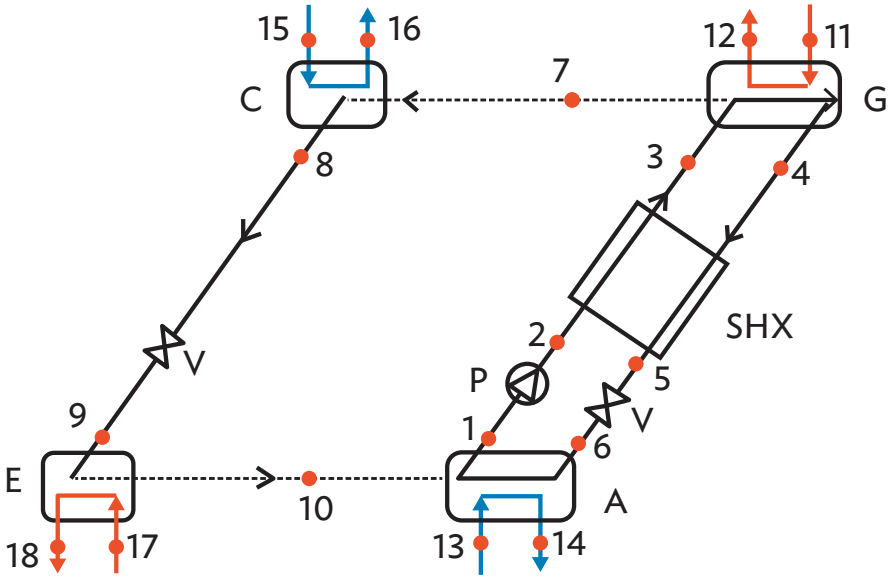
Source: Sarbu, I. and C. Sebarchievici. 2017b. Solar Thermal-Driven Cooling Systems. In I. Sarbu and C. Sebarchievici, eds. Solar Heating and Cooling Systems – Fundamentals, Experiments and Applications. Academic Press. pp. 241–313.

There are several variants of absorption chillers, including half-effect, single-effect, double-effect, and triple-effect systems, with a working pair of water-LiBr or ammonia-water. The main practical difference between these systems is the driving temperature required for regenerating the solution and their relative coefficients of performance (COPs) as well as capital cost and complexity. A common configuration is the single-effect water-LiBr system that requires heat at around 80°C and typically achieves a COP of around 0.7 for a chilled water application.

As the desorption process requires low-grade heat, solar thermal heat provides an ideal heat source to drive an absorption chiller and produce a cooling effect. Options for solar collectors include a flat plate, an evacuated tube, a parabolic trough collector, a parabolic concentrator, and so on. Different solar collectors produce heat at different temperatures, while different configurations of absorption chillers require different driving temperatures. For example, a flat-plate solar collector may work well for a single-effect system, but not for a double-effect system which requires a much higher driving temperature. Therefore, temperature is key to the proper combination of solar collector and absorption chiller. Sometimes, an auxiliary heat source is used to complement the solar collector to enhance the system's ability to operate continuously.

A single-effect absorption chiller has the simplest configuration and the highest commercial availability, as compared to other variants of absorption chillers. Due to these advantages, it is the most commonly used type in solar absorption cooling systems. Usually, the system COP is around 0.7–0.8. The system design depends on the working fluid types. In practice, the system shows better performance with a nonvolatile working pair, such as water-LiBr. If a volatile working pair is used, such as ammonia-water, an extra rectifier should be used before the condenser to provide pure refrigerant (Sarbu and Sebarchievici 2017b). A systematic diagram of a single-effect water-LiBr absorption cycle is shown in Figure 57. Solid lines represent liquid flow and dashed lines represent vapor flow. Here, a solution heat exchanger (SHX) is used to improve the cycle efficiency and chiller performance. The strong solution from the generator is cooled by the weak solution from the absorber. This configuration recovers the sensible heat of the strong solution and therefore reduces the heat input required for the generation process. A low-cost, nonconcentrating flat-plate or evacuated-tube solar collector is normally sufficient to obtain the required temperature for the generator. However, this comes with a lower COP. A higher COP can be obtained by multi-effect systems such as double-effect and triple-effect absorption chillers, which are run by steam produced from concentrating solar collectors.

Figure 57: Schematic of a Single-Effect Water-LiBr Absorption Cycle



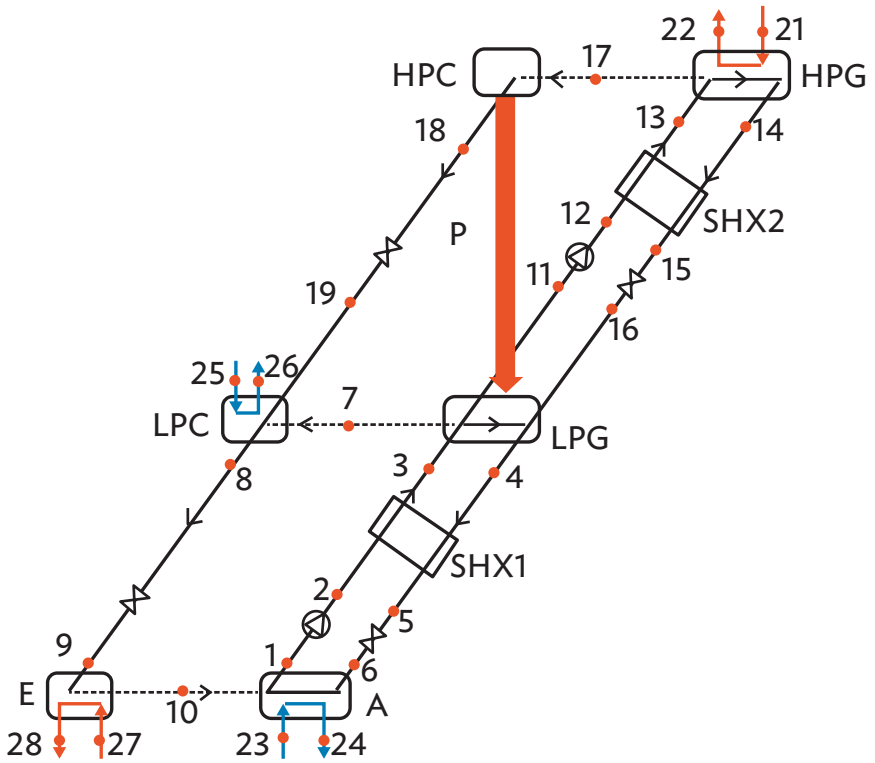
Source: Xu, Z.Y. and R.Z. Wang. 2016. Solar-Powered Absorption Cooling Systems. In R.Z. Wang and T.S. Ge, eds. *Advances in Solar Heating and Cooling*. Elsevier Science. pp. 251–298.

The half-effect absorption cycle, also called the double-life cycle or two-stage cycle, is another configuration that utilizes low-temperature solar collectors, providing a heat source lower than 100°C. This type of chiller has two solution loops and one refrigerant loop. The refrigerant and solution loops are the same as those of the single-effect absorption chiller, but the connections are different. A half-effect absorption chiller can operate at a driving temperature lower than a single-effect absorption chiller. This advantage, however, comes at the cost of a lower COP of around 0.3–0.4, which is about half that of the single-effect chiller.

The relatively low COP of half-effect and single-effect systems can be improved by double-effect systems, which use heat sources at higher temperatures. A double-effect water-LiBr absorption chiller can achieve a COP of 1.1 to 1.2 with a driving temperature of about 140°C (Ullah et al. 2013). Using gas as the heat source for the chiller is a mature technology. When using solar thermal energy as the heat source, medium-temperature solar collectors, such as concentrating parabolic collectors or parabolic trough collectors, can produce heat at a temperature between 100°C and 200°C, enough to drive a double-effect water-LiBr absorption chiller. Figure 58 illustrates a double-effect cycle using a water-LiBr working pair. Essentially, the cycle can be seen as a combination of two single-effect sub-cycles. The two sub-cycles are coupled by recovering the condensation heat of the high-pressure vapor, leaving the high-pressure condenser to heat the low-pressure generator to boiling.

Triple-effect absorption cooling takes two forms, i.e., a single-loop cycle or a dual-loop cycle. Single-loop triple-effect cycles are basically double-effect cycles with an additional generator and condenser. The system, with three generators and three condensers, operates on principles similar to those of double-effect systems. Primary heat concentrates the absorbent solution in a first-stage generator at a temperature of approximately 200°C to 230°C. A working pair other than water-LiBr is required for the high-temperature cycle. The refrigerant vapor produced is then used to concentrate additional absorbent solutions in a second-stage generator at approximately 150°C. Finally, the refrigerant vapor produced in the second-stage generator concentrates additional absorbent solution in a third-stage generator at approximately 93°C. Theoretically, these triple-effect cycles can obtain COPs of approximately 1.7.

Figure 58: Schematic of a Double-Effect Water-LiBr Absorption Cycle



Source: Xu, Z.Y. and R.Z. Wang. 2016. Solar-Powered Absorption Cooling Systems. In R.Z. Wang and T.S. Ge, eds. *Advances in Solar Heating and Cooling*. Elsevier Science. pp. 251–298.

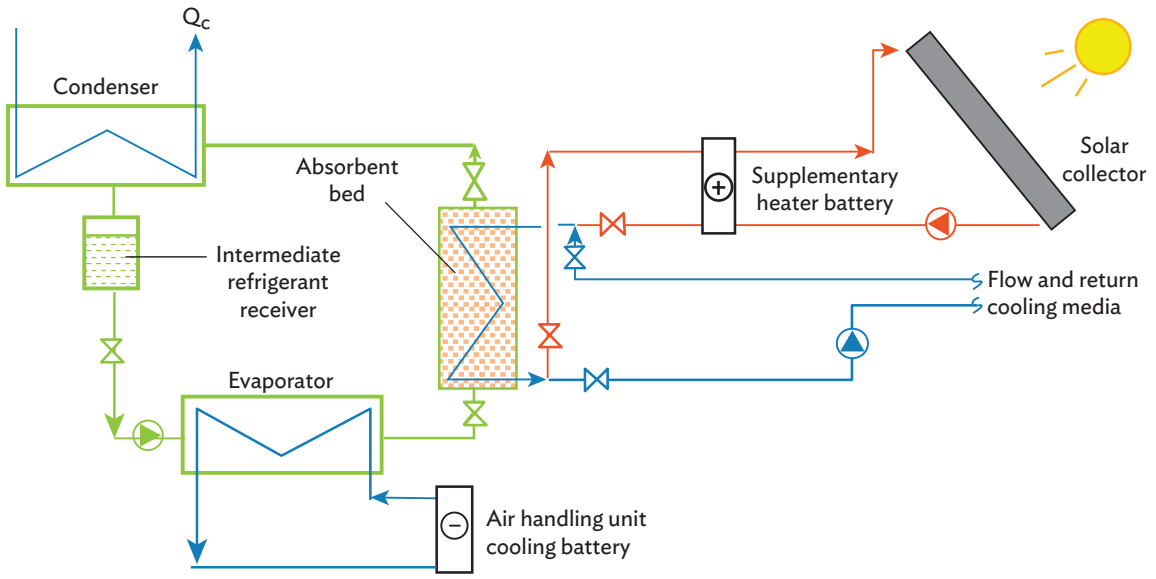
A double-loop triple-effect cycle consists of two cascaded single-effect cycles. One cycle operates at normal single-effect operating temperatures, and the other at higher temperatures. The smaller high-temperature topping cycle has a generator temperature of approximately 200°C to 230°C. A working pair other than water-LiBr is required for the high-temperature cycle. Heat rejected from the high-temperature cycle at 93°C is used as the energy input for the conventional single-effect bottoming cycle. The theoretical COP of this triple-effect cycle can reach approximately 1.8.

Multi-effect absorption cycles are costlier but more energy-efficient due to the use of additional generators and heat exchangers with decreased heat input. The requirements on high temperature and high pressure result in limited choices of working pairs and more stringent technical specifications of generators. The available solar intensity, cooling load, overall performance, and cost considerations collectively determine a particular configuration of the system.

Adsorption Cooling

Like absorption cooling and refrigeration, adsorption cooling and refrigeration is also a thermal-driven technology that can use low-grade heat, such as solar heat or industrial waste heat. Adsorption involves a solid sorbent that attracts refrigerant molecules onto its surface by physical or chemical force and does not change its form in the process. Physical adsorption occurs when the molecules of the refrigerant (adsorbate) fix themselves to the surface of a porous solid adsorbent. Through heating, the refrigerant molecules can be released, i.e., desorption. Chemical adsorption results from the ionic or covalent bonds formed between the refrigerant molecules and the solid adsorbent. The bonding forces are much greater than those of physical adsorption, thereby requiring more heat for desorption.

Figure 59: Schematic of a Basic Adsorption Cycle



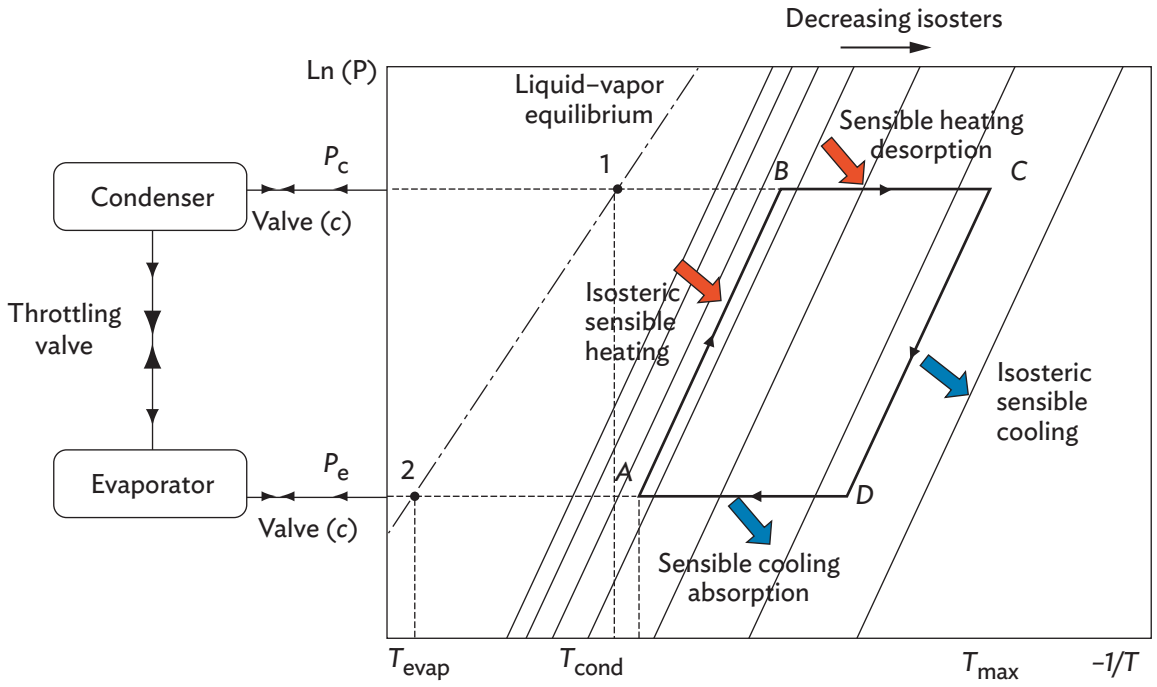
Source: Maidment, G.G. and A. Paurine. 2012. Solar Cooling and Refrigeration Systems. In A. Sayigh, ed. *Comprehensive Renewable Energy. Elsevier,* pp. 481–494.

A basic solar adsorption system is a closed system consisting mainly of an adsorber powered by a heat source such as solar collectors, a condenser, a refrigerant receiver, and an evaporator (Figure 59).

The adsorption cycle consists of four stage processes (two isobaric and two isosteric processes), as delineated in the Clapeyron diagram in Figure 60.

- **Process A to B (heating and pressurization).** The process starts at point A, when the adsorbent is at adsorption temperature and low evaporation pressure. The mass of the refrigerant is at its maximum level. The adsorber is closed, and the adsorbent is heated. This increases the temperature and pressure along the isosteric line A-B. The mass of the refrigerant remains constant at its maximum.
- **Process B to C (desorption and condensation).** From point B, the desorption process starts along the isobaric line B-C. Progressive heating of the adsorbent causes the refrigerant vapor to be released. The vapor is liquefied in the condenser, and condensation heat is released at the condensation temperature. The liquid refrigerant is then collected in the receiver. The heat consumed to regenerate the adsorbent is supplied by a low-grade heat source, such as solar heat or industrial waste heat.
- **Process C to D (cooling and depressurization).** The previous process ends when the adsorbent reaches its maximum regeneration temperature, and the refrigerant content drops to its minimum value. From point C, the adsorbent cools down, along the isosteric line C-D. Meanwhile, the refrigerant mass remains constant at is minimum value. In this process, the control valve is opened so that the refrigerant flows into the evaporator, and the system pressure decreases until the evaporating pressure is reached.
- **Process D to A (evaporation and adsorption).** The refrigerant evaporates in the evaporator and produces the cooling effect, i.e., heat of evaporation is drawn from the space, which is usually air or water in the case of air-conditioning. The control valve is opened so that the vaporized refrigerant flows from the evaporator to the adsorber, where it is adsorbed until its maximum content is reached. Along the isobaric line D-A, the adsorbent temperature continues to drop, and the heat of adsorption is released into the ambient. At the end of this process, the control value is closed, and the cycle starts over.

Figure 60: Clapeyron Diagram of a Basic Adsorption Cycle



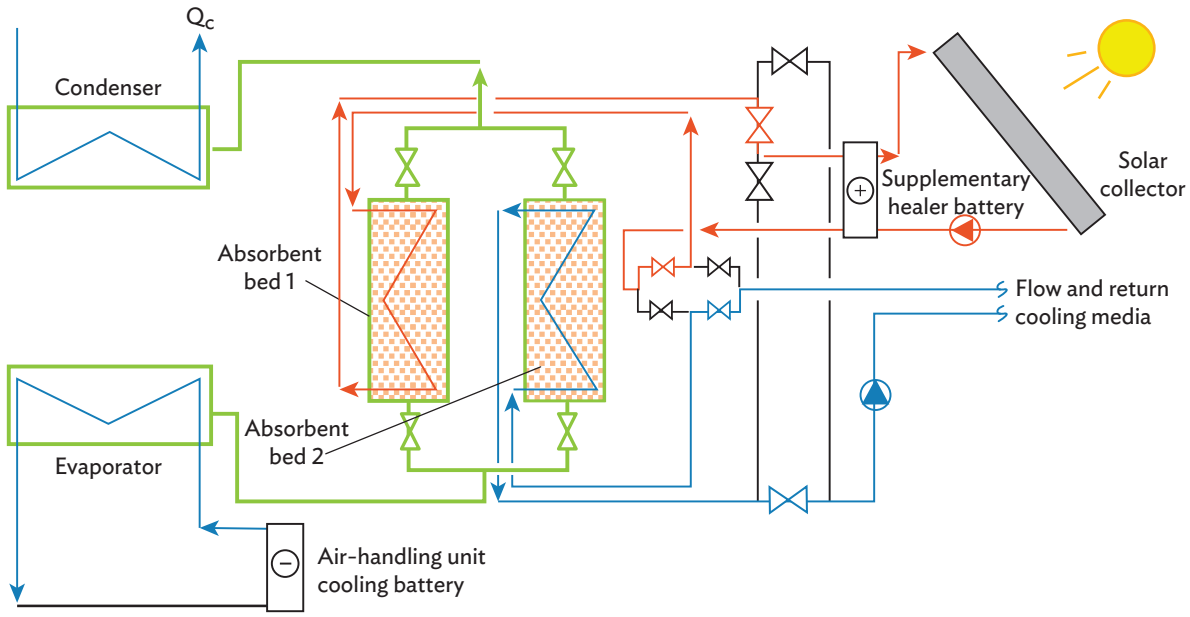
Ln = natural logarithm; P = pressure; T = temperature

Source: Hassan, H.Z., A. Mohamad, and R. Bennacer. 2011. Simulation of an Adsorption Solar Cooling System. *Energy*. 36 (1). pp. 530–537.

This basic cycle is intermittent, which means the cooling effect produced by the cycle is discontinuous. The adsorber's function changes between adsorption and desorption. This decreases the system's COP. To enable the system to operate continuously, two or more adsorbers need to be designed and operated. A common type of continuously working adsorption cooling system is the dual-absorber system, as shown in Figure 61. The heating and cooling processes of the two adsorbers are arranged complementarily. The heating and cooling water media interchange between the two adsorbent beds. While adsorbent bed 1 is heated, adsorbent bed 2 is cooled, and vice versa. This design ensures the desorption and adsorption processes work simultaneously, and the cooling effect can be delivered continuously.

The thermal properties of the adsorbent or refrigerant working pair play a critical role in determining the performance of an adsorption cooling system. The common working pairs include activated carbon-methanol, activated carbon-ammonia, activated carbon fiber-methanol, zeolite-water, silica gel-water, metal hydrides-hydrogen, calcium chloride-ammonia, etc. Among these working pairs, silica gel-water is the most used working pair for adsorption air-conditioning. The advantage of using water as the refrigerant is water's nontoxicity and large latent heat of vaporization. In general, hot water of 55°C to 90°C is good for driving silica gel-water adsorption chillers to produce chilled water of 5°C to 15°C. This low operating temperature range is suitable for commonly used solar collectors such as flat plates and evacuated tubes, which produce hot water below 100°C. For a middle-temperature solar heat source at a temperature between 100°C and 250°C, adsorption cooling with a zeolite-water working pair is still a good option for air-conditioning purposes.

Figure 61: Schematic of a Continuous Adsorption Cycle



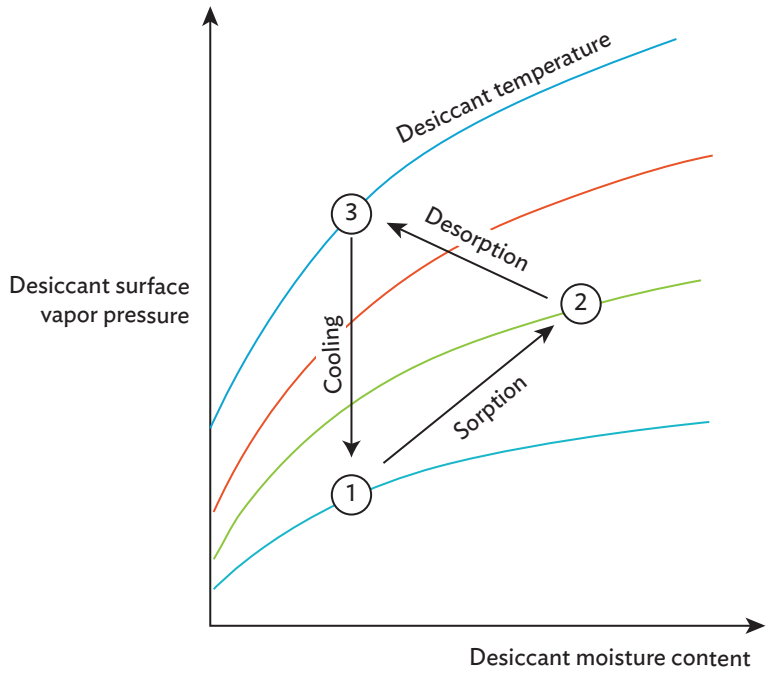
Source: Maidment, G.G. and A. Paurine. 2012. Solar Cooling and Refrigeration Systems. In A. Sayigh, ed. *Comprehensive Renewable Energy*. Elsevier. pp. 481–494.

Desiccant Cooling

Open sorption systems, also commonly known as desiccant cooling systems, are based on the principles of sorption dehumidification and evaporative cooling. In a desiccant cooling system, moisture is transferred from one air stream to another through a sorption process and a desorption process. The sorption process is for dehumidifying air through the difference in water vapor pressure between the humid air and the dry and cold desiccant material. Moisture in the air is absorbed into the desiccant material. In the desorption process, also known as the regeneration process, the desiccant is heated, and moisture previously captured by the desiccant is desorbed. This way, the desiccant is "regenerated" and reusable, and thus ready to absorb moisture again. By going through these processes in parallel, the desiccant system cyclically changes the desiccant's surface vapor pressure and thereby enables the moisture to be transferred continuously (Figure 62). In addition to removing the latent load of the processed air through this dehumidification process, a desiccant cooling system is also equipped with an evaporative cooler, which is used to handle the sensible load of the dehumidified air. With a lowered relative humidity and temperature, the processed air is supplied to the conditioned space for cooling purposes.

Compared with the dehumidification realized by conventional vapor-compression cooling, the sorption desiccant dehumidification system is more energy-efficient because there is no need to first cool the to-be-conditioned air down to its dew-point temperature for condensation of water vapor and then reheat the dehumidified air to the desired temperature (Wang, Xu, and Ge 2016; Chen et al. 2020). Mixed solvent desiccants have become research hot topics recently. Various types of dehumidifiers and their integration with liquid desiccant dehumidification systems have been reviewed. The combination of a liquid desiccant dehumidification system with a solar collector, a vapor compression system, a heat pump system, a combined heat and power system, etc. has been grouped and compared. It is shown that the majority of the recent research work for liquid desiccant dehumidification systems has concentrated on numerical simulations, but a considerable amount of works is still required for the practical investigations of innovative material (mixed solvents). While the desorption process for regenerating desiccant material requires heat, low-grade

Figure 62: Process of Moisture Transfer by Desiccant



Source: Sarbu, I. and C. Sebarchievici. 2017b. Solar Thermal-Driven Cooling Systems. In I. Sarbu and C. Sebarchievici, eds. Solar Heating and Cooling Systems – Fundamentals, Experiments and Applications. Academic Press. pp. 241–313.

heat at a temperature of about 60°C–95°C is usually sufficient for this purpose (Dincer and Rosen 2007). Therefore, renewable energy such as solar, geothermal, or even waste heat from conventional fossil fuel systems may be used to provide the heat. Owing to these advantages, desiccant cooling is viewed as a good alternative to conventional vapor-compression systems (Dincer and Rosen 2007; Ge and Xu 2016).

There are mainly two types of desiccant cooling systems, namely solid desiccant cooling and liquid desiccant cooling, as introduced in the following paragraphs. Various desiccants are available in liquid or solid phases. In general, all water-absorbing sorbents can be used as desiccant (Sarbu and Sebarchievici 2017b).

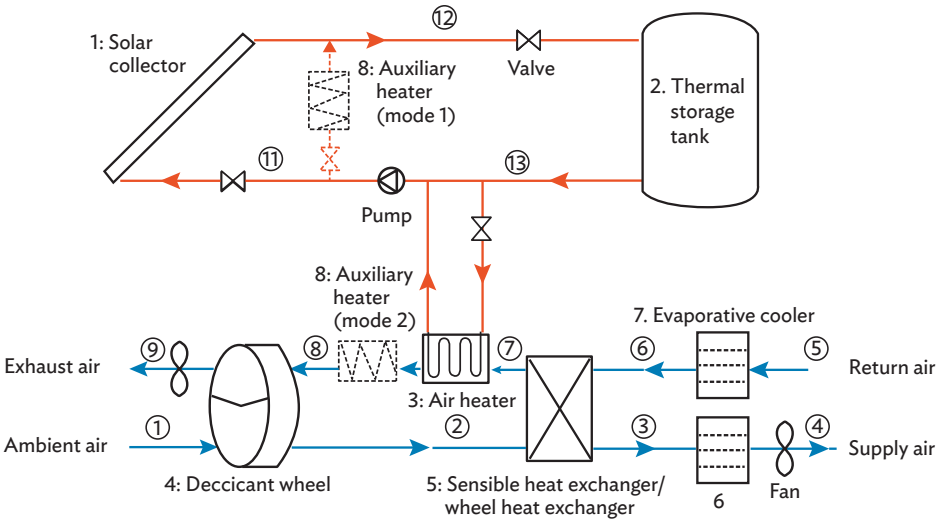
Solid Desiccant Cooling

Solid desiccant usually takes the form of a rotary desiccant wheel into which a desiccant material (such as silica gel) is filled. Figure 63 shows a typical example of a solar thermal-driven desiccant wheel evaporative cooling system. The system consists of a desiccant cooling subsystem and a solar subsystem. Within the desiccant cooling subsystem, there are a slowly revolving desiccant wheel, an air heater, a heat exchanger, evaporative coolers, and several other components. Through the two air streams (return air and supply air), flows from and to a conditioned space. The ambient air for conditioning first enters the desiccant wheel for dehumidification. The dehumidified and heated air leaving the wheel is then sensibly cooled down by a heat exchanger, which can be either a plate-type heat exchanger or a heat exchanger wheel. Depending upon its temperature, the conditioned air may either be directly supplied to the conditioned space or be further cooled through an evaporative cooler. In parallel, the return air from the conditioned space goes through the process in a reverse order. It first passes through an evaporative cooler and then enters the heat exchanger, where heat is transferred from the supply air to the return air. The resultant warm and humid stream of return air leaving the heat exchanger is then further heated by the air heater. Afterward, the hot return air enters the desiccant wheel to regenerate part of it before finally being exhausted to the ambient.

The hot water in the air heater for heating the return air is supplied by the solar subsystem, which is largely like a conventional solar hot water system. The solar collector absorbs solar radiation and heats up the water, which is then pumped to the air heater. Common types of solar collectors include flat plates, vacuum tubes, and concentrated collectors. A water tank is part of the subsystem for thermal storage and adjusting the water flux. Depending on the availability of solar radiation, dehumidification, and cooling demand, an auxiliary heater using gas or electricity may be installed for the solar subsystem or the return air side (before regeneration of the desiccant wheel) to provide supplementary heating capacity to ensure continuous operation of the system.

Thermal COP is the most commonly used parameter to evaluate the performance of a solid desiccant cooling system. It is defined as the ratio of the enthalpy change of conditioned air to the thermal energy for the regeneration of desiccant material. In principle, the thermal COP of a solid desiccant cooling system, as an open sorption system, is similar to that of closed sorption systems. Another important indicator to evaluate the performance is the solar fraction, which is defined as the ratio of energy provided by the solar collector for regeneration of the desiccant material to the total energy required for generation, including the auxiliary heater.

Figure 63: Schematic of a Solar Thermal-Driven Desiccant Wheel Evaporative Cooling System



Source: Ge, T.S. and J.C. Xu. 2016. Review of Solar-Powered Desiccant Cooling Systems. In R.Z. Wang and T.S. Ge, eds. *Advances in Solar Heating and Cooling. Elsevier Science.* pp. 329–379.

Box 11: Case Studies of Solar Thermal-Driven Solid Desiccant Cooling Systems

Henning et al. (2001) investigated the performance of a solar-assisted solid desiccant cooling system installed at Riesa, Germany. The system featured a flat-plate collector of 20 square meters (m^2), a hot water buffer storage of 2 cubic meters (m^3), and a nominal air volume flow of 2,700 m^3/hour. On-site measurement results indicated that the system achieved a solar fraction of 76%, an overall collector efficiency of 54%, and a cooling coefficient of performance (COP) of 0.6 under typical summer conditions. Based on further system simulation under climatic conditions in Denmark, Germany, and Italy, they found that combining the solar-assisted solid desiccant cooling system with a backup conventional vapor-compression chiller would be feasible from not only an energy perspective but also an economic perspective, especially in warm and humid climates. Such a feasibility could be maintained even under the requirement that indoor standard comfort criteria had to be met for every hour of the year. The system was found to be able to achieve 50% savings of primary energy at low incremental overall costs.

The performance of solar-assisted desiccant cooling systems using two different desiccant materials: silica gel (SiO_2) and titanium dioxide (TiO_2), with various specifications under East Asian climatic conditions was numerically studied by Enteria et al. (2016). The system was applied in temperate climate (Beijing and Tokyo), subtropical climate (Taipei,China and Hong Kong, China) and tropical climate (Manila and Singapore). In general, it was found that the system could provide the required indoor temperature and humidity ratio in these cities. TiO_2 tended to perform better than SiO_2 in supporting lower indoor temperature and humidity ratio. For hot and humid climate such as in Manila or Singapore, larger size of the solar thermal system and higher volumetric flow of air to support the high cooling load would be required.

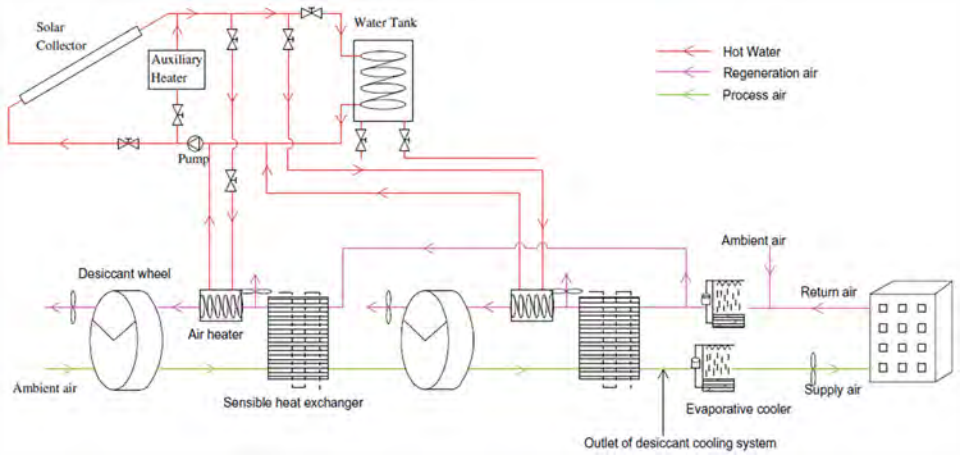
In a similar study by Ali et al. (2018)environment-friendly, and reliable water conditioning systems has led to the introduction of several standalone and/or hybrid alternatives. The technology of desiccant evaporative cooling (DEC, five configurations of solar-assisted desiccant cooling systems under five different climatic conditions, covering Karachi in Pakistan, Sao Paulo in Brazil, Shanghai in the People's Republic of China, Adelaide in Australia, and Vienna in Austria, were evaluated and compared. It was observed that the systems were more suitable to be applied in Karachi and Shanghai due to their semiarid and humid climatic conditions. The minimum overall average COP of basic operation cycles (ventilated, recirculated, and dunkle[a]) was greater than one for both climatic zones. In addition, the average cooling capacity for these regions was twice as much as for cities in continental climate conditions, e.g., Vienna.

To improve the performance of solar thermal-driven rotary desiccant wheel cooling system, Ge et al. (2010) proposed a two-stage rotary wheel system and compared its performance with a conventional vapor-compression system (Box Figure 11.1). Both systems were designed to meet the cooling demand of one floor in a commercial office building in two locations under different climatic conditions, namely Berlin and Shanghai. The required regeneration temperatures were 55°C in Berlin and 85°C in Shanghai. The system in Shanghai achieved a higher thermal COP than that in Berlin due to higher-humidity ratio in Shanghai. Compared with the conventional vapor-compression system, the desiccant cooling system had the merits of a higher fresh air ratio and less electricity consumption. While the initial cost of the desiccant cooling system was higher than that of the vapor-compression system, the operating cost was significantly reduced due to the utilization of low-grade solar energy. The dynamic investment payback periods were estimated to be only 4.7 years in Berlin and 7.2 years in Shanghai.

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Box 11 *continued*

Box Figure 11.1: Schematic of a Solar Thermal-Driven Two-Stage Rotary Desiccant Cooling System

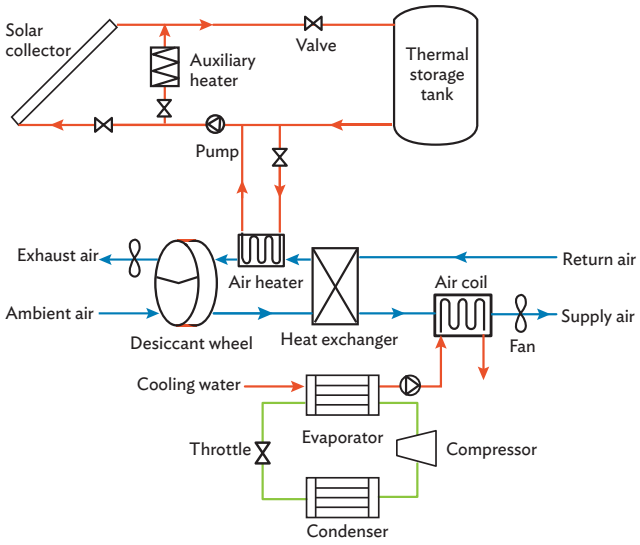


[a] Dunkle is one of the operating cycles of the solid desiccant cooling system with an additional heat exchanger. It is named after Dunkle who proposed such an operating cycle.

Source: Ge, T.S. et al. 2010. Performance Comparison Between a Solar Driven Rotary Desiccant Cooling System and Conventional Vapor Compression System (Performance Study of Desiccant Cooling). *Applied Thermal Engineering*. 30 (6–7). pp. 724–731.

A variant of the solar thermal-driven desiccant wheel evaporative cooling system is a hybrid solar thermal-driven desiccant cooling and vapor-compression system (Figure 64). The hybrid system brings together the good capacity of the desiccant wheel system in handling latent load and that of the conventional vapor-compression system in handling sensible load. Compared with a conventional vapor compression, a hybrid system usually consumes less energy to provide the same cooling capacity.

Figure 64: Schematic of a Hybrid Solar Thermal-Driven Desiccant Cooling and Vapor-Compression System

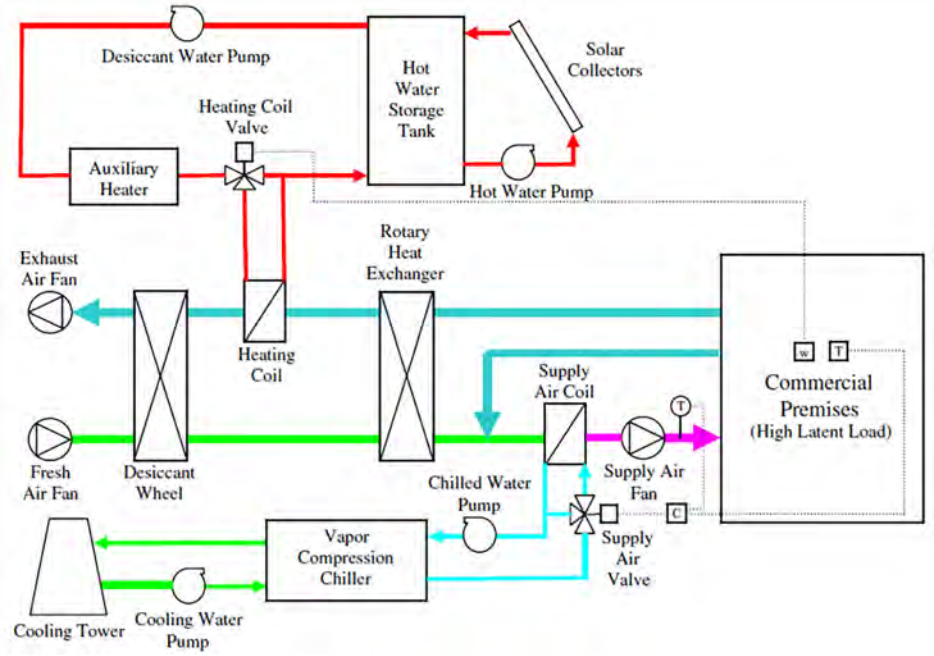


Source: Ge, T.S. and J.C. Xu. 2016. Review of Solar-Powered Desiccant Cooling Systems. In R.Z. Wang and T.S. Ge, eds. *Advances in Solar Heating and Cooling. Elsevier Science*. pp. 329–379.

Box 12: Case Studies of Hybrid Solar Thermal-Driven Desiccant Cooling and Vapor-Compression Systems

A study in subtropical Hong Kong, China, found that solar-assisted hybrid desiccant cooling systems had the potential to be more effective in handling commercial premises with high latent cooling loadsin hot and humid climatic conditions compared to conventional air-conditioning systems (Fong et al. 2011). Their hybrid system used an electricity-driven vapor-compression chiller to provide chilled water to a supply air cooling coil to handle the sensible cooling load (Box Figure 12.1). No evaporative coolers were included. The conditioned spaces included a Chinese restaurant and a wet market, which are typical commercial premises in Hong Kong, China, and Guangdong province in the south of the People's Republic of China. The designed zone sensible and latent loads were 19 kilowatts (kW) and 13 kW for the restaurant and 27 kW and 13 kW for the wet market, respectively. Results showed that the hybrid system was able to maintain indoor temperature and humidity ratios much more steadily compared with a conventional system under different loading and climatic conditions throughout a year. At a designed zone relative humidity of 60%, the hybrid system could achieve an annual primary energy savings of 49% for the restaurant and 13% for the wet market. If the humidity control requirement was loosened to 70% for the restaurant, the hybrid system still outperformed the conventional system with an annual primary energy saving as much as 22.7%.

Box Figure 12.1: Schematic of a Hybrid System for Commercial Premises with High Latent Cooling Load



Source: Fong, K.F. et al. 2011. Investigation on Solar Hybrid Desiccant Cooling System for Commercial Premises with High Latent Cooling Load in Subtropical Hong Kong. *Applied Thermal Engineering*. 31 (16). pp. 3393–3401.

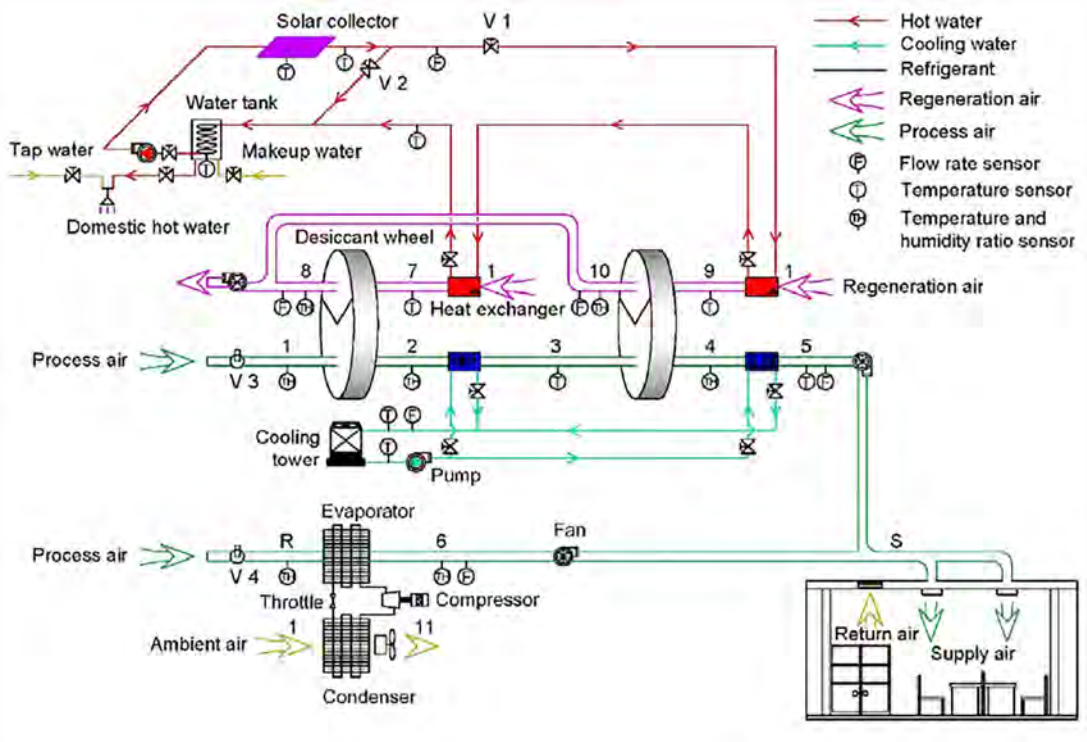
Khalid et al. (2009) developed and evaluated a hybrid solar-assisted desiccant cooling and vapor-compression system in Karachi, Pakistan. The system was characterized by using two indirect evaporative coolers instead of a direct evaporative cooler on the processed air side. One was installed before the desiccant wheel to precool the ambient air, and the other was used between the sensible heat exchanger and the cooling coil of the vapor-compression subsystem. Measurements found that due to the climatic conditions of Karachi, the solar-assisted desiccant cooling system alone was not able to handle the high latent and sensible loads and treat the air to the desired comfort conditions. Therefore, the auxiliary vapor-compression cooling unit had an important role to play. It was also demonstrated from measurements that by using indirect evaporative coolers, the regeneration temperature was brought down by 15% while the decrease in the dehumidification was only 6%, thereby saving thermal energy.

continued on next page

Box 12 *continued*

A solar hybrid desiccant air-conditioning system was configured, experimentally investigated, and theoretically analyzed (La et al. 2011). The system, installed at an office building in Jiangsu Province, People's Republic of China, was mainly composed of a solar collection subsystem with a 72-square meter (m^2) flat-plate solar collector array and a 4 m^2 hot water tank, a two-stage desiccant cooling subsystem with a design cooling capacity of 10 kW, an air-source vapor-compression air-conditioning subsystem with a nominal cooling capacity of 20 kW, and a cooling tower that supplied cooling water to the desiccant cooling subsystem (Box Figure 12.2).

Box Figure 12.2: Schematic of a Hybrid Two-Stage Desiccant Cooling and Vapor-Compression System



Source: La, D. et al. 2011. Case Study and Theoretical Analysis of a Solar Driven Two-Stage Rotary Desiccant Cooling System Assisted by Vapor Compression Air-Conditioning. *Solar Energy*. 85 (11). pp. 2997–3009.

On-site operation measurements showed that under the local climatic conditions of an average ambient air temperature of 34.6°C, a humidity ratio of 21.54 grams (g)/kilogram (kg), and a solar radiant intensity fluctuating between 122.2 watts per square meter ((W)/m^2) and 539.9 W/m^2, the average efficiency of the solar collector was 0.32 and the two-stage desiccant cooling subsystem achieved an average cooling capacity of 10.9 kW, with the thermal and electric coefficient of performance (COPs) reaching 1.24 and 11.48, respectively. For the whole hybrid system, its electric COP was 4.41, about 34% higher than the conventional vapor-compression subsystem. The system's performance was further analyzed through simulation under different climatic conditions in Beijing (temperate), Shanghai (humid), and Hong Kong, China (extremely humid). The results demonstrated the feasibility of the hybrid system for a wide range of operating conditions. Compared with conventional systems, the hybrid system could achieve a seasonal electricity saving rate of 22% to 34%.

Source: La, D. et al. 2011. Case Study and Theoretical Analysis of a Solar Driven Two-Stage Rotary Desiccant Cooling System Assisted by Vapor Compression Air-Conditioning. *Solar Energy*. 85 (11). pp. 2997–3009.

Liquid Desiccant Cooling

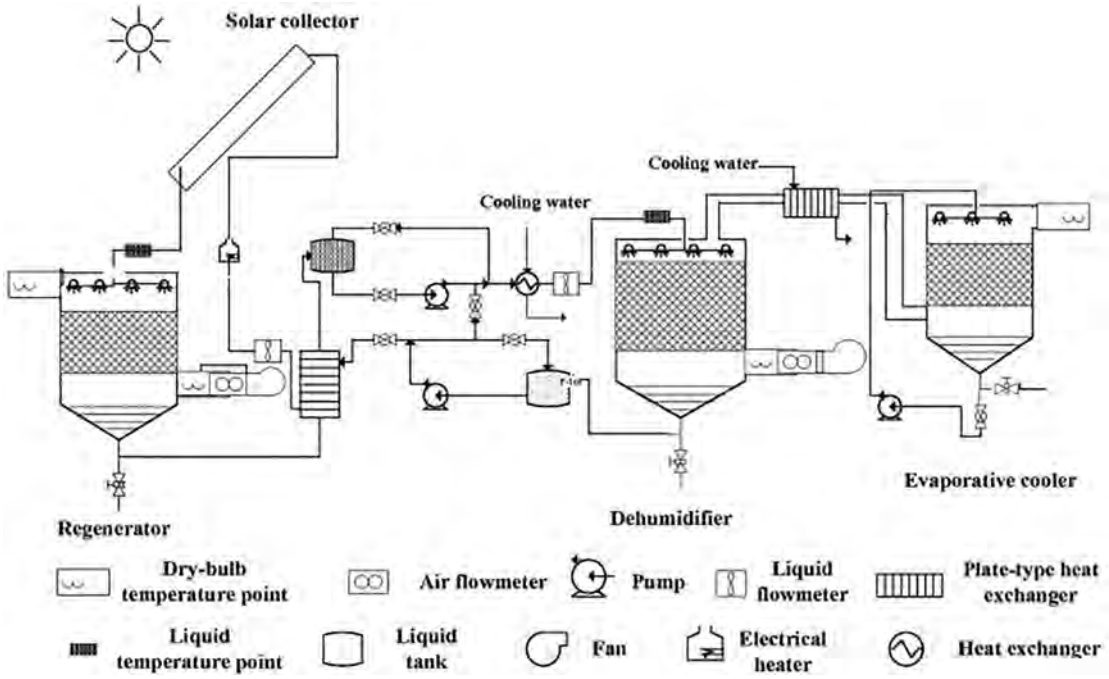
Liquid desiccant systems usually consist of an absorber for dehumidifying incoming air, a regenerator for regenerating the solution of liquid desiccant, an evaporative cooler for sensibly cooling air, and a series of heat exchangers. Key to the systems are dehumidification and regeneration. Depending upon specific climatic conditions and application, a liquid desiccant system can either be used as a stand-alone system or in conjunction with a vapor-compression system or a vapor absorption system, i.e., as a hybrid system. In practice, hybrid systems are used more commonly than stand-alone systems (Ge and Xu 2016).

Commonly used liquid desiccant materials include lithium chloride (LiCl), calcium chloride (CaCl2), and lithium bromide (LiBr) (Sarbu and Sebarchievici 2017b). Compared to solid desiccants, liquid desiccants have a generally greater ability to hold moisture (Chen et al. 2020). Due to the low pressure drop across various system components, the regeneration temperatures of liquid desiccants are mostly between 40°C and 70°C, much lower than those of solid desiccants (between 60°C and 115°C), thereby requiring a lower temperature for regeneration (Elsarrag 2008; La et al. 2010). Thus, as in the case of solid desiccant, low-grade energy such as solar energy is well-placed to meet part of the energy demand of a liquid desiccant system. Also, with the ability to pump liquid desiccant, a liquid desiccant cooling system can be made small and compact (Sahlot and Riffat 2016). Given the relatively lower cost of liquid desiccant materials, liquid desiccant systems generally have a shorter payback period (Chen et al. 2020). However, liquid desiccants do have some disadvantages, including potential corrosion and damage to the system, requiring larger pumps to handle large volumes of liquid, and the problem of crystallization (Sahlot and Riffat 2016).

It is worth noting that the liquid desiccant in a liquid desiccant cooling system circulates between an absorber and a regenerator in a way largely similar to that in an absorption system. The major difference is that the equilibrium temperature of a liquid desiccant is determined by the partial pressure of water in the humid air in contact with the desiccant solution, rather than the total pressure (Kim and Infante Ferreira 2008; Sarbu and Sebarchievici 2017b).

Figure 65 shows a schematic of a basic solar-assisted liquid desiccant dehumidification and cooling system and the principles under which the system operates. The system is characterized by two circulations—an air circulation and a liquid desiccant circulation.

Figure 65: Schematic of a Solar-Assisted Liquid Desiccant Dehumidification and Cooling System



Source: Peng, D., X. Zhang, and Y. Yin. 2008. Theoretical Storage Capacity for Solar Air Pretreatment Liquid Collector/ Regenerator. *Applied Thermal Engineering*. 28 (11–12). pp. 1259–1266.

In the air circulation, the humid and hot air, which may be ambient air or a mix of ambient air and return air from the conditioned space, is dehumidified in the liquid dehumidifier where the air is brought into contact with a sprinkled concentrated solution of the liquid desiccant. Water vapor is absorbed by the solution. The dehumidified air is then cooled through heat exchange with cooling water and further cooled by an evaporative cooler to the desired condition for supply. In the conditioned space, the humidity and temperature of the supply air increase as a result of removing latent and sensible cooling loads. Part of the return air leaving the conditioned space and some ambient air, as make-up air is supplied as the regenerative air to the regenerator where it gets humidified and heated before being exhausted to the ambient. The other part of the return air is mixed with fresh ambient air and then supplied to the dehumidifier to repeat the dehumidification process. This completes the air circulation.

For the liquid circulation, mass transfer takes place in the dehumidifier. Water vapor in the air is transferred into the strong solution of liquid desiccant because the partial pressure of water vapor in the liquid film is much lower than that of the processed air. The resultant diluted weak solution of liquid desiccant is then pumped to a liquid-liquid heat exchanger, in which it receives heat from the hot concentrated solution of desiccant from the regenerator. Subsequently, it passes through an electrical heater. The diluted solution of desiccant with a raised temperature then flows into the solar collector for further heating to the temperature of the regeneration point. After entering the regenerator, the hot, diluted solution is exposed to the regenerative air. Driven by the difference in vapor pressure, moisture is transferred from the solution to the regenerative air—a reverse of the process in the dehumidifier. This increases the concentration of the solution to an acceptable level near the initial concentration. The regenerated liquid desiccant then passes through the liquid-liquid heat exchanger and transfers heat to the to-be-regenerated diluted solution. Before entering the dehumidifier, the precooled regenerated liquid proceeds to get cooled more deeply by a cooling coil to gain the desired dehumidification capability. This circulation maintains the continual operation of the system.

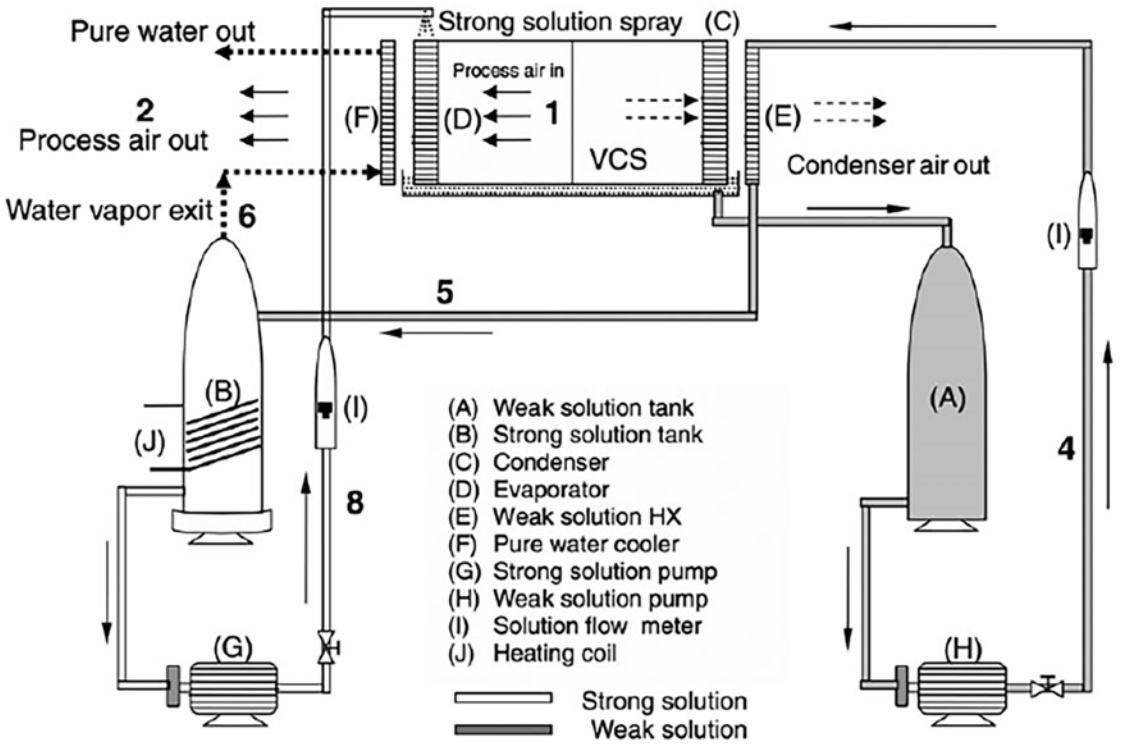
The flow pattern and various configurations of the dehumidifier have a strong impact on the performance of the dehumidification process. In the humidifier, the incoming humid air gets in contact with the liquid desiccant and has its moisture absorbed. The patterns in which the air-desiccant contact occurs can be broadly categorized into parallel flow, counter flow, cross flow, and counter-cross flow. Depending on whether an internal cooling source is provided, a dehumidifier can either be an adiabatic one or an internally cooled one. The former is a simple unit in which mass is transferred from incoming air to the liquid desiccant, while heat transfer also takes place due to temperature differences and the latent heat of condensation of water vapor. Heat discharge reduces the efficiency of dehumidification. This can be avoided by an internally cooled dehumidifier, which uses an embedded cooling coil to provide an extra cooling source to cool the desiccant solution and effectively remove the heat produced during the dehumidification process. This way, the vapor pressure of the desiccant solution is maintained at a lower level favorable for the dehumidification process, thereby improving system efficiency. The internally cooled dehumidifier can further be categorized into three types, including parallel plate, fin coil, and packed tower with tubes. A comprehensive review of the technical characteristics can be found in (Sahlot and Riffat 2016; Chen et al. 2020).

Also, in single-stage dehumidification, an adverse temperature increase in the desiccant solution will lower the driving force for mass transfer between desiccant solution and processed air. This can be addressed by using a multistage dehumidification with an array of single dehumidifier modules. The liquid desiccant flows through the modules and is cooled separately in each single module. This configuration keeps the vapor pressure difference between the desiccant solution and the processed air at a moderate level with drastic change, and therefore ensures the dehumidification performance (Mei and Dai 2008; Ge and Xu 2016).

As already shown in Figure 66, a liquid desiccant dehumidification system can be combined with an evaporative cooling system to achieve a cooling effect. A liquid the desiccant dehumidification system can also be combined with a vapor-compression system to provide a subcooling effect from the condenser outlet to the compressor inlet and therefore improve the cooling capacity and COP of the vapor-compression system (Chen et al. 2020). Li, Lu, and Yang (2010) modeled the performance of a solar-assisted hybrid system in the hot, wet weather in Hong Kong, China. With the use of a solar-assisted desiccant dehumidification unit, the capacity of the vapor-compression unit could be reduced from 28 kW to 19 kW. The energy-saving potential was significant due to a higher COP resulting from a higher supply of chilled water from the chiller. The annual operation energy savings for the hybrid system reached 6.8 megawatt-hours (MWh). With an extra initial cost of HK$6,360, the payback period of the hybrid system was around 7 years. These results demonstrated the technical and economic viability of hybrid systems in subtropical areas. Khalil (2012) investigated the potential of a hybrid system, which had a total cooling capacity of 6.2 kW. The liquid desiccant was lithium chloride. As shown in Figure 66, a strong solution from the tank was pumped and sprayed uniformly over the evaporator surface area. Process air to be dehumidified passed through the evaporator in the crossflow direction. The evaporator and desiccant enabled simultaneously cooling and dehumidifying the process air while the diluted desiccant solution was collected in the weak solution tank. After that, the diluted solution was pumped to absorb heat from the heat exchanger, which used the waste heat rejected from the condenser of the vapor-compression unit to preheat the diluted solution. A heating coil in the regenerator tank provided the additional heat required by the solution for regeneration. The results showed that, compared with a conventional vapor-compression system with a reheat configuration, the investigated system increased the COP by 68% and attained an annual energy savings of 53%.

There are also merits to combining a liquid desiccant dehumidification system with a heat pump system. Heat released from the condenser of the heat pump can be utilized to regenerate solution in the liquid desiccant cycle (Niu, Xiao, and Ma 2012). Separate control of indoor temperature and humidity can be achieved by a hybrid liquid desiccant and heat pump system, with a system COP higher than conventional systems, as found in applications in the PRC (Zhao et al. 2011; Chen, Yin, and Zhang 2014).

Figure 66: Schematic of a Hybrid Solar-Assisted Liquid Desiccant Dehumidification and Vapor-Compression System



HX = heat exchanger; VCS = vapor compression system.

Source: Khalil. A. 2012. An Experimental Study on Multi-Purpose Desiccant Integrated Vapor-Compression Air- Conditioning System. *International Journal of Energy Research*. Vol. 36(4). pp. 535–544.

Thermal Storage—Phase-Change Materials

By storing and utilizing energy, thermal storage techniques can smooth out the peaks and troughs in cooling demand, thus improving the loading and efficiency of chillers, and reducing energy consumption. The use of phase-change materials (PCMs) is an established method of storing energy because of the large latent storage capacity of PCMs during an almost isothermal process. This means PCMs can provide a large storage density at small temperature intervals.

Materials suitable for thermal storage purposes should have large latent heat and a high thermal conductivity. Their melting temperature should be adaptable to a practical range of operations. They should be chemically stable, flammable, low- or noncorrosive, and nontoxic. Their costs should be low. Some of the widely used PCMs include paraffin, salt hydrates, eutectics, and fatty acids. The main advantages and disadvantages of PCMs are summarized in Table 9. When selecting a PCM, it is important to focus on the following properties: the melting point that assures the storage and extraction of heat; the heat of fusion required to obtain a high storage density; the thermal conductivity required to perform a suitable charging and discharging process; the material density; the need for congruent melting; minimal volume change following phase change; and a high specific heat to ensure a significant sensible storage capacity, among others.

Table 9: Main Advantages and Disadvantages of Organic and Inorganic Phase-Change Materials

	Advantages	Disadvantages
Organic PCM	• Large temperature range • Low super-cooling • Noncorrosive • High congruency in melting • Highly compatible with building materials • Chemically stable • High fusion heat • Recyclable	• Low thermal conductivity • Low volumetric latent heat storage capacity • Flammability
Inorganic PCM	• High volumetric latent heat storage capacity • Low cost and easy availability • High thermal conductivity • Nonflammability	• High volume change • Super-cooling

PCM = phase-change material.

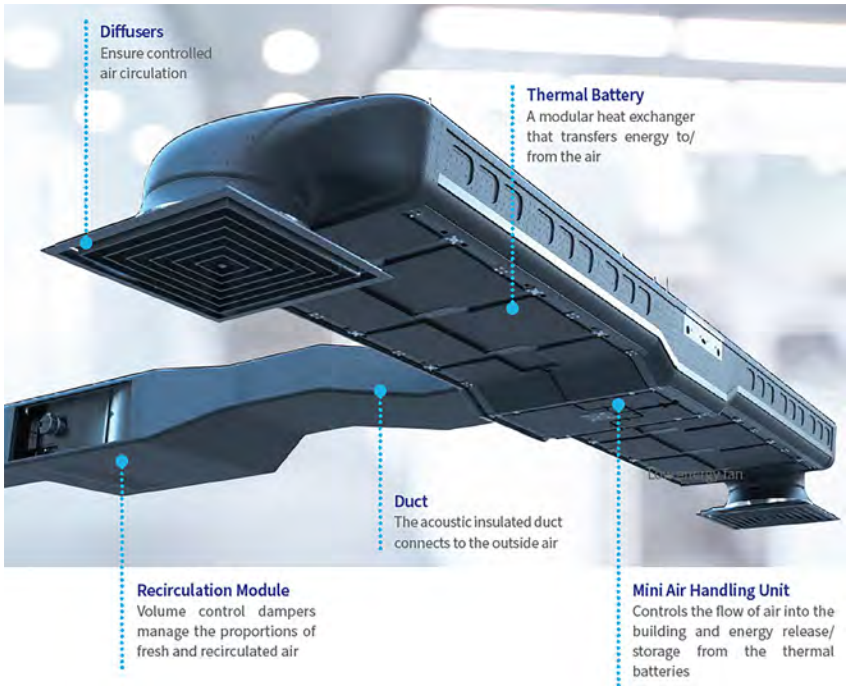
Sources: Cabeza, L.F. et al. 2011. Materials Used as PCM in Thermal Energy Storage in Buildings: A Review. *Renewable and Sustainable Energy Reviews*. 15 (3). pp. 1675–1695; Cui, Y. et al. 2017. A Review on Phase Change Material Application in Building. *Advances in Mechanical Engineering*. 9 (6). Sage Journals; Kuznik, F. et al. 2011. A Review on Phase Change Materials Integrated in Building Walls. *Renewable and Sustainable Energy Reviews*. 15 (1). pp. 379–391.

There are various techniques to integrate PCMs into buildings, such as micro, macro, composite, and structural encapsulation. In the microencapsulation process, the small PCM particles are encapsulated in a thin, high-molecular-weight polymeric film. This technique has the advantage of improved heat transfer and stability. For larger-scale encapsulation, the PCM is enclosed in a container that can be used to build products. This technique avoids the issue of phase-change volume adjustments in building applications. Building-integrated PCMs can also be manufactured as composite materials to improve their properties. Structural encapsulation of PCMs may be applied to various building materials such as plaster, wood, concrete, cement, or vermiculite, which are used in buildings' ceilings, walls, or flooring for cooling and/or heating purposes.

Figure 67 shows an example of a PCM-based ventilative cooling system. It is the "cool phase" system for natural cooling, manufactured by Monodraught. It is a modular device, either ceiling-mounted or integrated within the suspended ceiling, that guides ventilation air through thermal battery modules filled with paraffin PCM. During the night, cool air is circulated and is stored in the form of latent heat in the thermal battery. During the following day, the high-temperature ambient air is circulated through the thermal battery, where the material cools the air by changing its phase.

The efficiency of a PCM-based ventilation and cooling system hinges primarily on the phase-change temperature of the material, the temperature of the ambient air during the night period, and the airflow rate. As found by previous applications, a PCM system using fatty acid, if carefully designed and applied, had the potential to further decrease the maximum room temperature of the following day by almost 2°C, on top of what could be achieved by a common night ventilation approach. Also, using PCM for night ventilation could offer the opportunity for downsizing the mechanical ventilation system in climates with outdoor air temperatures below 18°C at night. It was also found that using a PCM wallboard could reduce peak cooling loads by 28%.

Figure 67: Phase-Change Material Ventilation and Cooling System—"Cool Phase"



(a)



1. Ventilation
Dampers modulate open to expel stale air and provide natural ventilation as CO_2 levels rise. When temperature differences are sufficient, external air provides cooling.

2. Outside Air Ventilation and Cooling
Dampers modulate open and mechanical fans direct fresh air over the thermal batteries, cooling it before ventilating the room. Especially useful in summer months.

3. Recirculation and Cooling
Dampers modulate open and mechanical fans expel stale warm air, some of which is recirculated to temper fresh external air which is delivered via a separate pathways. Recirculated indoor air passes over the thermal batteries when cooling is required.

(b)

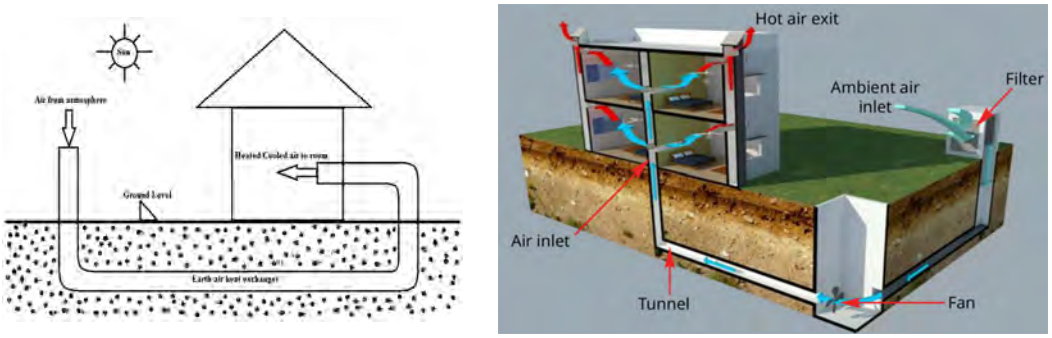
CO_2 = carbon dioxide.
Source: Monodraught. 2010. Natural Cooling: Cool-Phase.

Renewable Cooling Sources

Ground Cooling (Air)

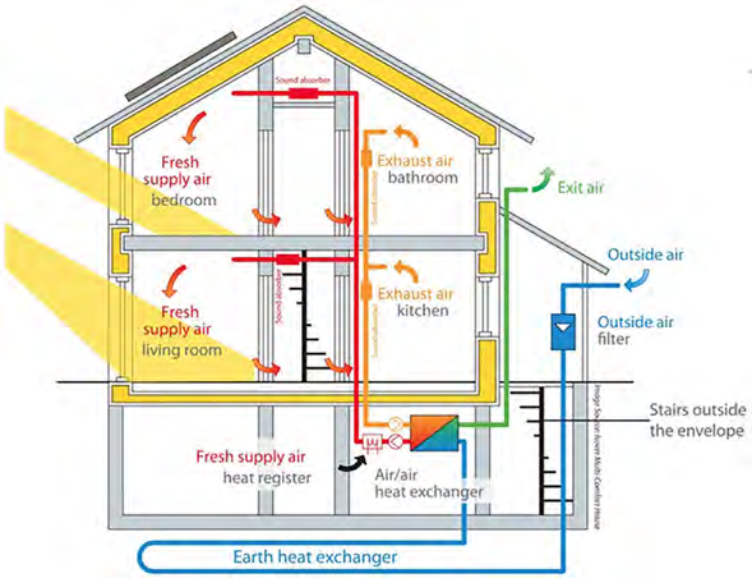
The concept of ground cooling through heat exchange between air and earth is simple and straightforward. The system uses an underground duct, or a network of them, buried into the ground at around two to four meters of depth, at which level the temperature of the ground is constant. This temperature, known as the earth's undisturbed temperature, remains lower than the ambient air temperature during summer, and therefore can serve as a cooling source. As shown in Figure 68, the ambient air is drawn through the duct, cooled through heat exchange with the ground, and then supplied to the building. In some applications, the cooled air is not supplied to the rooms directly, but used to cool the indoor air through an air-to-air heat exchanger (Figure 69).

Figure 68: Ground Cooling (Air) System for Direct Supply



Source: BEBuilding Energy Efficiency Project (BEEP). 2020a. Earth Air Tunnel; Bisoniya, T.S. 2015. Design of Earth–Air Heat Exchanger System. *Geothermal Energy*. 3 (18).

Figure 69: Ground Cooling (Air) System with Air-to-Air Heat Exchanger



Source: VOLKsHouse. 2021. How Does a Passive House Work?

Ground Cooling (Water)

Ground-source cooling uses the relatively stable temperature of the ground or bodies of water as a source for providing cooling in buildings. There are two main types of ground-source cooling: groundwater cooling and ground-source heat pumps.

Groundwater Cooling

Groundwater cooling uses the relatively stable temperature of water in aquifers to provide space cooling within buildings. It works because, in summer, the groundwater temperature is generally lower than the indoor air temperature and therefore can be used as a cooling source. Groundwater cooling can be either a closed loop or an open loop, with the open loop being more common. Closed-loop applications are normally equipped with heat pumps, i.e., ground-source heat pump systems. Open-loop applications are provided cooled water directly to buildings. In open-loop, direct groundwater cooling systems, water is abstracted from the ground, which is typically an aquifer, a ground or surface water source such as a lake or river, and then passed through a heat exchanger to transfer heat to the ventilation and air-conditioning systems. Finally, the water is either returned to the ground or discharged into a river or sewer.

Open loop, direct groundwater cooling systems have the potential to meet larger cooling loads than closed-loop systems. The available volume of water that can be extracted and the temperature change that is allowed are key factors to determine the system capacity. As power is only required for driving water circulation pumps, the system efficiency is generally high, with a COP of 15 to 20 achievable. There are, however, a series of disadvantages of open-loop groundwater cooling systems, such as resource and regulatory uncertainties, design complexity, thermal interference, maintenance, and so on (Feuvre and Cox 2009).

Box 13: Case Study of Groundwater Cooling

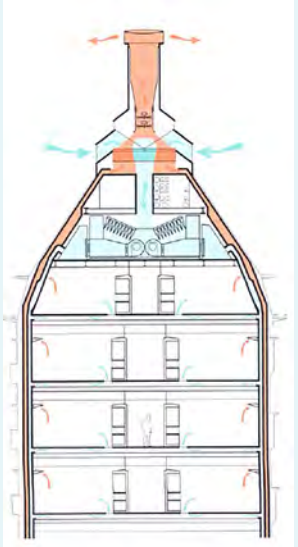
Portcullis House, London

Located in Westminster, London, Portcullis House is a seven-story building housing the United Kingdom's 650 members of Parliament with a number of offices, conference rooms, and committee rooms.

The house was designed to integrate building services. It features a highly active construction of a facade system, which consists of a triple plane glazing with argon filled and low-emissivity coating. A ventilative cavity serves as air distribution ducts. During winter, louvers are used to block lower sun angles. During summer, a light shelf is used to block higher sun angles. Glass prism surfaces act as a reflector of daylight upon the interior space. This brings the benefit of doubling the daylight, especially in north-facing offices, which have their sky views obstructed by adjacent buildings. The facade with a low U-value helps to block heat from outside to inside, and vice versa. Thermal mass materials with high thermal resistance are used at the interior finishes and at the ceiling to absorb heat.

For ventilation strategy, the house uses a low velocity displacement ventilation system, which, owing to buoyancy force and vertical temperature gradient, is more energy efficient as compared to a conventional system. The plan is organized around a central courtyard. Along the building perimeter, a total of 14 chimney stacks provide ventilation for the building. Air is drawn at the base of the chimneys and distributed through the duct system integrated into the facade. Each floor has a ventilation plenum at the floor level where air circulates before entering the occupied spaces. Air is exhausted at ceiling level

Box Figure 13.1: Ventilation Strategy of Porticullis House, London



Buchanan, P. 2005. *Ten Shades of Green: Architecture and the Natural World*. Architectural League of New York.

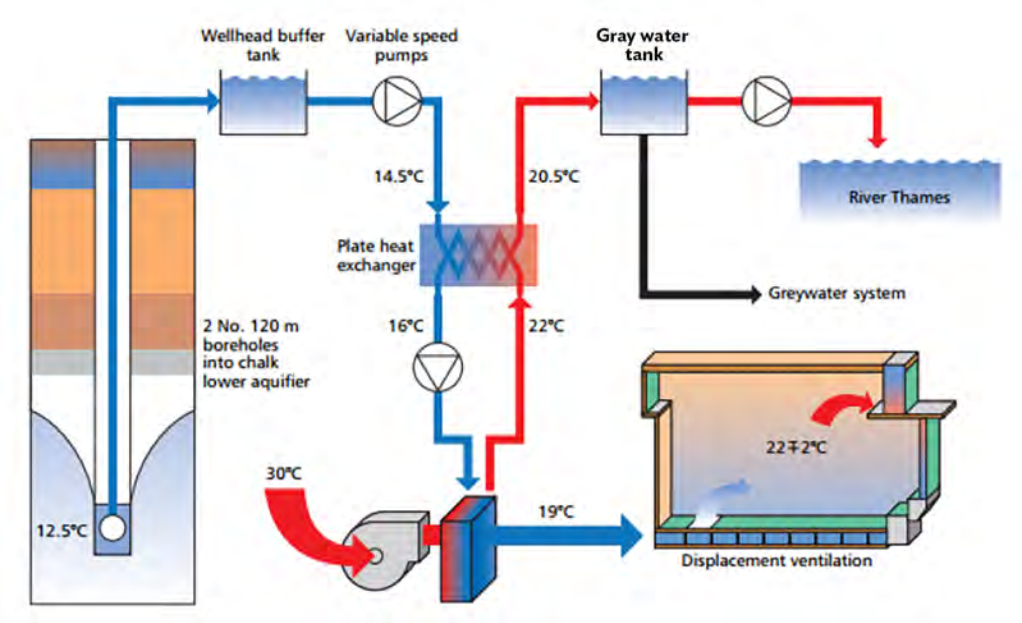
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Box 13 *continued*

and distributed through the duct system leading to the chimneys. The exhaust air is not recirculated but used for heat recovery through a roof-mounted rotary hygroscopic thermal wheel. The recovered heat in the exhaust air comes from solar heat captured at the facade, internal heat gains from occupants and devices, and heat emitted by radiators.

The cooling of the building is provided by a groundwater cooling system, which extracts groundwater from two boreholes sunk 150 meters into a chalk aquifer below the building. When the outdoor temperature goes high, the groundwater of around 12.5°C is pumped and stored in two 16,500-liter buffer tanks located in the basement. The groundwater is then pumped through plate heat exchangers connected to cooling coils in air-handling units to cool outdoor fresh air down to room temperature, around 19°C. The cooled air is sent to occupied spaces through the displacement ventilation system. Upon leaving the heat exchanger, the groundwater is discharged at a temperature of about 21°C. Some of the groundwater is fed to a gray water system for flushing toilets, whereas the rest is discharged into the river. Groundwater cooling is supplemented by nighttime ventilation when needed. The night ventilation helps to enhance the building's cooling strategy and avoid overheating. It facilitates the removal of internal heat gains absorbed by the thermal mass materials during the daytime. The ventilation rate during night ventilation is about half of the rate during daytime, contributing to reducing the overall energy consumption of the building.

Box Figure 13.2: Schematic of Groundwater Cooling System of Portcullis House, London



m = meter.

Source: Ampofo, F., Maidment, G.G. and Missenden, J.F. 2006. Review of Groundwater Cooling Systems in London. *Applied Thermal Engineering*. 26 (17–18). pp. 2055–2062; Feuvre, P. Le and C.S.J. Cox. 2009. Ground Source Heating and Cooling Pumps – State of Play and Future Trends; Wincott, N. 2019. Low Carbon Heating and Cooling from Groundwater for Commercial and Residential Developments and District Networks.

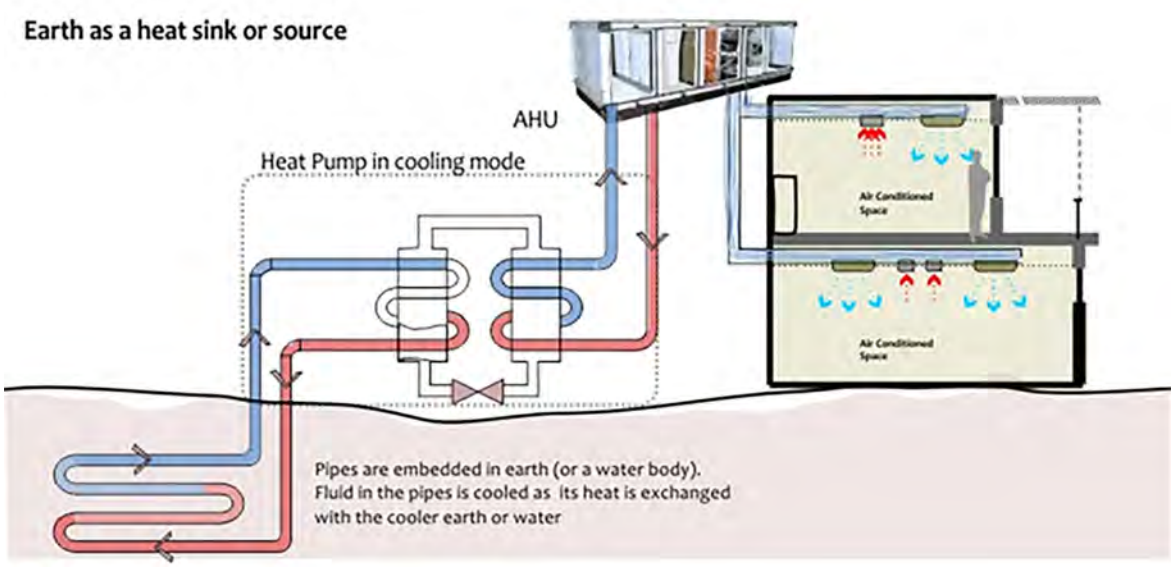
Ground-Source Heat Pump for Space Cooling

Reversible ground-source heat pumps can be an effective way to provide either cooling or heating. The basic principle is to make use of the relatively stable temperature of the earth at a certain depth from the surface, of groundwater from wells, or of surface water from a lake, pond, or stream. With the temperature between this heat source or sink and the air in the conditioned space, the refrigerant of the heat pump is driven by an electric compressor to go through the conventional vapor-compression cycle to produce a heating or cooling effect for the conditioned space.

When operating in cooling mode, a ground-source heat pump works like an air-conditioning system, by using the ground, groundwater, or surface water as the heat sink. The heat pump extracts heat from the air in the conditioned space and transfers it to its circulating refrigerant. When the heat pump is of a water-to-water type, this heat transfer takes place between the refrigerant and the chilled water of an air-handling unit (Figure 70). By undergoing the continual vapor-compression cycle, the refrigerant transfers the absorbed heat to the ground through the working fluid (water, or antifreeze solution) in the ground connection subsystem, which takes the form of tubes vertically placed in boreholes, or horizontally placed in trenches, or submerged in a body of water such as a pond or lake.

More details on heat pump classification and description are given in section 5.1 of this handbook.

Figure 70: Schematic of Ground-Source Heat Pump for Cooling



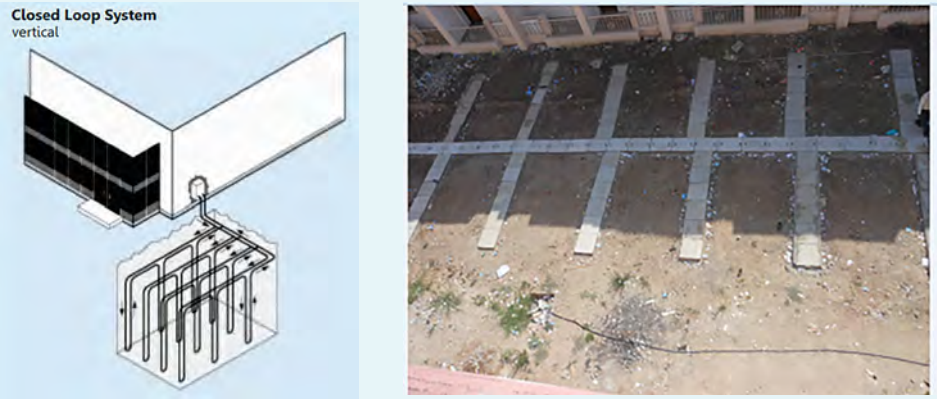
AHU = air-handling unit.
Source: NZEB Alliance.2021e. Ground-Source Heat Pump (GSHP) Systems.

Box 14: Case Studies of Ground-Source Heat Pump for Space Cooling

CASE 1: CENTRAL UNIVERSITY OF RAJASTHAN, INDIA

The Central University of Rajasthan is in Ajmer, Rajasthan, India, where the climatic condition is hot and dry. A geothermal hybrid cooling system was installed at the university's student hostel. Water from the boreholes is used to cool the air before being introduced into indoor spaces. Heat exchange between water from the boreholes and supply air takes place inside specially designed air-handling units. After this, air is further cooled through a two-stage evaporative cooling system. The system uses full fresh air and is designed to reduce the temperature of the supply air by around 10°C. The design temperature for the hostel rooms is 29°C. The average outlet water temperature from the boreholes is recorded at 25°C. Outlet temperatures in winter are around 19°C. The energy performance index of the system was measured to be approximately 78 kilowatt-hour/square meter/year in 2012.

Box Figure 14.1: Boreholes of Ground-Source Heat Pump System at Central University of Rajasthan



Source: United States Agency for International Development. 2014. HVAC Market Assessment and Transformation Approach for India.

CASE 2: SPACE COOLING BY GROUND-SOURCE HEAT PUMP IN TROPICAL SOUTHEAST ASIA (THAILAND, VIET NAM)

A major concern regarding the applicability of ground-source heat pumps (GSHP) for space cooling in Southeast Asian countries is that the subsurface temperature is very close to the average atmospheric temperature and therefore may not be appropriate to be used as a cold source (heat sink). A solution is to use the effect of cold groundwater, which infiltrates in the underground in high mountain regions and flows toward the nearshore regions with the densely populated Southeast Asian cities.

Yasukawa and Uchida (2018) conducted groundwater temperature surveys at Chao Phraya Plain, Thailand, and the Red River Plain, Viet Nam. The surveys found that (i) in Bangkok, Ayutthaya, Phitsanulok, and Nakhon Sawan of Thailand, subsurface temperature was lower than monthly mean maximum atmospheric temperature throughout the year; and (ii) in Ha Noi, Viet Nam, subsurface temperature was lower than monthly mean maximum atmospheric temperature from May to October by 2–7 degrees Kelvin. These results suggested the applicability of GSHPs in these places.

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Box 14 *continued*

Several experimental and demonstrational GSHP systems in Thailand, Viet Nam, and Indonesia were installed and operated by the authors (Table 14.1). All were closed-loop systems. The first four systems were only experimental and were removed after a couple of years' operation. The remaining ones were demonstrational systems for longer periods of operation. Improvements have been applied to these installations for better cost performance, including drilling and well completion technologies for a higher heat exchange rate, a combination of horizontal and vertical heat exchangers, and a controlling system for the heat pump operation.

Table 14.1: Experimental and Demonstrational Ground-Source Heat Pump Systems in Thailand and Viet Nam

No.	Location	Period	Subsurface Heat Exchanger	Surface System	Note
1	Kamphaengphet (DGR), Thailand	October 2006 to March 2008	57-meter (m) deep borehole with double U-tube	Water-water chiller, fan coil	First experiment in tropics. Mostly made in Japan.
2	Chiang Mai (DGR), Thailand	March 2008 to July 2010	80-m deep borehole with single U-tube + 60-m horizontal tube	Same as above	Moving the above system to another site.
3	Bangkok (Kasetsart University), Thailand	July 2010 to 2012	200-m horizontal tube	Same as above	Moving the above system to another site.
4	Bandung (ITB), Indonesia	July 2013 to 2015	200-m horizontal tube	Remodel from air-conditioner	Cooling efficiency 25% up. Done by Akita University.
5	Bangkok (Chulalongkorn University), Thailand	May 2014 to present	50-m deep borehole with single U-tube × 3 (150 m)	Combined chiller and fan unit	Cooling efficiency 30% higher than normal air-conditioner.
6	Saraburi (Chulalongkorn University), Thailand	June 2015 to present November 2016 to present	300-m carpet style (horizontal) 300-m coil style (horizontal)	Combined chiller and fan unit	Machine made in Thailand Remodel from air-conditioner.
7	Pathumthani (Geology Museum, DMR) Thailand	March 2015 to present	50-m deep borehole with double U-tube × 2 (400 m)	Combined chiller and fan unit	Mostly made in Japan. No cementing borehole for higher heat exchange.
8	Ha Noi (VIGMR), Viet Nam	October 2016 to present	50-m deep borehole with double U-tube × 2 (400 m)	Combined chiller and fan unit	Mostly made in Japan. No cementing borehole for higher heat exchange.

Source: Yasukawa, K. and Y. Uchida. 2018. Space Cooling by Ground Source Heat Pump in Tropical Asia. In *Renewable Geothermal Energy Explorations*. IntechOpen.

The installation and operation of these GSHP systems offered the following findings:

- Application of horizontal subsurface heat exchangers is effective in reducing the installation cost of heat exchangers. Combination of horizontal and vertical ones is effective to maintain higher heat exchange rate while reducing installation costs.
- Shorter piping and thermal insulation of the surface pipe are important for effective cooling. The subsurface pipe for the horizontal system should not be bended to maintain high fluid circulation with a small water pump.
- Application of local materials, such as domestic heat pumps and domestic tubes is effectivein reducing total cost. Electrofusion welding is useful to connect the head part of the U-tube and local tubes so that import of whole U-tube is not necessary.

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Box 14 *continued*

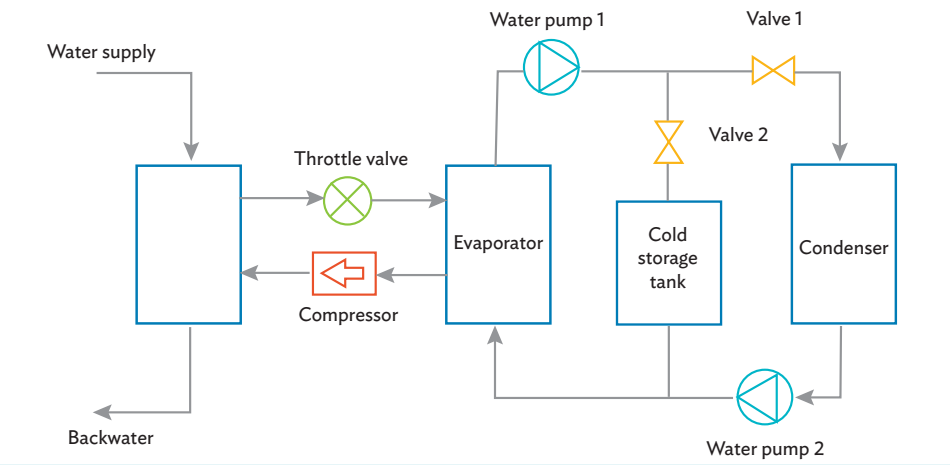
- For higher performance and cost reduction of the vertical heat exchanger, well completion without cementing is essential. Polymer mud is effective for such drilling, and local crews may handle it without problem.
- A sophisticated heat pump control system with a proper heat exchanger achieved 30% electricity savings compared to a conventional air-conditioner.

Sources: Link, K. 2017. Example of Geothermal Cooling with Ground Source Heat Pumps in South-East Asia; Yasukawa, K. and Y. Uchida. 2018. Space Cooling by Ground Source Heat Pump in Tropical Asia. In *Renewable Geothermal Energy Explorations*. IntechOpen; Widiatmojo, A. et al. 2019. Ground Source Heat Pump Application in Tropical Countries. In *44th Workshop on Geothermal Reservoir Engineering*, Stanford University; Chokchai, S. et al. 2018. A Pilot Study on Geothermal Heat Pump (GHP) Use for Cooling Operations, and on GHP Site Selection in Tropical Regions Based on a Case Study in Thailand. *Energies*. Vol. 11(9).

CASE 3: THE PEOPLE'S REPUBLIC OF CHINA'S FIRST GROUND-SOURCE HEAT PUMP SYSTEM AND ICE STORAGE PROJECT—BEIJING TIANCHUANG SHIYUAN BUILDING

The Tianchuang Shiyuan building is in Chaoyang District, Beijing, which has a hot summer and a cold winter. The large commercial facilities at the bottom of the building have an air-conditioned space totaling to about 40,000 square meters, with a design cooling load of 6.05 megawatts (MW) and a heating load of 4 MW. The project adopts the GSHP and ice storage air-conditioning system designed by the China Academy of Building Sciences. Completed in September 2002, the system was the first-of-its-kind in the People's Republic of China.

Box Figure 14.2: Schematic of a Ground-Source Heat Pump System Coupled with Cold Storage



Source: Song, C. et al. 2021. Application and Development of Ground Source Heat Pump Technology in China. *Protection and Control of Modern Power Systems*. 6.

In the hybrid system of GSHP with ice storage equipment, a cold storage tank is added in parallel with the evaporator and end heat exchanger in the conventional heat pump system. This makes possible four operational modes of the system, including conventional cooling cycles, cold storage cycles, combined cooling cycles, and single cold storage and supply cycles. The optimal scheduling among different operation modes can effectively reduce the power consumption of refrigeration equipment, as well as the operational cost of the air-conditioning system during the peak period.

If the heat pump system was used without cold storage, 11 wells would have been needed, and the groundwater consumption would have been quite large. With the hybrid system in operational mode, seven wells are sufficient for energy supply, which reduces system power consumption. The total project investment was about CNY3 million, with a large percentage subsidized by the local government. Compared with conventional systems, the annual operational cost can be reduced by CNY1.58 million, demonstrating a high economic viability.

Source: Song, C. et al. 2021. Application and Development of Ground Source Heat Pump Technology in China. *Protection and Control of Modern Power Systems*. 6.

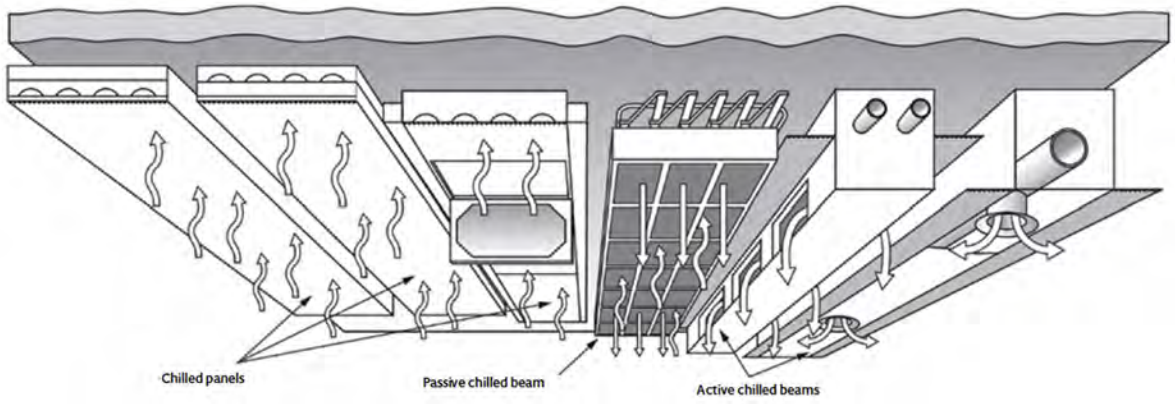
Sustainable Air Distribution

Chilled Beams and Ceilings

Static cooling devices taking the shape of long rectangular beams, named chilled beams, and rectangular panels, named chilled ceilings, deliver cooling to occupied spaces by using chilled or cooled water passing through coils that exchange heat with ambient air to reduce the air dry-bulb temperature. The water as the cooling medium has a temperature in the range of 13°C to 18°C and can be obtained using natural cold-water storage or free cooling from outside air during cold periods of a year. Compared to all-air ventilation and cooling systems, chilled beams and ceilings, being water-based, are more energy- efficient because of the high specific heat capacity and thermal conductivity of water. Moving heat around a building can be undertaken far more efficiently by pumping cool water in pipes than by moving the same amount of heat in ducted air.

There are a wide range of different types of chilled beams and ceilings, but they fall into three main categories: radiant chilled ceilings, passive chilled beams, and active chilled beams (Figure 71).

Figure 71: Schematic of Chilled Beams and Ceilings



Source: CIBSE. 2012. Guide F Energy Efficiency in Buildings.

(i) Radiant Chilled Ceilings

Radiant chilled ceilings usually incorporate a chilled water coil into the rear of the ceiling finish material. This means placing a copper pipe matrix on the rear of metal ceiling tiles or panels (Figure 72). Insulation is usually applied to the upper surface of the chilled ceiling. As chilled water passes through the coil, it offers a cool ceiling surface that provides space cooling, mainly by radiation.

Radiant cooling involves the direct absorption of heat radiated from warm surfaces within the room, which occurs when there are cooler surfaces visible to the warmer surfaces. This type of system results in low air velocity and an evenly distributed temperature in the occupied zone, thus ensuring a good level of thermal comfort. As for indoor air quality, a separate ventilation system is required to supply fresh air to the space. Often, chilled ceilings are used with displacement distribution systems.

Figure 72: Radiant Chilled Ceiling Panel



Source: Frenger Systems. 2012. *An Introduction to Chilled Beams and Ceilings*.

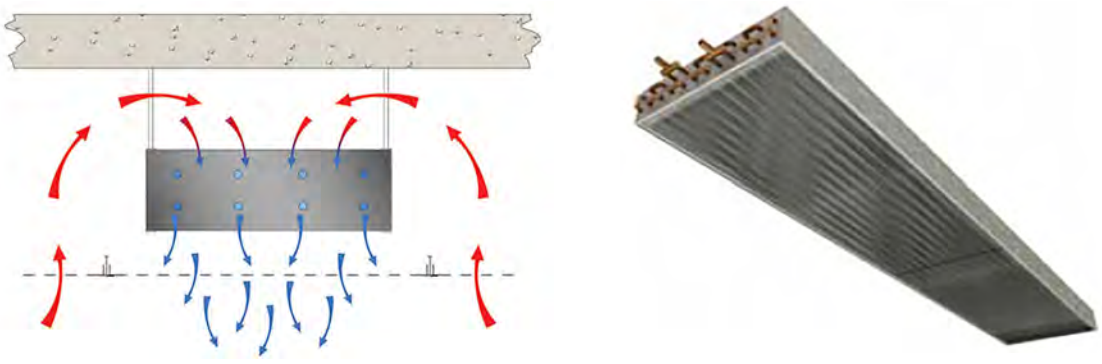
(ii) Passive Chilled Beams

Chilled beams are mounted at high levels in the conditioned space and can be fully encased and suspended from a soffit or integrated into a false ceiling. The basic thermal transfer component for chilled beams is a fin and tube heat exchanger, i.e., coils. Chilled beams provide convective cooling. Because of the larger fin surface area, a higher thermal performance can be achieved with chilled beams as opposed to chilled ceilings.

Passive chilled beams respond to natural convection currents in the room. Warm air rising in the space passes over the top and into the passive chilled beam. As the air between the fins is cooled, it becomes denser and drawn downward by gravity, displacing the less dense, warmer air to a higher level (Figure 73).

Passive chilled beams need to be arranged at regular intervals along the ceiling plane to provide uniform cooling to the occupied space. It is important to ensure good air circulation for the operation of passive chilled beams. There need to be sufficiently large openings above the passive beam casing or ceiling system to allow air to circulate properly.

Figure 73: Passive Chilled Beam



(a) (b)

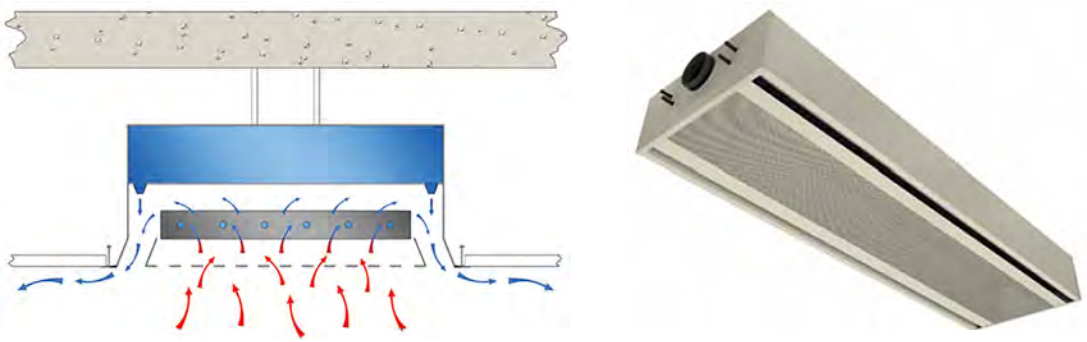
Source: Frenger Systems. 2012. *An Introduction to Chilled Beams and Ceilings*; CIBSE. 2014. Module 65: Applying Chilled Beams to Reduce Building Total Carbon Footprint.

(iii) Active Chilled Beams

Active chilled beams are supplied with ducted primary air from a centralized system that is often used to meet the fresh air requirement in the space. This air also provides the dehumidification required for the conditioned space by having a supply air moisture content set at a level to offset the latent loads in the space.

The primary air is discharged into the beam through nozzles directed toward the outlet of the beam casing that induce room air up from the room and through the cool coils. The cooled room air is then entrained into the stream of fast-moving supply air, before being discharged into the space through the slots (Figure 74). This enhanced induction helps to significantly increase the velocity of the room air passing across the coils, thereby improving heat transfer. As in the case of passive beams, regular intervals along the ceiling are key to the arrangement of active chilled beams.

Figure 74: Active Chilled Beam

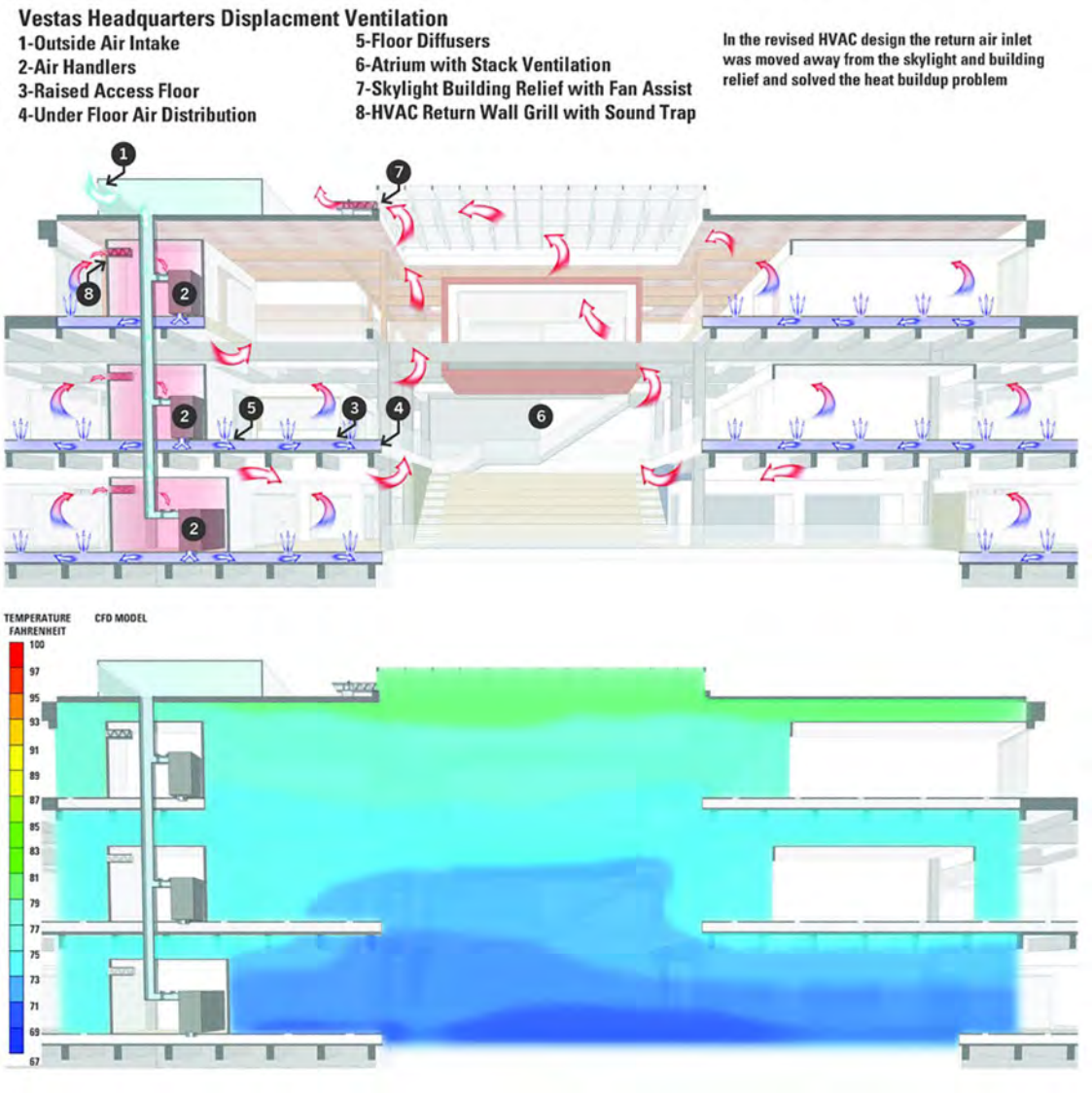


Source: Frenger Systems. 2012. *An Introduction to Chilled Beams and Ceilings*; CIBSE. 2014. Module 65: Applying Chilled Beams to Reduce Building Total Carbon Footprint.

Displacement Ventilation

Displacement is a proven solution to energy-efficient ventilation and cooling of buildings, particularly those suitable for office buildings. Its basic principle is illustrated in Figure 75. The cool fresh air is supplied at a low velocity, usually 0.25–0.35 meters per second (m/s), and at a lower level, usually through a raised floor. This creates a reservoir of cold air around the level of occupancy. When it gets into contact with an internal heat source, the air is heated and then rises due to the effects of momentum and buoyancy forces. As the air gets gradually warmer while flowing upward, a vertical temperature gradient is formed. The air is extracted through upper-level outlets, usually mounted at the ceiling, where there is a concentrated layer of warm air and pollutants. The movement of the air can be further driven by the heat emitted by the light fittings at the ceiling. Displacement ventilation is more energy-efficient than conventional overhead mixed air systems because the air is supplied near the occupied zone at lower velocity and a higher temperature, which means reduced cooling requirements and fan power consumption. The lower velocity and higher temperature relative to conventional systems also offer the advantage of thermal comfort due to the reduced draft. In some applications, a displacement ventilation has limited cooling capacity and is therefore operated in conjunction with chilled beams or chilled ceilings.

Figure 75: Displacement Ventilation Application in Office—Vestas Headquarters



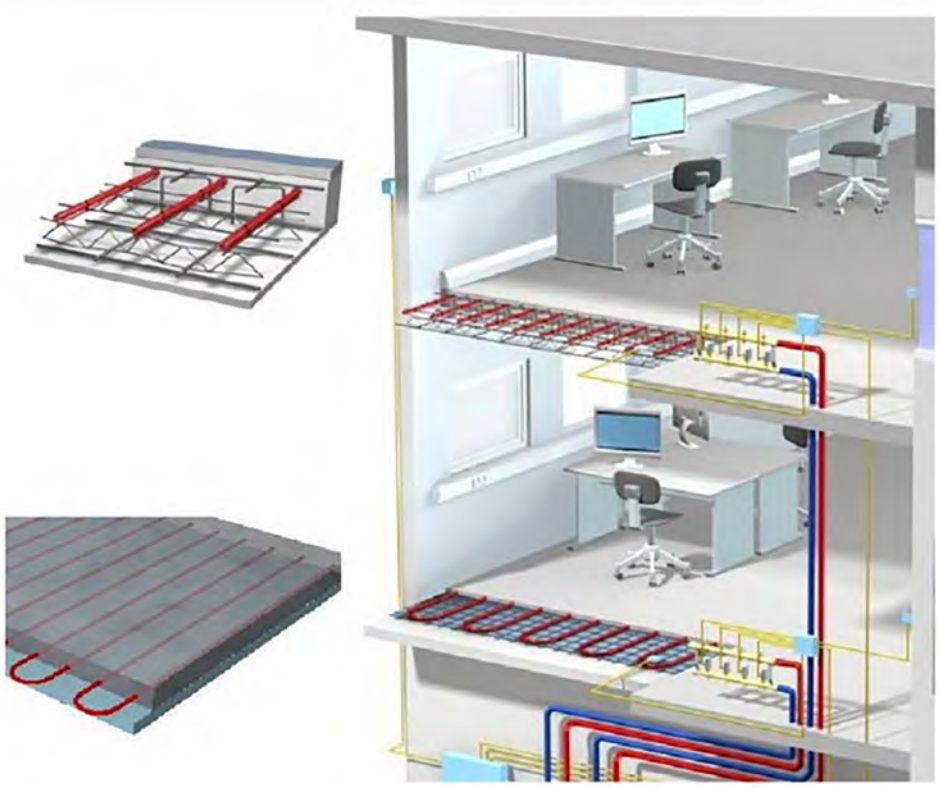
HVAC = heating, ventilation, and airconditioning.
Source: Glumac. 2016. Maximize Displacement Ventilation Opportunities.

Slab Cooling

Slab cooling, also commonly known as a subcategory of radiant cooling, can be realized using air or water. For air applications, slab cooling is often used with night ventilation to maximize the potential of cooling. The slab is constructed in such a way that it allows air to be passed through embedded pathways. During the night, cool air is passed through the slab to enhance the cooling of the slab. During the day, warm air is injected through the cool slab for precooling before being used to condition a space or sent to the air-conditioning system for further cooling.

Often, slab cooling is implemented by using embedded water coils and pipes through which chilled water circulates. The circulating chilled water cools down the slab, which in turn becomes a cold surface acting as a heat sink for sensible loads of internal heat gain (Figure 76). The chilled water can be generated either through conventional electric chiller systems or low-energy systems such as absorption chillers, desiccant chillers, etc.

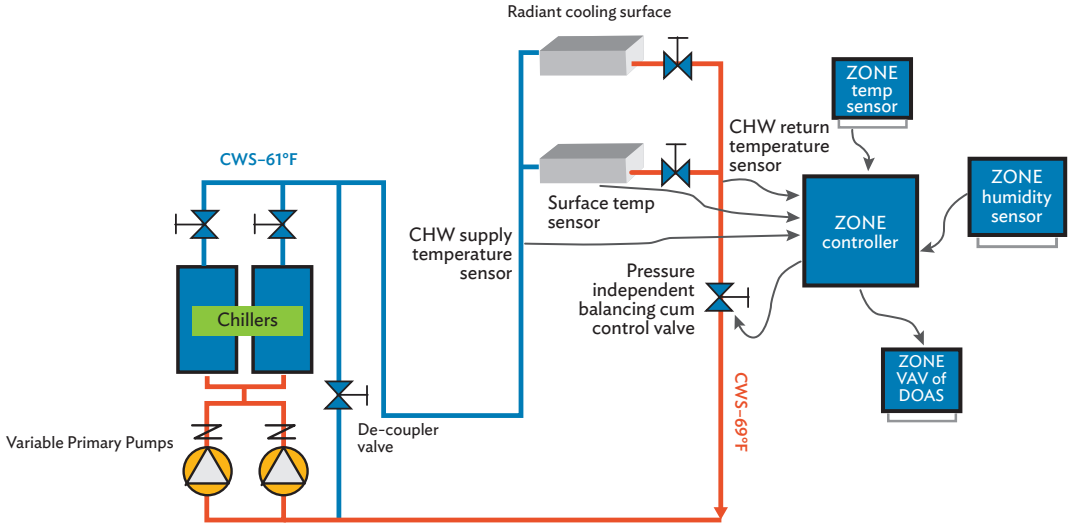
Figure 76: Slab (Radiant Floor) Cooling and Heating



Source: Fairconditioning. 2021d. Radiant Cooling Working Principle.

Concrete structures typically used with slab cooling systems also increase the thermal mass of buildings. This introduces inertia in the structure against temperature fluctuations and allows it to absorb heat from internal spaces. This advantage of the thermal mass can help reduce the need for air-side systems. Thus, the conventional air-conditioning system can be downsized substantially, and operational energy can be saved. Due to potential condensation on building structural elements, slab cooling is more suitable for applications with low latent loads. It is important to control the operation to ensure the surface temperature is always above the dew-point temperature of the surrounding area so that condensation does not occur (Figure 77). As radiant cooling can only address a sensible load, air humidity must be separately handled by an air-conditioning system or a dehumidifier. In general, the capital cost of this system is similar to that of a high-efficiency chilled water system, but the operational cost is lower.

Figure 77: Schematic Diagram of Operation Control of Slab Cooling



CHW = chilled water, CWS = cooling water system, DOAS = dedicated outdoor air system, VAV = variable air volume.
Source: Fairconditioning. 2021d. Radiant Cooling Working Principle.

Box 15: Case Studies of Slab Cooling

CASE 1: INFOSYS HYDERABAD CAMPUS, INDIA

Infosys constructed the first radiant cooled commercial building in India on its campus in Hyderabad, where the climatic conditions are hot and dry. The total built-up area was 24,000 square meters (m^2). The building was split into two symmetric halves: one with conventional air-conditioning (high efficiency and surpassing ASHRAE standards by about 30%), and the other with radiant floor cooling. The radiant system was designed for a cooling output of 75 watts per square meter (W/m^2). Chilled water design temperatures were 14°C for supply and 17°C for return. The cooling tower approach temperature was 2°C. A low-pressure piping and ducting distribution system was installed. An energy recovery system was also installed to provide dehumidified air to offices.



Infosys Campus, Hyderabad, India.
Source: Fairconditioning. 2021c. Radiant Cooling Case Studies.

The energy index for the radiant system was 25.7 kilowatt-hours (kWh)/m^2, about 33% lower than the conventional system (38.7 kWh/m^2). The average chiller plant efficiency was 0.45 kilowatts per ton of refrigeration (kW/TR) for the radiant system and 0.6 kW/TR for the conventional system. The quantity of water required by the radiant system was about 20% of that required by a conventional chiller of similar capacity. As no recirculation was involved, contamination was reduced, and air quality was improved. Comfort conditions measured inside the building were within the permissible limits of ASHRAE 55-2004 and ASHRAE 62.1-2007 for most of the time. The capital costs of the two systems were comparable, with the radiant system costing ₹3,302/m^2 and the conventional system costing ₹3,327/m^2.

Source: NZEB Alliance.2021g. Radiant Cooling Systems; Fairconditioning. 2021d. Radiant Cooling Working Principle; Fairconditioning. 2021c. Radiant Cooling Case Studies.

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Box 15 *continued*

CASE 2: UNDER FLOOR INSTALLATION AT L&T HAZIRA, SURAT, INDIA

Design Brief:

- Site location: L&T Hazira Surat, Gujarat
- Climate conditions: hot and humid, with high latent load
- Design conditions: indoor design temperature 25°C, relative humidity 60%

Solutions:

- Radiant cooling was used for the ground floor
- Insulated ground floor slab mitigated loss of cooling effect
- Latent load and residual sensible load were met by conventional air-conditioning system
- Underfloor cooling system was installed in areas containing workstations connected to electrical conduits in the floor

Impact of Radiant Colling on Total Power Requirement

Parameter	Conventional HVAC	Radiant + Conventional HVAC
AHU Power	65 kW	21 kW
Chiller Power	181.3 kW	56.5 kW
Water Pumps		50 kW
TOTAL	246 kW	127.5 kW
SAVINGS		118.5 kW (48%)

AHU = air handling unit; HVAC = heating, ventilation, air-conditioning; kW = kilowatt.
Source: Fairconditioning. 2021c. Radiant Cooling Case Studies.

CASE 3: A SLAB-INTEGRATED RADIANT COOLING SYSTEM IN PUTRAJAYA, MALAYSIA

Kwong et al. (2017) conducted a comprehensive study on the energy conservation potential and cost-effectiveness of a slab-integrated radiant cooling system installed at a green office building in Putrajaya, Malaysia.

The Office Building

Completed in 2010, the eight-story office building has a total area of approximately 23,284 m^2, of which about 15,225 m^2 were air-conditioned. The building was north–south oriented, and the center of the building was designed to be hollow to allow penetration of natural daylight. Most of the building facilities were located around the building perimeter. The office building consisted of three main parts, including the base (one and a half stories), the office block (six stories), and the rooftop. The rooftop consisted of an open-air garden built under the concept of "green building." For air- conditioning, chilled water was supplied from a centralized chiller plant, where both electric and gas-fired chillers were installed, to the office building through pre-insulated seamless underground pipes.

The Slab Cooling System

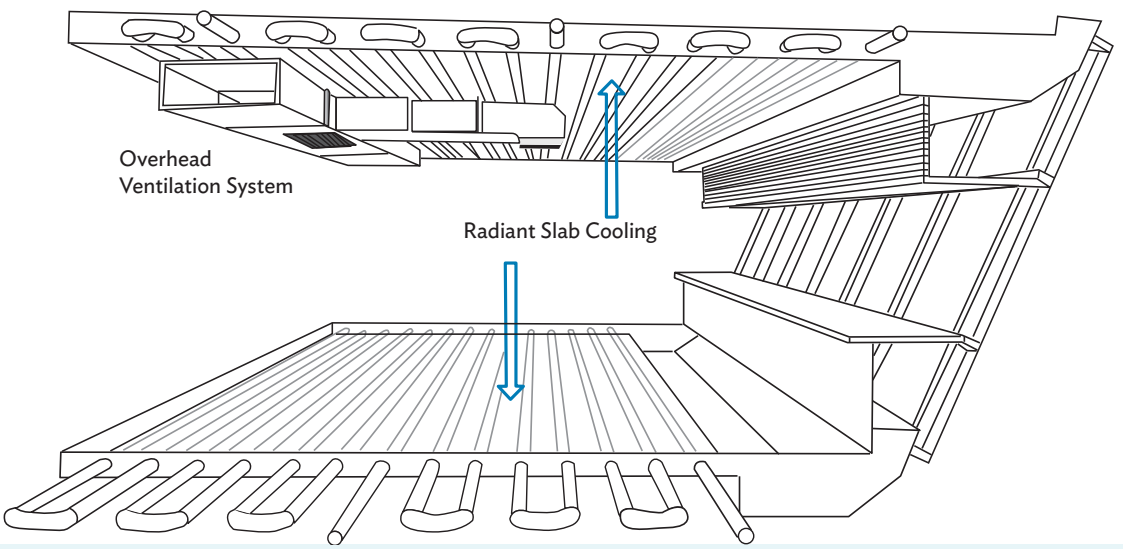
The multi-floor radiant slab cooling system was designed to handle 40% of the sensible cooling loads generated from the internal heat gains of the office building. The 22-millimeter (mm) cross-linked polyethylene (PEX) pipes were embedded at 50 mm above the underside of the 200 mm thick concrete slabs during construction. This turned the building structure into a thermal storage system. With no insulation layers in the slabs, the system acted as both a chilled ceiling and a chilled floor. The chilled water was supplied and circulated on the concrete floors at night to cool the building

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Box 15 *continued*

structure down to 18°C–20°C. A timer was installed to control the operating time of the chilled water flow in the hydronic tubes to ensure that the thermal mass was sufficient to absorb 40% of the sensible heat. Typically, the thermal mass charging was from 10:00 p.m. to 6:00 a.m. The system was shut off during office hours to allow the floor slabs to passively absorb heat gained from occupants, office equipment and devices, solar irradiation, and other sources. This effectively reduced the cooling load and the resultant energy consumption of the air-side system. The ceiling surface temperature was maintained at 2°C or higher than the dew-point temperature of the circulated indoor air to avoid condensation. The latent load was handled by overhead air plenums installed on each floor, which supplied filtered and conditioned air to the indoor space. The indoor air relative humidity was maintained in the range of 50%–60% by modulating the intake of treated fresh air, whereby the risk of condensation problems commonly associated with radiant cooling systems was effectively mitigated.

Box Figure 15.1: Graphical Illustration of the Slab Cooling System Used in a Green Office Building in Putrajaya, Malaysia



Source: Kwong, Q.J. et al. 2017. Evaluation of Energy Conservation Potential and Complete Cost-Benefit Analysis of the Slab-Integrated Radiant Cooling System: A Malaysian Case Study. Energy and Buildings. 138. pp. 165–174.

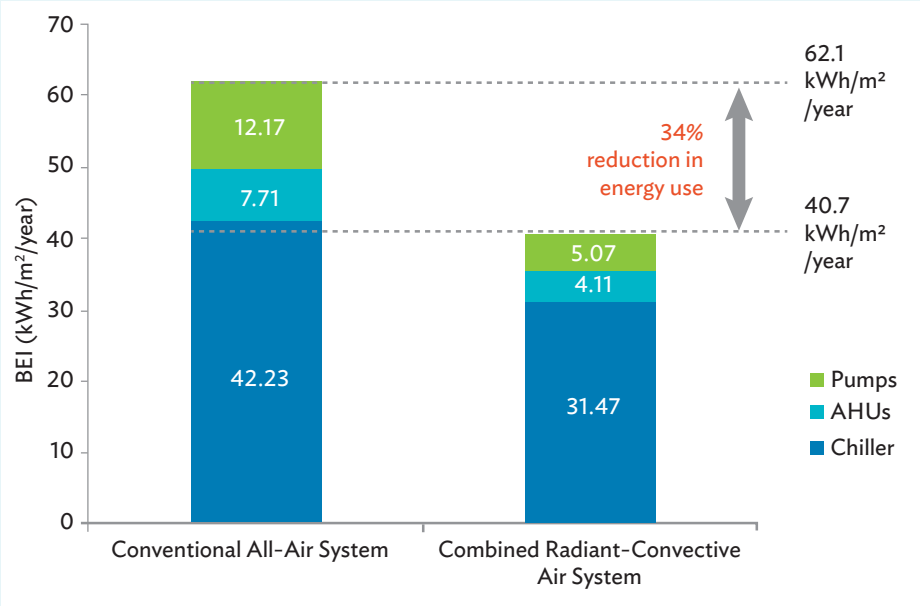
Energy Performance

The energy consumption pattern of the system was studied using the operation data collected from the building energy management system. For comparison purposes, a reference conventional air-conditioning system, which was an all-air variable air volume system, was designed for the same building, using the simulation software eQuest. The simulated energy consumption of the reference system was then compared with the actual performance data of the radiant slab cooling system. Results showed that the radiant cooling system consumed 34% less energy per m^2 per year than the conventional system (Box Figure 15.2), leading to a substantially lower yearly electricity bill (Box Table 15.1).

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Box 15 *continued*

Box Figure 15.2: Comparison of Building Energy Index* Between the Radiant Slab Cooling System and the Conventional System



AHU = air-handling unit, BEI = building energy intensity, kWh = kilowatt-hour, m^2 = square meter.
*(kWh/m^2/year).
Source: Kwong, Q.J. et al. 2017. Evaluation of Energy Conservation Potential and Complete Cost-Benefit Analysis of the Slab-Integrated Radiant Cooling System: A Malaysian Case Study. Energy and Buildings. 138. pp. 165–174.

Box Table 15.1: Comparison of Electricity Usage and Bill Between the Radiant Slab Cooling System and the Conventional System

Details	Radiant cooling	Conventional system
BEI (kWh/m^2/year)	40.7	62.1
Operating hour (hour/day)	10	10
Monthly usage (kWh/month)	51,638.13	78,789.38
Tariff rates (RM/kWh)	0.192	0.312
Monthly bill (RM)	9,914.21	24,582.29
Yearly bill (RM)	118,974.25	294,987.48

BEI = building energy intensity, kWh = kilowatt-hour, m^2 = square meter, RM = Malaysian ringgit.

Cost–Benefit Analysis

The total costs for the radiant slab cooling system (together with the integrated air-side system) and the conventional variable air volume system of similar cooling capacity were calculated based on the price quotations and service contract agreements obtained from several internationally renowned air-conditioning product manufacturers and service providers. As shown in Box Table 15.2, while the radiant system had a higher initial cost than the conventional system, its annual operating cost was significantly lower. This led to a lower total cost over the 20-year operational lifespan. The system cost per m^2 per year of the radiant cooling system was approximately 79% of the conventional system. The simple payback period of the radiant cooling system was as short as 2.5 years.

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Box 15 *continued*

Box Table 15.2: Cost-Benefit Analysis of the Radiant Slab Cooling System and the Conventional System

Description	Radiant slab cooling system (RM)	Conventional variable-air-volume system (RM)
Initial cost		
Water-cooled chiller	509,000	674,100
Pumps (cooling water + chilled water)	80,000	80,000
Air-handling units (AHUs)	208,800	744,000
Cooling tower	108,000	126,000
Ductwork	510,500	947,610
Direct digital control	600,000	800,000
Cooling water pump and chilled water pump pipes	20,995	80,844
Slab-integrated pipes and accessories	1,858,532	
Building energy management system	300,000	300,000
Miscellaneous	300,000	300,000
Estimated maintenance cost (20 years)		
Scheduled maintenance	2,202,193	2,202,193
Annual preventive service maintenance	575,733	575,733
Service repair cost (20 years)		
Major overhauls (chiller and cooling tower)	165,330	165,330
Bearings, seal, and belting (pumps and AHU)	174,300	174,300
Coil replacement (AHU)	550,000	550,000
Infill replacement (cooling tower)	120,000	120,000
Miscellaneous repair (all equipment)	727,500	727,500
Operating cost (20 years)		
Operating cost	2,379,485	5,901,648
Total cost	11,390,368 ($3,722,342)	14,469,218 ($4,728,503)
Simple payback period (year)	2.52	
Cost/m²/year	RM 37.41 ($12.22)	RM 47.52 ($15.53)

AHU = air-handling unit, m² = square meter, RM = Malaysian ringgit.

Source: Kwong, Q.J. et al. 2017. Evaluation of Energy Conservation Potential and Complete Cost-Benefit Analysis of the Slab-Integrated Radiant Cooling System: A Malaysian Case Study. Energy and Buildings. 138. pp. 165–174.

5 CLEAN HEATING

While many ADB DMCs are geographically located in climate zones that are cooling-dominated or have significant cooling demand during summer, there exists significant heating demand during a year in DMCs in the temperate climate zone, such as Mongolia and the northern PRC in East Asia, and countries in Central and West Asia. For example, Kazakhstan has a heating season lasting more than 6 months, varying from 132 to 231 days per year, with its annual average temperature ranging from 2°C in the north to 13°C in the south. In 2018, 30% of Kazakhstan's households used coal and/or firewood for heating (IEA and EU4Energy 2020). In Mongolia, the share of space heating in the total annual energy consumption of urban households in 2018 was 68% for houses, 75% for *gers* (tents), and 79% for apartments, respectively. Out of Mongolia's total households, 70% used stoves, and 27.5 had access to district heating. The rest used low-pressure boilers or electric heating systems (Economic Research Institute for ASEAN and East Asia 2021).

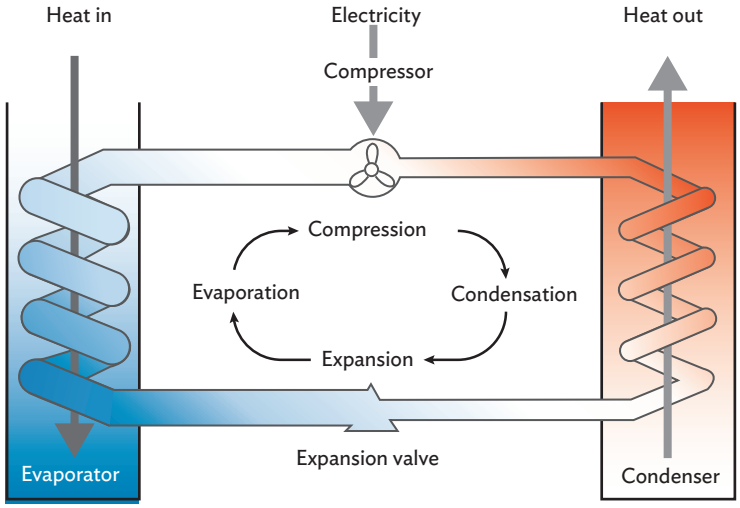
To bring down energy and emission intensities of space and water heating and accelerate low-carbon transformation of the buildings and building construction sector in these countries, it is important to promote and scale up the applications of higher-efficiency heating technologies and renewable energy as a clean heat source. This chapter introduces various heat pump technologies, including air-source and ground-source, and the utilization of solar energy for space heating and hot water, which have high relevance to and immense potential in the aforementioned DMCs.

Heat Pump

A heat pump is a thermal installation that extracts heat from a source at a low temperature to a sink at a high temperature by consuming drive energy. This produces a thermal effect, which can be applied for space heating or cooling for buildings, domestic hot water heating, heating or cooling for industrial processes, etc. This means all cooling and refrigeration equipment, including air-conditioners and chillers with refrigeration cycles, are heat pumps in light of the fundamental principles of their operations. In fact, a heat pump operating in cooling mode is technically an air-conditioning system. However, in the general context of engineering, the term heat pump is usually reserved for installations that produce heat for process or comfort, such as space heating, rather than those removing heat for cooling purposes only. Reversible heat pumps can operate in dual modes to provide both heating and cooling. In this section, unless otherwise specified, heat pump is discussed in the context of space heating and domestic hot water supply.

There are four basic types of heat pump cycles: closed vapor-compression cycle, open vapor recompression cycle, mechanical vapor recompression cycle with heat exchanger, and heat-driven Rankine cycle. Among them, the closed vapor-compression cycle, driven by electricity, is the most used heat pump cycle for HVAC applications and industrial processes. It uses a conventional, separate refrigeration cycle consisting of an evaporator, a condenser, a compressor, and an expansion valve (Figure 78).

Figure 78: Schematic of Closed Vapor-Compression Cycle of Heat Pump



Source: Heat Pump Association. 2021. The Vapour Compression Cycle.

Various sources can be potentially used as the heat source and sink for a heat pump application, depending upon the climatic condition, geographical location, availability, cost, and type of structure. The main sources are air, water, and the ground. Outdoor air is a universal heat source and sink medium for heat pumps, and is widely used in residential and commercial systems. Exhaust air from ventilation can also be used as a heat source, but it is often insufficient for typical loads and therefore needs supplemental heat. Water from various sources can be used for heat pumps. A good option is groundwater, which has a relatively high and nearly constant temperature. Surface water such as rivers, lakes, open ponds, and so on can also be used, although there is a risk of freeze-up due to the temperature drop across the evaporator during winter. Sewage often has temperatures higher than those of surface water or groundwater and may be an acceptable heat source. Another possibility is wastewater from industrial processes. The ground is used extensively as a heat source and sink. Soil composition and moisture content have a significant effect on thermal properties and heat transfer performance.

Usually, the heat source and the heating and cooling distribution fluid are used as the basis for the classification of heat pumps. Thus, a heat pump can be designated as an air-to-air, air-to-water, water-to-air, or water-to-water heat pump. Alternatively, based on the "system" (air, water, ground) into which a heat pump is installed, a heat pump can be designated as an air-source, water-source, or GSHP. Since groundwater and surface water are more commonly used than sewage or wastewater for space heating and cooling applications, sometimes they are considered as a subset of the general GSHPs in this context. For the specific type of GSHPs that transfer heat from soil through vertical boreholes or horizontal trenches, rather than through groundwater or surface water, it is often referred to as a "ground-coupled" heat pump.

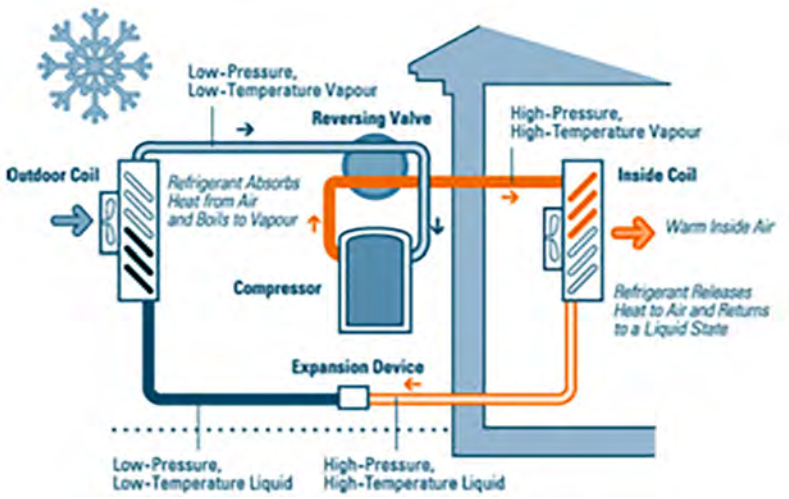
Air-Source Heat Pumps

Air-to-Air Heat Pumps

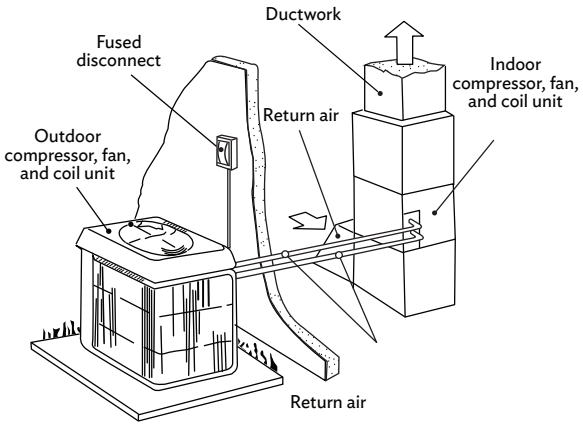
Air-to-air heat pumps are the most common type, which is particularly suitable for factory-built unitary heat pumps. This type of heat pump is widely used in residential and commercial applications. Multiunit and multi-split system installations are particularly advantageous as they allow zoning and, therefore, heating (or cooling) in different

zones on demand. A typical air-to-air heat pump has a full-hermetic compressor, finned heat exchangers for the evaporator and condenser, and an expansion valve. They normally operate in dual modes, i.e., heating and cooling. Under heating mode, the outdoor fan coil unit extracts heat from outdoor air and transfers it, via the refrigerant loop, to indoor space through the indoor fan coil (Figure 79). As the outdoor air temperature decreases, the indoor heat demand increases, and the capacity of the system decreases accordingly.

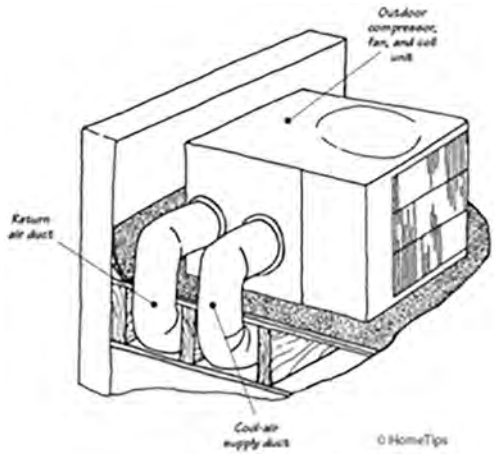
Figure 79: Air-to-Air Heat Pump: (a) Air-to-Air Heat Pump Cycle; (b) Split Stem; (c) Package System



(a)



(b)



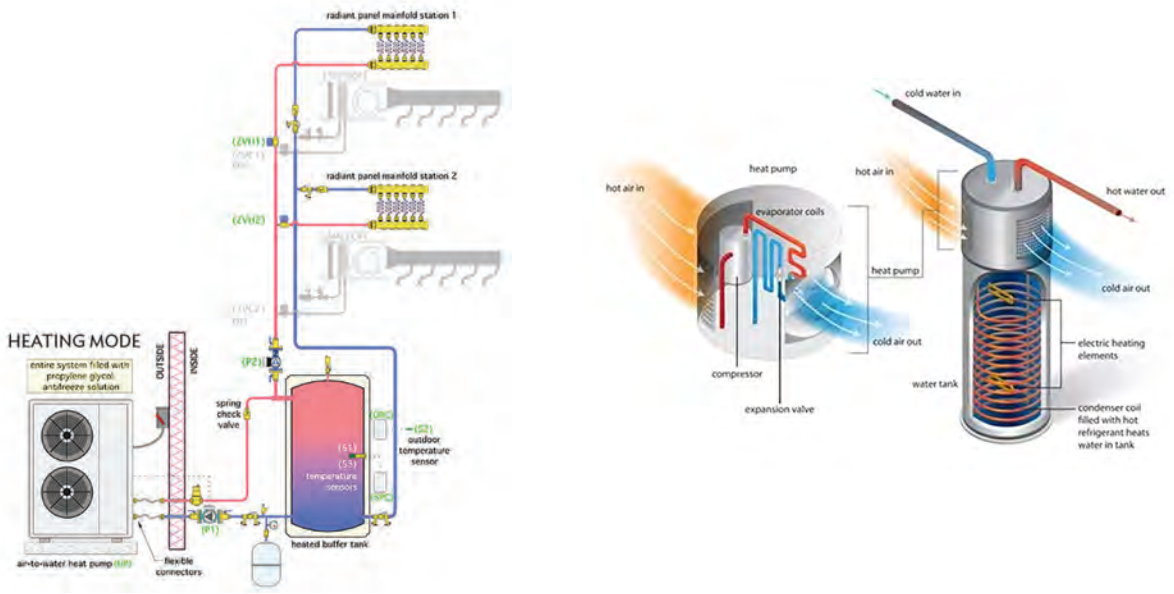
(c)

Sources: Science Learning Hub. 2014. Heat Pumps and Energy Transfer; Vandervort, D. 2020. How a Heat Pump Works.

Air-to-Water Heat Pumps

Air-to-water heat pumps use outdoor air as their heat source and are mostly operated in bivalent heating systems (either parallel or alternate), as well as for cooling, heat recovery, and domestic hot water production. The indoor unit contains most of the components and is connected to the outdoor unit via refrigeration lines. In some tropical climates, the sensible and latent heat in ambient air can be used to heat water economically where power systems are costly and local natural gas is scarce, e.g., in small island countries. Thus, air-to-water heat pumps are also sometimes called heat pump water heaters (Figure 80).

Figure 80: (a) Air-to-Water Heat Pump Providing Zoned Heating; and (b) Heat Pump Water Heater

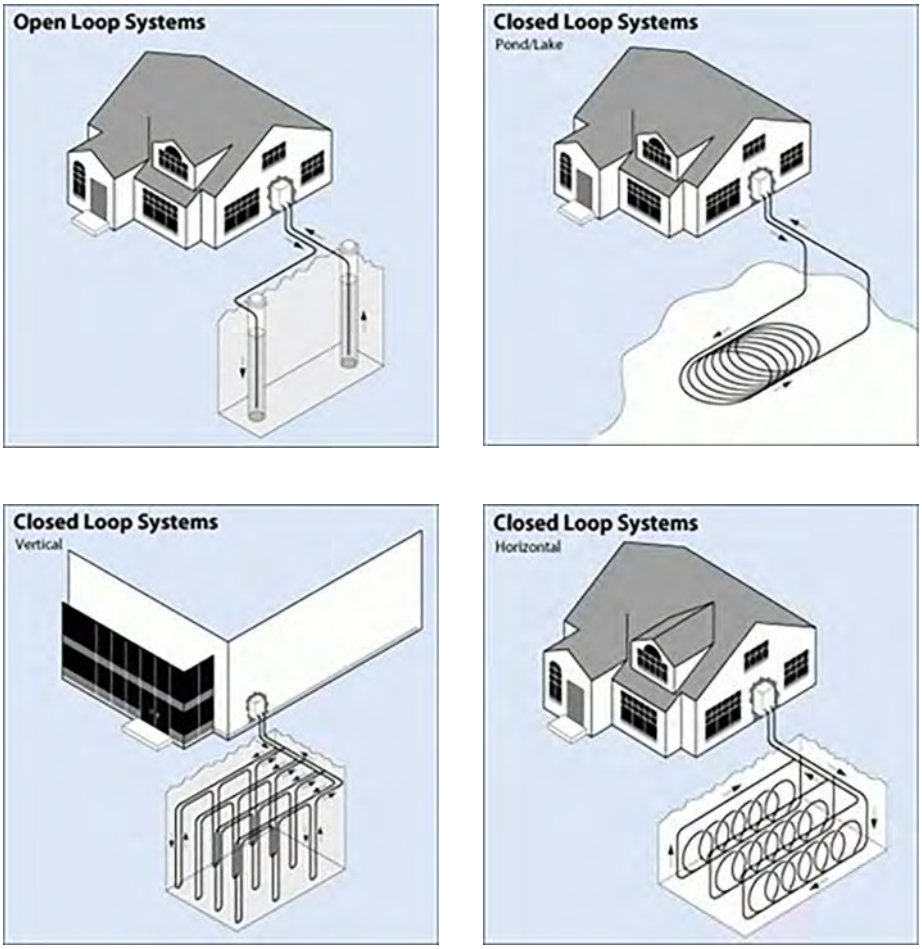


Sources: Siegenthaler, J. 2018. A Look at Air-to-Water Heat Pump Systems; Energy Star. 2021. How it Works—Heat Pump Water Heaters (HPWHs).

Ground-Source Heat Pumps

Ground-source heat pumps comprise a wide variety of configurations that can use ground, groundwater, or surface water as the heat source or sink (Figure 81). A typical ground-source heat pump is composed of three loops, or subsystems, i.e., a ground connection subsystem, a heat pump subsystem, and a distribution subsystem for space heating, hot water, or cooling. The performance of a ground-source heat pump is usually good when it is in heating mode and optimized to operate at a lower water temperature than radiator, radiant floor, or radiant wall systems. A ground-source heat pump tends to be more cost-effective than conventional systems when: (i) the heat pump is for new construction where the installation and connection are relatively easy to complete, or for replacing an existing heating system reaching the end of its operational lifetime; (ii) the heat pump is operated in climatic conditions characterized by cold winter and hot summer, or geographical locations where natural gas has limited availability and/or a cost higher than electricity.

Figure 81: Various Types of Ground-Source Heat Pumps



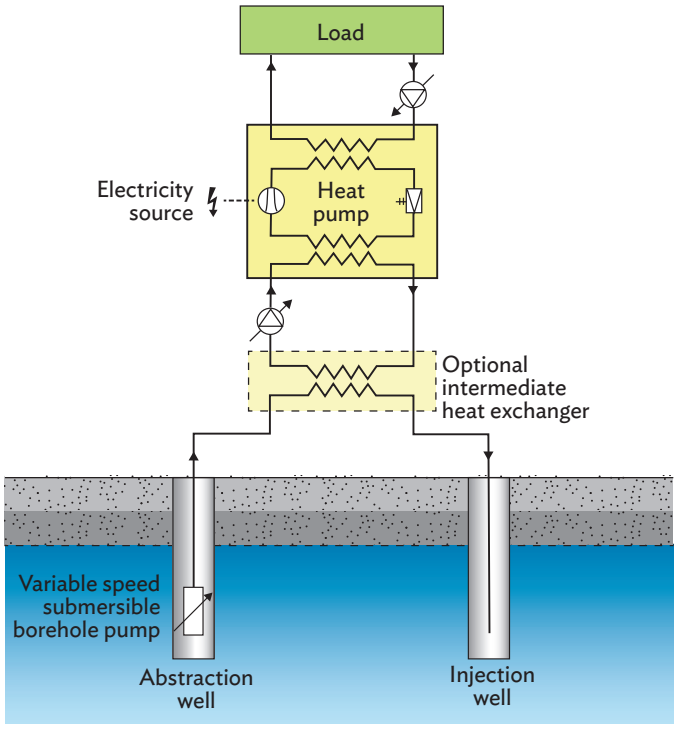
Source: Government of the United States, Department of Energy, Office of Energy Saver. 2021b. Geothermal Heat Pumps.

Groundwater Heat Pumps

Groundwater heat pumps use groundwater from wells as a heat source and/or sink. They can either circulate source water directly to the heat pump or use an intermediate fluid in a closed loop. After it has circulated through the system, the water is either reinjected into the ground through a reinjection well or discharged to a surface system such as a river, lake, or drain (Figure 82). This system can be designed as either a unitary type or a central plant. For the unitary type, a large number of small water-to-air heat pumps are distributed throughout a building. For the central plant, one or a small number of large-capacity chillers are used to supply hot or chilled water to a two- or four-pipe distribution system. The unitary design is more commonly used and more energy-efficient.

Compared with other ground-source heat pumps, groundwater heat pumps have the advantages of a low initial cost and a minimal requirement for ground surface area. However, some key operational factors, such as the limited availability of groundwater resources and the high maintenance cost due to fouling corrosion in pipes and equipment seriously restrict the wide application of these systems. Limited availability of groundwater resources means this type of heat pump is only practical in locations where there is an adequate supply of relatively clean water and the relevant regulations about groundwater utilization and discharge are fully complied with. High maintenance costs due to corrosion issues may be addressed through the installation of an intermediate plate-type heat exchanger to protect the heat pump unit. This issue is site-specific and should be evaluated in a local context.

Figure 82: Schematic of Groundwater Heat Pump



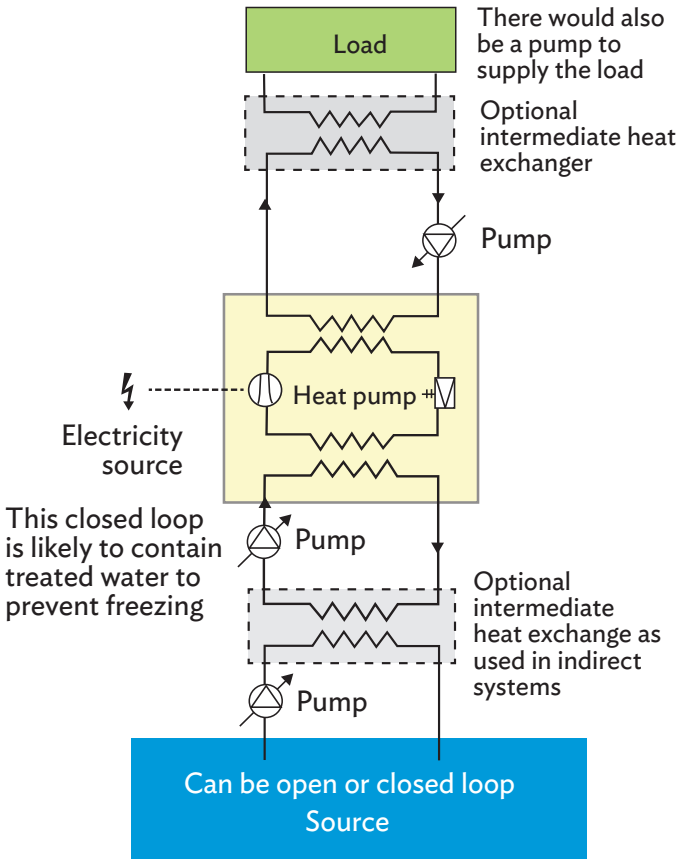
Source: CIBSE. 2019. Opening the Loop – CP3 Guide.

Surface Water Heat Pumps

Surface water can be a good heat source and sink if used properly. Surface water heat pumps can be either closed-loop systems, similar to ground-coupled heat pumps (discussed in the following section), or open-loop systems, similar to typical groundwater heat pumps. For open-loop systems, surface water from a nearby lake, pond, reservoir, or stream is pumped to the heat pump for heat exchange (Figure 83). The heat pump itself can be of either the water-to-air or water-to-water type. After passing through the heat pump, the water is returned to the source or a drain, with its temperature several degrees higher or lower, depending upon the operating mode of the heat pump. Closed-loop systems use a closed loop of working fluid (water or a water-antifreeze solution) that includes pipes or tubing submerged in the surface water (lake, river, large pond, or other open body of water). Usually, the pipes are made of high-density polyethylene (HDPE). A pump circulates the water or water-antifreeze solution through the heat pump water-to-refrigerant heat exchanger and the submerged piping loop for transferring heat from or to the body of water, depending upon the operating mode.

Compared to typical groundwater or ground-coupled heat pump systems, closed-loop surface water heat pumps can cost less due to reduced excavation costs. These systems have reduced pumping energy and operating costs, along with low maintenance requirements. However, there is the possibility of coil damage in public bodies of water. Also, the performance of systems using small and shallow bodies of water tends to vary substantially as a result of the wide fluctuation in water temperature. Thus, when designing a system, it is important to duly consider the adequacy of the total thermal capacity of the body of water under different weather conditions.

Figure 83: Schematic of Surface Water Heat Pump



Source: CIBSE. 2020. Ensuring Robust Selection and Design of Surface Water Source Heat Pump Systems.

Ground-Coupled Heat Pumps

The ground can serve as an ideal heat source and sink. For ground-coupled heat pumps, a closed pipework loop is buried in the ground, either vertically via boreholes or horizontally via coiled or straight pipes in trenches. This creates a ground heat exchanger (GHE). The working fluid, e.g., water or water-antifreeze solution, is pumped through this GHE to extract heat from the earth, which is then transferred to the heat pump evaporator (under heating mode), or to reject heat to the earth, which is received from the heat pump condenser (under cooling mode). The massive thermal capacity of the earth provides a temperature-stabilizing effect on the circulating working fluid. Soil type, moisture content, composition, density, and uniformity close to the surrounding field areas affect the heat exchange performance. With some piping materials, the material of construction for the pipe and the corrosiveness of the local soil and underground water may affect the heat transfer and service life.

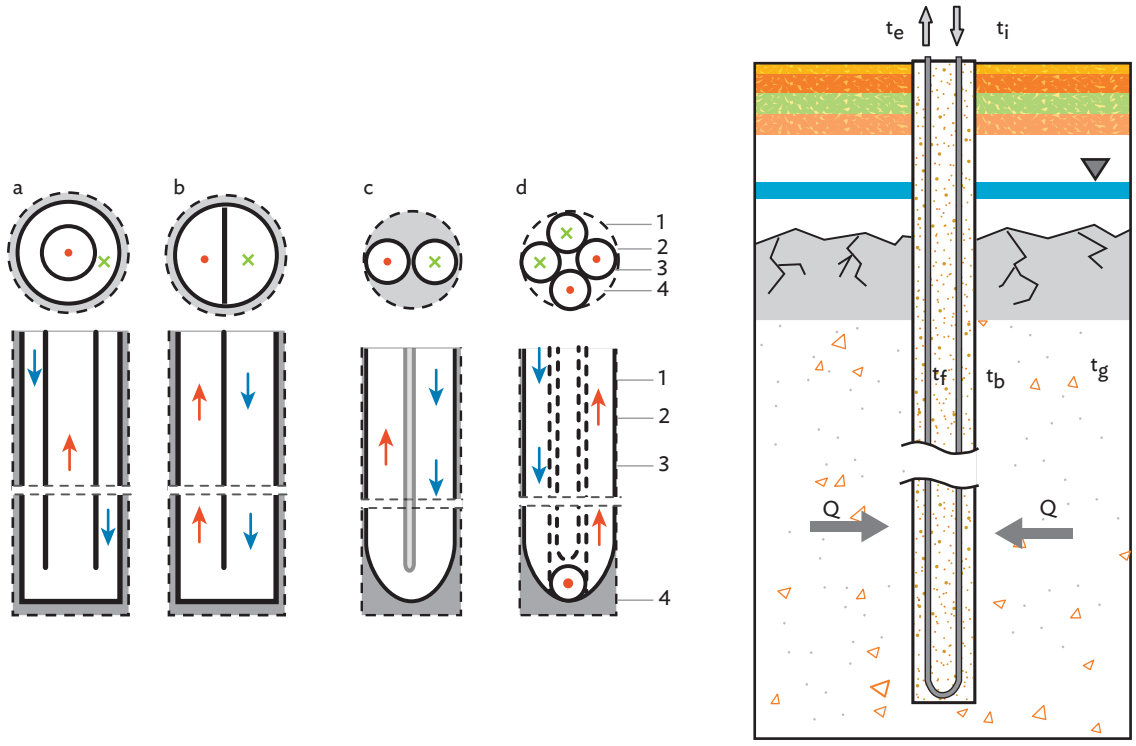
Vertical Ground Heat Exchanger

A vertical GHE consists of one or more vertical boreholes down which a HDPE pipe loop is placed. The borehole is backfilled with a solid medium, either sand or a high-heat transfer material commonly referred to as grout. The individual vertical loops are then joined together to form one or more circuits to be connected to the heat pump. The depth of boreholes varies, as a function of the required energy output, geological conditions, and the space

availability. In general, vertical boreholes are suitable for applications that require the installation of sufficient heat exchange capacity under a confined surface area, such as a limited land area, an existing landscape to which disturbance needs to be minimized, or rocky earth close to the surface.

The HDPE pipe loop in a borehole can take two forms of configuration, namely U-tube and coaxial tube. The U-tube configuration can be single- or double-pipe, whereas the coaxial tube can either use a simple configuration of two straight pipes of different diameters or use more complex configurations (Figure 84).

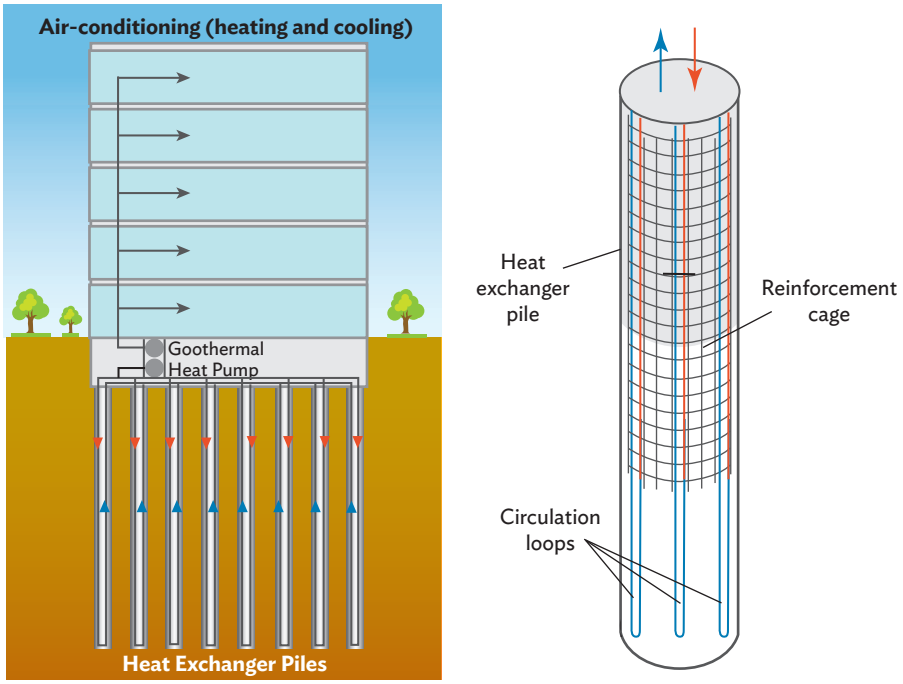
Figure 84: (a) Vertical Borehole Pipe Loop Designs; (b) Vertical Grouted Borehole



Sources: Hanson, P. 2019. Vacuum Insulated Tubing for Deep Borehole Heat Exchangers; Sarbu, I. and C. Sebarchievici. 2017a. Solar-Assisted Heat Pumps. In I. Sarbu and C. Sebarchievici, eds. *Solar Heating and Cooling Systems – Fundamentals, Experiments and Applications*. Academic Press.

A specific configuration of vertical GHE is to integrate the HDPE pipes into the structural foundation piles of the building (Figure 85). The pipes are attached to a reinforcing bar or cage and then placed into the foundation bore before concrete is poured. This method has the benefit of saving the cost and time required for drilling dedicated boreholes and installing conventional vertical loops. The limitation, however, is that its energy output may be limited because foundation piles do not normally go as deep as dedicated vertical boreholes for heat pumps.

Figure 85: Ground-Coupled Heat Pump Using Energy Piles



Source: Olgun, C.G. et al. 2015. Long-Term Performance of Heat Exchanger Piles. *Acta Geotechnica*. 10 (5). pp. 553–569.

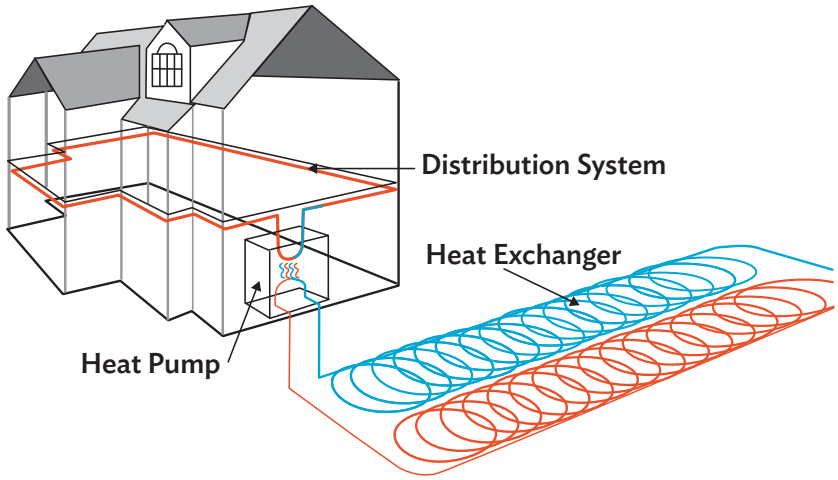
In general, apart from the advantage of requiring a relatively small ground area, ground-coupled heat pumps using vertical boreholes can achieve a high efficiency of operation thanks to reduced variability in soil temperature and thermal properties. They require a reduced amount of piping and associated pumping energy. However, a key disadvantage is the high cost incurred by drilling the vertical boreholes.

Horizontal Ground Heat Exchanger

Compared to vertical GHEs, horizontal GHEs generally require much more ground area. However, they offer the benefits of installation simplicity and reduced installation costs. Typical configurations include single-pipe, multiple-pipe, and stretched coil (also called spiral slinky) (Figure 86). A single-pipe horizontal GHE consists of a series of parallel pipe arrangements laid out in trenches. It requires more ground area than multiple-pipe and stretched coil. A multiple-pipe configuration usually places two to six pipes in a single trench. This reduces the required ground area, but the total pipe length needs to be increased to overcome the interference from adjacent pipes. The stretched coil configuration consists of pipes unrolled in circular loops in trenches with a horizontal configuration. This can reduce the required ground area substantially. However, sometimes trench lengths may have to be increased for greater thermal performance.

In general, the installation of horizontal ground loops is the easiest for the construction of new buildings. Retrofitting is also feasible and is becoming easier with technological advances. Digging technologies allow drilling horizontal boreholes and thus make possible the installation of these systems into existing buildings with limited disturbance of the topsoil. Options for installing the loops under existing buildings, car parks, or driveways are all possible. However, a disadvantage of horizontal loops is their operation at a reduced efficiency due to their proximity to the ground surface and consequent susceptibility to seasonal soil properties and air temperature fluctuations. The higher pumping energy requirements also affect the efficiency level. For horizontal loops operating in heating-only mode, the main way of thermally recharging the ground is through solar radiation. Therefore, it is necessary to ensure the surface above the loops is not covered.

Figure 86: Horizontal Spiral Slinky Heat Exchanger



Source: Gibson, S. 2016. Is This Ground-Source Heat Pump Plan Workable?

Box 16: Case Study of Ground-Source Heat Pump for Space Heating

Beijing's First Ground-Source Heat Pump Project—Linked Hybrid MOMA

Beijing Linked Hybrid MOMA is in the Dongcheng District and has a total construction area of 220,000 square meters, comprising apartments, commercial areas, parking, hotels, cinemas, and educational facilities. This mega-scale complex, connected by steel-structured corridors, adopted a ceiling radiant cooling and heating system and displacement ventilation system, coupled with the largest ground-source heat pump system in the world at the time. Approximately 70% of the complex's annual heating and cooling load is handled by this ground-source heat pump system, which consists of 655 vertical ground tube heat exchangers with a depth of 100 meters below the basement foundation. The system received the 2006 American Popular Science Engineering Award for the largest geothermal housing complex.

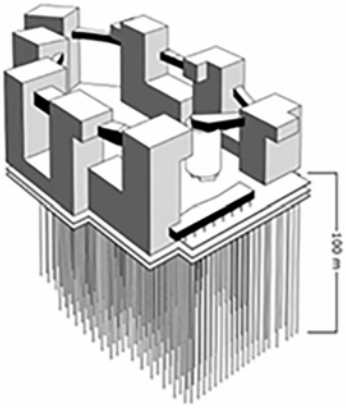


Beijing's Linked Hybrid MOMA and its buried pipes of ground-source heat pump system.

continued on next page

Box 16 *continued*





Sources: Cucchiaro, R. 2011. Beijing's Linked Hybrid: one of the largest geothermal cooling and heating systems in the world; Song, C. et al. 2021. Application and Development of Ground Source Heat Pump Technology in China. *Protection and Control of Modern Power Systems*. 6.

Solar Space Heating

Solar space heating refers to the utilization of solar energy to meet the heating demands of conditioned spaces. In general, solar space-heating systems can be broadly classified into active and passive ones. Active systems use active mechanical and electrical devices to transfer heat from solar collectors. In passive systems, building structure components like the facade or roof are used to absorb and store solar radiation energy, which is then transferred to indoor spaces to meet heating demand.

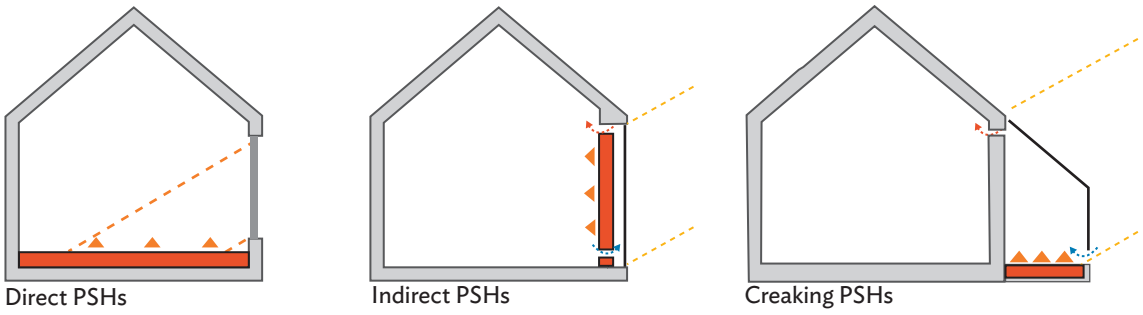
Passive Solar Space Heating

The architectural design of buildings is at the heart of passive solar space-heating systems. Construction, morphology, and internal environmental and thermal comfort requirements are key factors to be considered. The form and orientation of a building are closely related to the building's exposure to thermal stress, therefore having a fundamental impact on the extent to which solar heat gains result in thermal comfort (or discomfort). Ideally, an optimal form should be able to collect most of the available solar radiation during the heating season while rejecting most of it during the other seasons. Under temperate climatic conditions, a building form that is elongated along the east–west direction is preferred, as it maximizes solar heat gains from the south during winter and limits solar heat gains from the east and west when being close to the horizon during summer. Under hot arid climatic conditions, given the thermal stress due to indoor–outdoor air temperature differences, compact building forms should be the option to limit heat transfer through the building envelope.

The amount of solar radiation absorbed within the building form depends on building envelope characteristics. These may include the glazed areas, overall transmittance, shading devices, insulated shutters, solar reflectors, etc. The heat capacity of a building determines its ability to store the absorbed solar energy before releasing it. To ensure that the heat gains will not result in large temperature fluctuations and thermal discomfort, it is important to balance the design of solar capture and regulating devices (windows, clerestories, skylights, shading devices, reflectors, shutters), heat storage (dark surface, thermal mass, phase-change materials), and heat distribution (conduction, convection, and irradiation).

Based on the design and operation of solar capture and heat storage in a building, passive solar space heating can be broadly classified into direct, indirect, and isolated systems, through which the heat is stored directly inside, in-between, or outside the heated space (Figure 87).

Figure 87: Passive Solar Space-Heating System—(a) Direct; (b) Indirect; (c) Isolated



PSHs = passive solar houses.

Source: Finocchiaro, L., L. Georges, and A.G. Hestnes. 2016. Passive Solar Space Heating. In R.Z. Wang and T.S. Ge, eds. *Advances in Solar Heating and Cooling*. Elsevier Science. pp. 95–116.

Direct Systems

As the simplest passive solar space-heating system, a direct system typically has the highest percentage of the total heating load met by solar energy. Through the solar capture and heat storage components of the building, the solar radiation is admitted and stored directly into the heated space. The heat storage thermal mass absorbs and detains the heat when the room temperature remains high. When there is no sunshine and the room temperature drops, the thermal mass slowly releases the heat due to thermal losses and reduced internal heat gains from occupants and equipment. In this system, the choice of thermal mass materials needs to take into consideration the climatic conditions and environmental space requirements. The solar capture components need to be appropriately sized to ensure that the admitted solar heat can be stored within the space and temperature fluctuations can be stabilized within the comfort zone.

Indirect Systems

Indirect passive solar space-heating systems are characterized by a heat storage mass placed in-between the solar capture components (e.g., glazed areas) and the space to be heated. Solar energy is indirectly transferred into the space through irradiation. Compared with direct systems, indirect systems have much lower risks of overheating.

A typical example of an indirect system is a Trombe wall, which is a combination of a dark masonry wall (often made of bricks, stone, or concrete) and a glazed area, with a narrow air cavity in between (Figure 88). Solar radiation passing through the glass is absorbed by the wall and then slowly released into the heated space. As direct solar radiation has a shorter wavelength, it is easily conducted through glass. The re-emitted heat from the wall takes the form of longer-wavelength radiation, which cannot pass through glass as easily as short-wavelength radiation. As a result, heat is trapped in the air cavity, allowing the wall to effectively absorb heat while limiting its re-emission into the environment. Since the glass panel is only on the exterior of the wall, heat can be freely transferred into the interior of the space. For a wall made of concrete with a thickness of 20–30 centimeters, this heat transfer process typically takes around 6–8 hours. Daily, this means that the wall absorbs heat during the day and slowly re-emits it into the space at night. Therefore, the need for conventional heating can be effectively reduced.

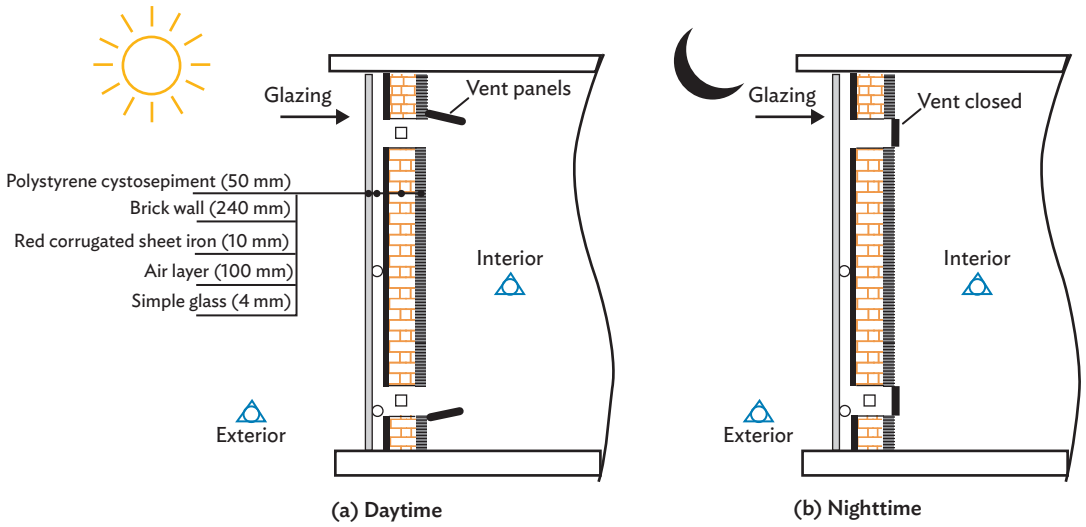
Figure 88: Basic Trombe Wall



Source: Williams, J. 2016. Two Ways to Make a Solar Wall. The Earthbound Report.

Often, the heat transfer through the masonry wall is supplemented with convection. This is realized by placing vents at the bottom and top of the wall (Figure 89). As the air in the cavity is heated, it rises into the top vent, through which it is redirected into the room. At the same time, lower-temperature air from inside the room passes through the lower vent into the cavity, where it is heated and later redirected back into the home through the upper vent. This creates a loop of natural convection. To avoid thermal losses that could reduce the efficiency of the system, or even a reversed heat transfer process in some circumstances, the air vents should be closed during the night when heat stored into the wall can still be slowly released in the space through irradiation.

Figure 89: Schematic of Ventilated Trombe Wall



mm = millimeter.

Source: Sergei, K., C. Shen, and Y. Jiang. 2020. A Review of the Current Work Potential of a Trombe Wall. *Renewable and Sustainable Energy Reviews*. 130.

Isolated Systems

An isolated passive solar space-heating system is attached to the living space. It is typically made of a flat panel placed over a storage thermal mass, such as a rock bed. Heat is transferred into the living space through convection by an air-based siphon system, until an equilibrium in the temperature distribution is reached. A common type of isolated system is a greenhouse, which structurally extends the living space and therefore can be used as a functional space when its environmental condition is reasonably comfortable. A greenhouse serves as a thermal buffer space. Usually, it should be elongated along the south side of the building to maximize thermal exchange with the living space while minimizing exposure to the east and west. Another typical example of isolated systems is the Barra–Costantini wall, which is technically a variant of the Trombe wall. The major variation is the use of an insulation layer placed between the thermal mass wall and the heated indoor space. This setup can better manage system heat losses under cold climatic conditions.

Active Solar Space Heating

Active solar space-heating systems use solar energy to heat a working fluid (liquid or air) in the solar collector loop and then transfer the solar heat to meet the heading load of the interior space, or to a storage tank from which the heat can be kept for later use. The key difference from passive systems is that active systems require continuous electricity to power pumps and fans to keep the system running. Liquid systems are more often used when heat storage is included, and they are well-suited for radiant heating systems and boilers with hot water radiators. They can also be combined with heat pumps for space heating. In some applications where the demand for space heating is large, an auxiliary system is integrated into the solar space-heating system to supply additional heat.

Classification of Solar Space-Heating Systems

In general, there are two loops in an active solar space-heating system, i.e., a solar collector loop in which a working fluid is mechanically circulated, and an indoor space-heating loop in which a heating medium is mechanically circulated. By the type of the working fluid and the heating medium, active systems can be broadly categorized into four types, which have different operational characteristics (Table 10).

Table 10: Types of Active Solar Space-Heating Systems by Working Fluid and Heating Medium

	Solar collector loop	Space-heating loop	Operational characteristics
1	Water or antifreeze solution	Water	Water works better than air as a heat transfer medium due to its higher thermal capacity and heat transfer coefficient. Often, space heating is in the form of radiant floor and/or wall heating. Mainly used for high-latitude countries in cold climates.
2	Water or antifreeze solution	Air	Often, space heating is in the form of traditional air space heating coupled with a ventilation system. Mainly used for low-latitude countries in warm climates.
3	Air	Air	Using air as the heat transfer medium has the benefit of avoiding issues of freezing and boiling in solar collectors, as in the case of using water as the medium. Often solar air collectors are integrated with the building envelope (roof or wall). So, an air-space-heating system is sometimes is considered as a semi-passive one.
4	Air	Water	The air-water combination has a low thermal efficiency. The system requires a high flow of air and a large heat exchange surface area for air to transfer heat to water, thus having energy and noise implications.

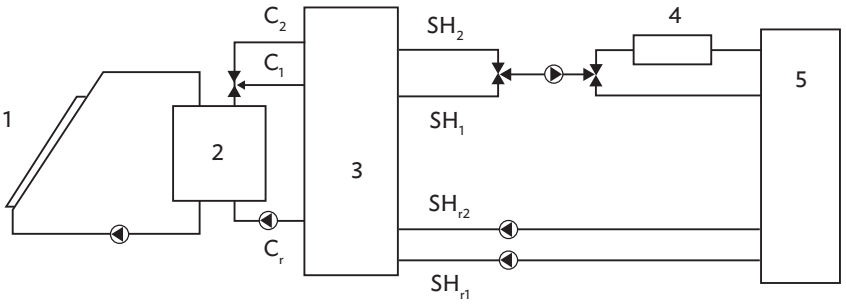
Source: Author.

By the number of energy sources used, active solar space-heating systems can be categorized into monovalent mode, bivalent mode, and multivalent mode. The monovalent mode uses solar energy as the only source of energy. This is a possible option for applications in low-latitude countries where the heating load is relatively low. In these applications, often the active system is integrated with passive solar heating. In bivalent mode, which is the standard operational mode of active solar space-heating systems, usually solar energy and electricity are the two energy sources used. An electric heater can serve as an auxiliary heater when solar energy cannot meet the heating load on its own. Preferably, the electricity is generated by renewable sources. Sometimes the auxiliary heater can be a fossil-fuel fired boiler, or a biomass boiler. When the availability of solar energy is very low, the auxiliary heater can be operated to serve as the primary energy source to supply heat. As for multivalent mode, the system involves the use of three energy sources. This mode is often found in new technologies and applications of space-heating systems aiming for high efficiency and reliability. Here, the priority of utilization of a specific energy source is dynamically dependent upon which energy source is the most operationally and economically efficient for heat production in real time. Apart from solar energy, the other two energy sources are usually electricity and heat generated by fossil fuel-fired or biomass-fired boilers. The complexity of a multivalent mode of operation requires well-planned, effective, and precise control of system components.

Figure 90 presents two standard active solar space-heating systems that use water or antifreeze solution as the solar collector working fluid, i.e., liquid-based systems. Part of each system is a heat exchanger between the solar collector loop and the storage tank. This is because water is used as a storage medium owing to its thermal properties, which

Figure 90: Schematics of Liquid-Based Active Solar Space-Heating Systems— (a) Water or Antifreeze Mixture-Water; (b) Water or Antifreeze Mixture-Air

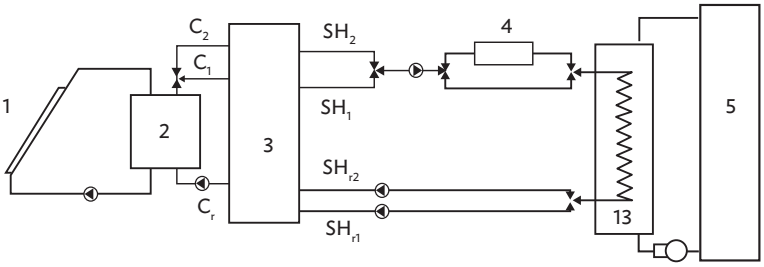
(a)



1 – Liquid solar collectors
2 – Heat exchanger in solar loop
3 – Water storage tank
4 – Auxiliary heater
5 – Space heated by water heating system

$C_{1,2}$ – Supply from collector to storage
C_r – Return from storage to collector
$SH_{1,2}$ – Supply form storage to heating space
$SH_{r1,r2}$ – Return from heating space to storage

(b)



1 – Liquid solar collectors
2 – Heat exchanger in solar loop
3 – Water storage tank
4 – Auxiliary heater
5 – Space heated by water-air heating system

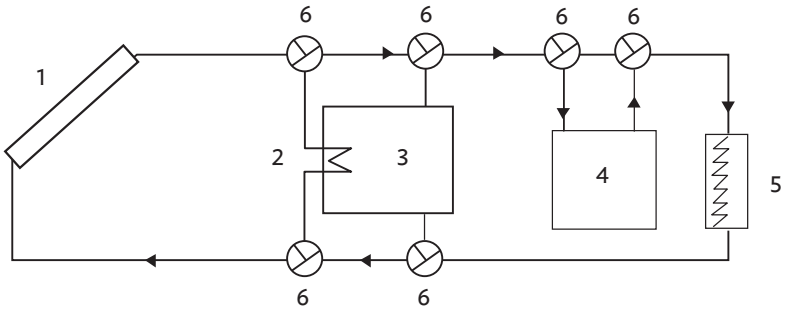
13 – Heat exchanger water-air (space heating system)
$C_{1,2}$ – Supply from collector to storage
C_r – Return from storage to collector
$SH_{1,2}$ – Supply form storage to heating space
$SH_{r1,r2}$ – Return from heating space to storage

Source: Chwieduk, D.A. 2016. Active Solar Space Heating. In R.Z. Wang and T. S. Ge, eds. *Advances in Solar Heating and Cooling.* Elsevier Science. pp. 151–202.

outperform those of the antifreeze mixture. In (a), water is used as the heating medium in the space-heating loop, which often uses radiators or a radiant floor heating system. In (b), the space-heating loop uses air as the heating medium for space heating through ventilation system.

Figure 91 presents an air-based system that uses air as the working medium in the solar collector loop. Air is also used as the heating medium for the space-heating loop.

Figure 91: Schematic of an Air-Based Active Solar Space-Heating System



1 – Air solar collectors
2 – Heat exchanger in solar loop
3 – Pebble bed storage tank
4 – Auxiliary heater
5 – Space heated by air heating system
6 – Three-way dampers

Source: Chwieduk, D.A. 2016. Active Solar Space Heating. In R.Z. Wang and T. S. Ge, eds. *Advances in Solar Heating and Cooling*. Elsevier Science. pp. 151–202.

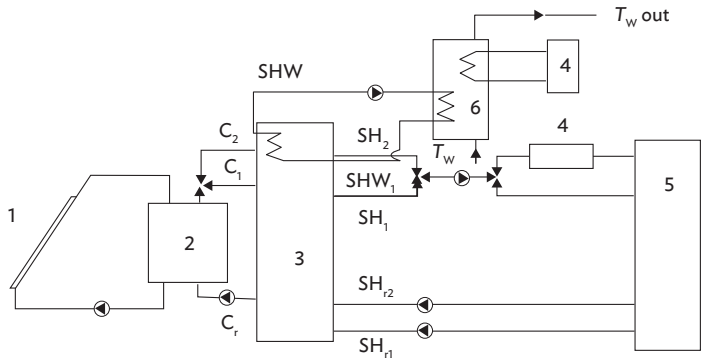
Solar Combi Systems

Solar combi systems provide both space heating and domestic hot water using a common array of solar thermal collectors backed up by an auxiliary non-solar heat source, such as an electric heater, a fossil fuel-fired boiler, or a biomass-fired boiler. The size of solar combi systems can range from small applications for individual properties to large ones serving a large group of buildings as a district heating system. Depending upon system installation, energy demand, and climatic conditions, the annual space heating contribution of a combi system can range from 10% to 60%, or more when the buildings being heated are low-energy buildings. When concentrating solar thermal heat and/or large inter-seasonal thermal storage are used, the contribution can even reach up to 100%.

Solar combi systems are relatively complex in terms of the system structure, configuration, and connections of various components. Compared to basic systems, combi systems require more sophisticated control and regulation of the functioning of all components and their interactions. As combi systems have at least two loops (space heating and domestic hot water), at least two thermal storage tanks are required. So are heat exchangers, which are integral to modern storage tanks. The more complex a system is, the more heat exchangers are required. Storage tanks are the central components that integrate different parts of a combi system. Thus, the design of storage has a fundamental impact on the overall system performance.

A standard active solar combi system is shown in Figure 92. The system uses liquid as the working medium in the solar collector loop, water as the storage medium and working fluid in the domestic hot water loop, and water as the heating medium in the room space heating loop. As there is heat stratification in the storage tank, the tank has various positions of hot water inlets, depending upon the temperature rise of the working medium in the solar collector loop. Likewise, the tank has various positions of hot water outlets to cater to the water temperatures required for domestic water and space-heating applications (floor heating, wall heating, radiators, etc.).

Figure 92: A Standard Active Solar Combi System (Water or Antifreeze Mixture-Water)



1 – Liquid solar collectors
2 – Heat exchanger in solar loop
3 – Water storage tank
4 – Auxiliary heater
5 – Space heated by water heating system

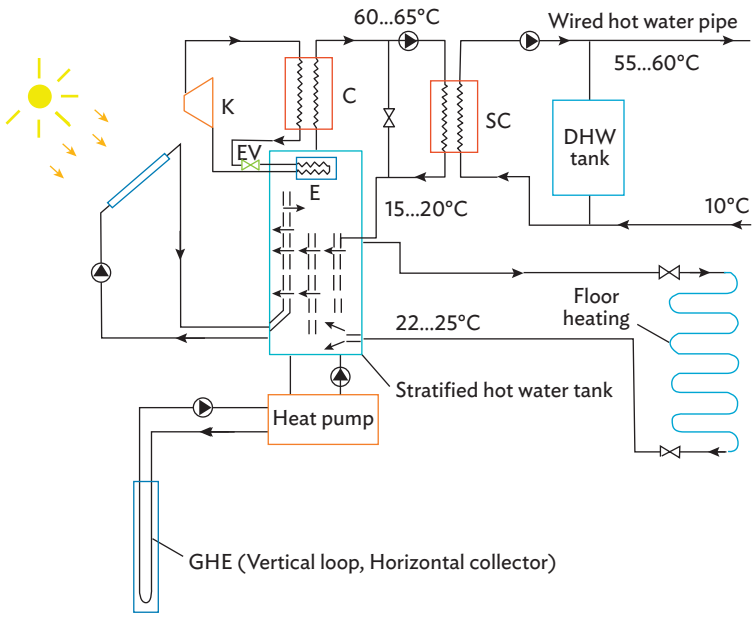
$C_{1,2}$ – Supply from collector to storage
C_r – Return from storage to collector
$SH_{1,2}$ – Supply from storage to heating space
$SH_{r1, r2}$ – Return from heating space to storage
SHW – Supply DHW
SHW_r – Return from DHW

DHW = domestic hot water.

Source: Chwieduk, D.A. 2016. Active Solar Space Heating. In R.Z. Wang and T. S. Ge, eds. *Advances in Solar Heating and Cooling*. Elsevier Science. pp. 151–202.

Figure 93 presents a radiant floor heating system with a vacuum tube solar collector and a groundwater heat pump. The system is operated at water temperatures of 20°C to 30°C. Heat is transferred from the solar collector and heat pump to a stratified hot water tank. Hot water is reheated by an additional heat pump. For a family house with a heat demand of 8 MWh/year, the solar collector can cover approximately 2 MWh/year. The rest is covered by the heat pump, whose electricity consumption is 1.5 MWh/year, reaching a coefficient of performance (COP) of 4.

Figure 93: A Radiant Floor Heating System with Solar Collector and Heat Pump



GHE = ground heat exchanger, EV = expansion value, DHW = domestic hot water, SC = secondary condenser.

Source: Sarbu, I. and C. Sebarchievici. 2015. *Ground-Source Heat Pumps: Fundamentals, Experiments and Applications*. Elsevier.

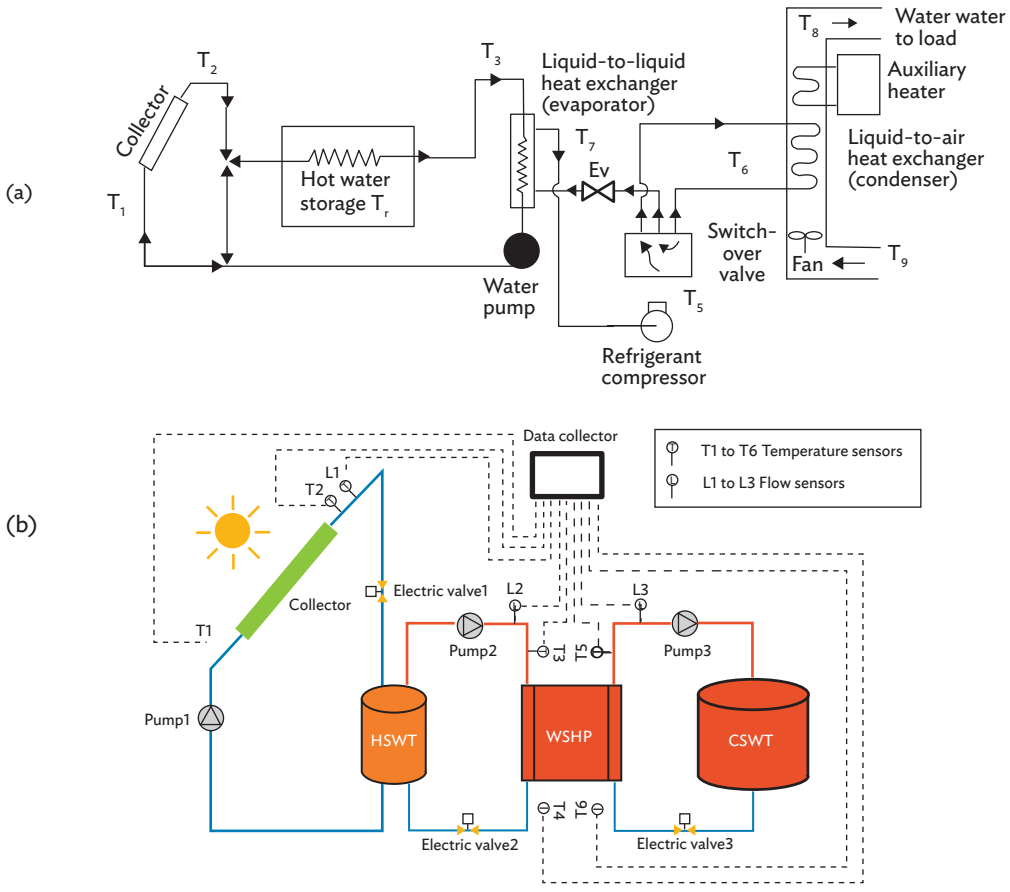
Solar-Assisted Heat Pump

An active solar system can be coupled with a heat pump to supply heat to a building for space heating and domestic hot water provision. The heat pump can achieve a much higher COP when the temperature of the heat source for its evaporator is raised by solar energy. The coupling can take various forms. In general, based on the heat source of the heat pump and the heat pump's connection with the thermal storage unit, solar-assisted heat pump (SAHP) systems can be broadly categorized into three basic configurations, including "series," "parallel," and "dual source."

Series Solar-Assisted Heat Pump System

A solar collector and a heat pump are aligned in series, directly or indirectly, through a storage tank, so that the working fluid heated in the collector loop is used by the evaporator of the heat pump as a heat source. The heat released from the condenser of the heat pump is used for space heating, either through radiant floor heating or a ventilation system. Figure 94 gives two examples of SAHPs with series connections. One is a solar-assisted water-to-air heat pump, and the other is a solar-assisted water-to-water heat pump.

Figure 94: Schematics of Solar-Assisted Heat Pumps with Series Connection—(a) Water-to-Air Heat Pump; (b) Water-to-Water Heat Pump



CSWT = consumer side water tank, HSWT = heat storage water tank, WSHP = water-source heat pump.

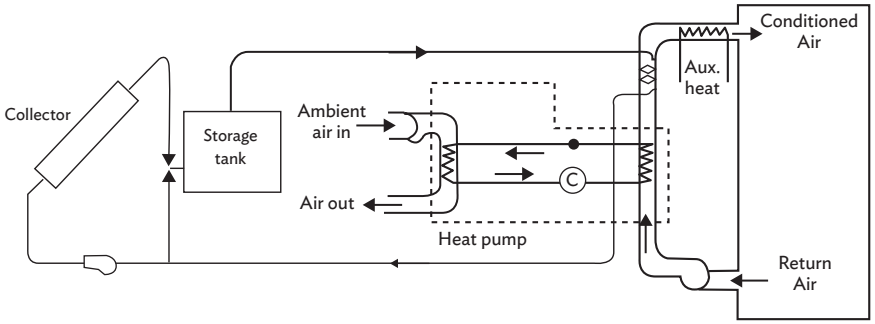
Sources: Kenisarin, M. and K. Mahkamov. 2007. Solar Energy Storage Using Phase Change Materials. *Renewable and Sustainable Energy Reviews*. 11 (9). pp. 1913–1965; Huan, C. et al. 2019. A Performance Comparison of Serial and Parallel Solar-Assisted Heat Pump Heating Systems in Xi'an, China. *Energy Science and Engineering*. 7 (4). pp. 1379–1393.

Parallel Solar-Assisted Heat Pump System

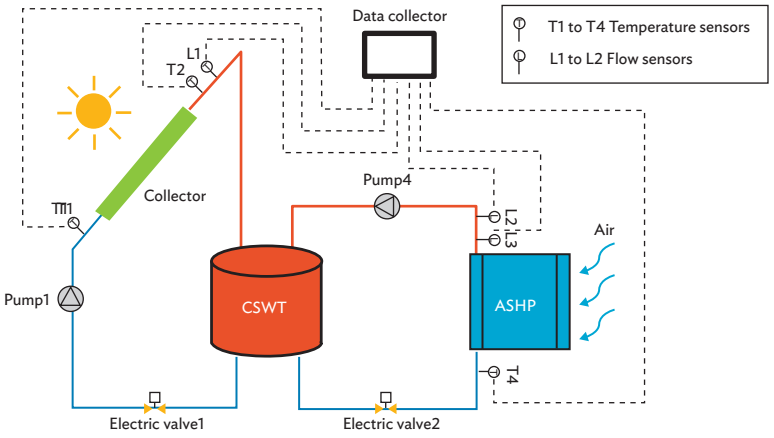
A solar collector and a heat pump are connected in parallel, both providing the space heating directly. The heat pump is "separated" from the solar collector by using a heat source other than solar energy. In other words, the heat pump can be air-source, ground-source, etc. Vice versa, the solar collector loop is independent of the heat pump subsystem. An automatic control system decides the subsystem (solar collector or heat pump) to be operated to deliver the best thermal performance. Figure 95 gives two examples of SAHPs with parallel connections. One is a solar-assisted air-to-air heat pump, and the other is a solar-assisted air-to-water heat pump.

Figure 95: Schematics of Solar-Assisted Heat Pumps with Parallel Connection—(a) Air-to-Air Heat Pump; (b) Air-to-Water Heat Pump

(a)



(b)



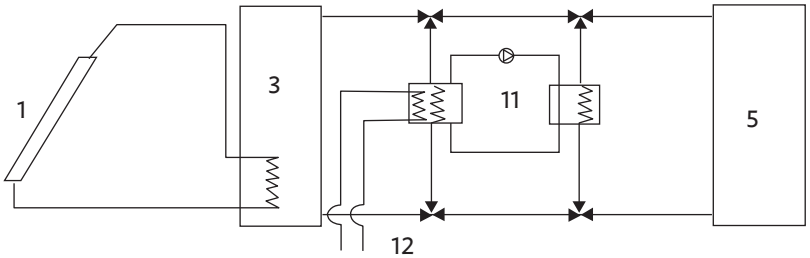
CSWT = consumer side water tank; ASHP = air-source heat pump.

Sources: Kenisarin, M. and K. Mahkamov. 2007. Solar Energy Storage Using Phase Change Materials. *Renewable and Sustainable Energy Reviews*. 11 (9). pp. 1913–1965; Huan, C. et al. 2019. A Performance Comparison of Serial and Parallel Solar-Assisted Heat Pump Heating Systems in Xi'an, China. *Energy Science and Engineering*. 7 (4). pp. 1379–1393..

Dual-Source Solar-Assisted Heat Pump System

A dual-source system can be viewed as a combination of a series system and a parallel system. Solar energy can be used either as the heat source for the heat pump evaporator, or for directly providing heat for space heating. Accordingly, the heat pump can either use the solar energy as a heat source (directly from the solar collector loop or directly through a storage tank) or use an alternative heat source such as air or ground, which is independent of the solar collector loop. The operation of the heat pump is modulated by an automatic control system that dynamically chooses a heat source based on the thermal properties of the two sources (solar and the alternative source), for optimal system performance. Figure 96 shows the schematic of a basic dual-source SAHP.

Figure 96: Schematic of a Basic Dual-Source Solar-Assisted Heat Pump for Space Heating

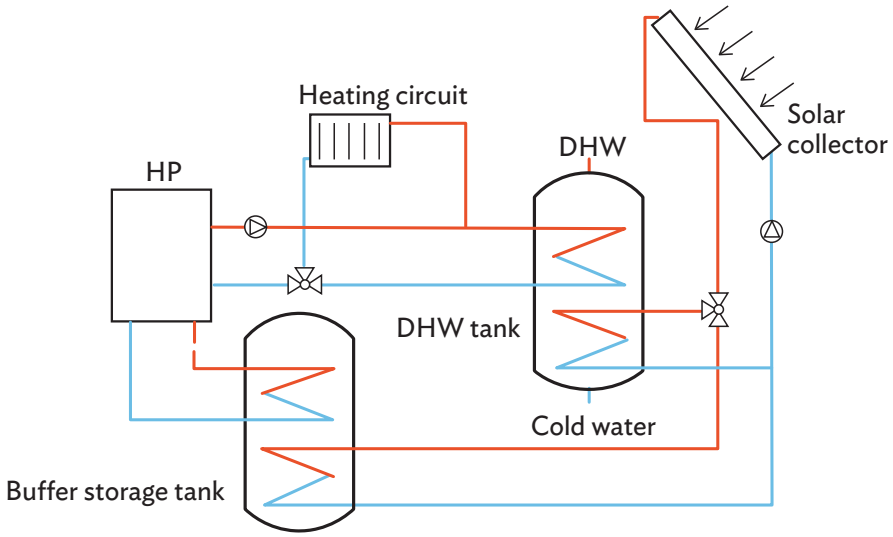


1 – Liquid solar collectors
3 – Water storage tank
5 – Space heated by water heating system
11 – Liquid solar collectors
12 – Water storage tank

Source: Chwieduk, D.A. 2016. Active Solar Space Heating. In R.Z. Wang and T. S. Ge, eds. *Advances in Solar Heating and Cooling*. Elsevier Science. pp. 151–202.

In many applications, the configuration of an SAHP is often different from, and probably more complex than, the typical ones above, i.e., series, parallel, and dual source. A system may not necessarily be classified as belonging to a specific type, but rather a variant, or an upgraded design for better efficiency of operation in specific application circumstances. For example, Figure 97 shows a water-to-water SAHP system for space heating and domestic hot water supply. Water heated by the solar collector is primarily supplied to the domestic hot water tank. When the water temperature in the buffer storage tank (as the heat source for the heat pump) is low, the water heated by the solar collector is fed into the buffer storage tank.

Figure 97: Schematic of a Solar-Assisted Water-to-Water Heat Pump



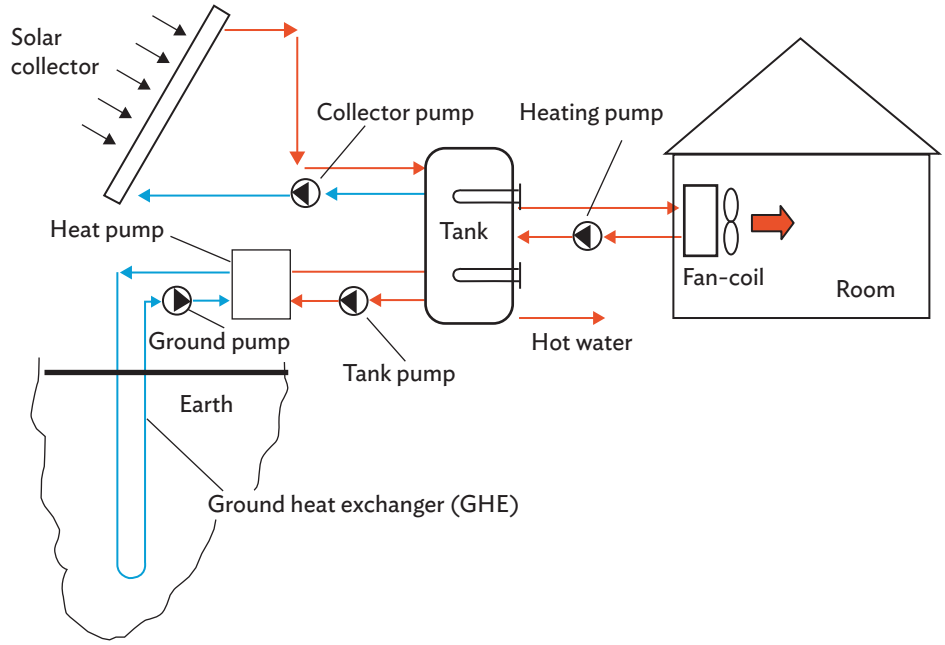
DHW = domestic hot water, HP = heat pump.

Source: Sarbu, I. and C. Sebarchievici. 2017a. Solar-Assisted Heat Pumps. In I. Sarbu and C. Sebarchievici, eds. *Solar Heating and Cooling Systems – Fundamentals, Experiments and Applications*. Academic Press.

With the increasing importance of thermal storage, the heat pump's condenser, instead of its evaporator as in many cases of traditional configurations, is sometimes connected to the thermal storage tank to store the heat produced from the condensation process. As shown in Figure 98, the thermal storage tank is the key component through which the solar collector loop is coupled with the GSHP loop. The condenser of the heat pump is connected to the storage tank to transfer heat to it. This is a variant of the traditional parallel configuration because the two energy sources (two loops) are not independent of each other. They both supply heat to the same storage, which means there is substantial interplay between their respective performances. In a way, the two loops (the solar collector and heat pump), both serving to provide space heating to the building, are complementary to each other. Therefore, the key to system operation control is to ensure efficient utilization of energy from both sources.

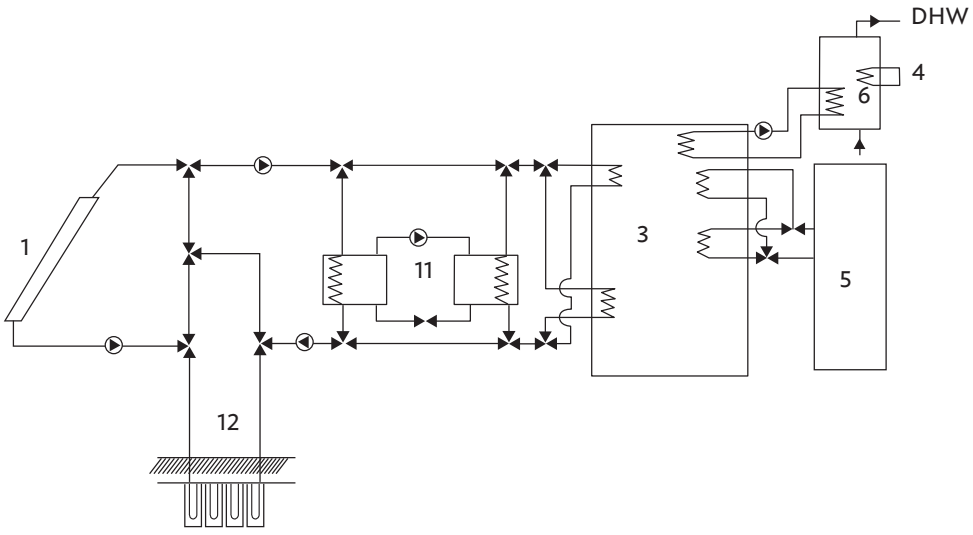
An SAHP system with more modes of operation is shown in Figure 99. The system features the use of an underground heat exchanger, which serves the function of storing extra solar heat during summer and providing space heating during winter. The relatively complex configuration of this system makes possible various closed loops involving the solar collector. The solar collector can supply heat directly to the thermal storage tank. It can also supply heat to the evaporator of the heat pump, which, through its condenser, supplies heat to the storage tank. Either the upper or lower heat exchanger in the storage tank can be used, depending upon the temperature of the working fluid in the loop (the solar collector loop, or the heat pump loop). The solar collector can also be connected to the piping of the vertical GHE loop to store extra solar energy gained during summer. The stored energy can then be extracted and supplied to the evaporator of the heat pump to generate heat for space heating during winter. On the condition that the same working fluid is used in the solar collector loop and the underground heat exchanger, when the working fluid in the solar collector loop has a higher temperature than that in the underground heat exchanger, the system can make the working fluid flow through the underground heat exchangers and the solar collector in sequence so as to gain more heat to raise its temperature before flow into the heat pump evaporator. This way, the working fluid with a higher temperature, used by the heat pump as its heat source, can render a better performance of the heat pump, i.e., a higher COP.

Figure 98: Schematic of a Solar-Assisted Ground-Source Heat Pump



Source: Coskun, S. 2020. Performance analysis of a solar-assisted ground-source heat pump system in climatic conditions of Turkey. *Thermal Science*. 24. pp. 977–989.

Figure 99: Schematic of a Solar-Assisted Heat Pump with Underground Seasonal Thermal Storage



1 – Liquid solar collectors
2 – Water storage tank
4 – Auxiliary heater
5 – Space heated by water heating system
6 – DHW Tank
11 – Heat pump
12 – Ground heat exchangers

DHW = domestic hot water.

Source: Chwieduk, D.A. 2016. Active Solar Space Heating. In R.Z. Wang and T. S. Ge, eds. *Advances in Solar Heating and Cooling*. Elsevier Science. pp. 151–202.

Solar Water Heating

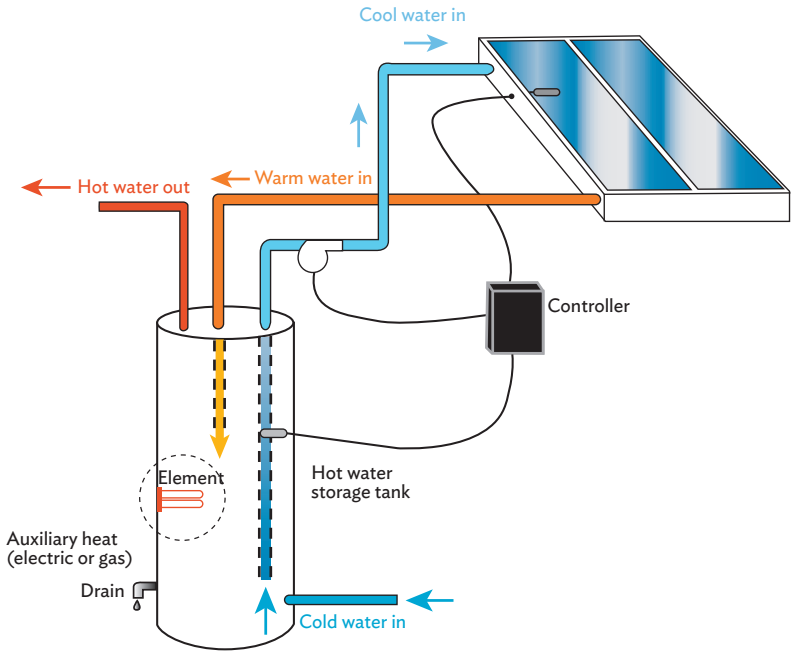
Similar to solar space heating, solar water heating can be broadly classified as passive and active systems. The difference between the two categories is that a passive system transfers heat from a solar collector to a water tank by natural circulation, or thermosiphon, whereas an active system uses an electric pump controlled by temperature sensors and relays, or a differential thermostat. Although passive systems are technologically simple and less costly, active systems have been proven to be more cost-effective and therefore have been gaining popularity in applications. This handbook focuses on active solar water heating systems.

Direct System

Direct systems, also called open-loop systems, use pumps to circulate water through collectors and operate at standard line pressure. These systems are suitable for single applications of domestic hot water supply in areas where the freezing period is short, and the water is not hard or acidic. Owing to their simple design and operation, direct systems cost the least among all active systems. No heat exchangers are used. Water is used as the working fluid and heated within the collector to 50°C–60°C. The simplicity and flexibility of direct systems make easy capacity addition and integration with existing systems possible to meet increased demand for hot water. In general, direct systems can offer higher operating performance than passive systems, which have nighttime heat losses from hot water stored on rooftops, and closed-loop systems, whose efficiency is affected by the heat exchange process.

The major disadvantage of direct systems is their limited freeze protection. A drain-down system is an improved version of direct systems to address this issue (Figure 100). When the risk of freezing is low, an open loop is used where collectors are filled with domestic water under supply pressure. Once the system is filled, a differential controller operates a pump to move water from the tank through collectors. A drain-down valve functions as

Figure 100: Drain Down Solar Water Heating System



Source: In Balance Energy. 2021. Solar Thermal System Design.

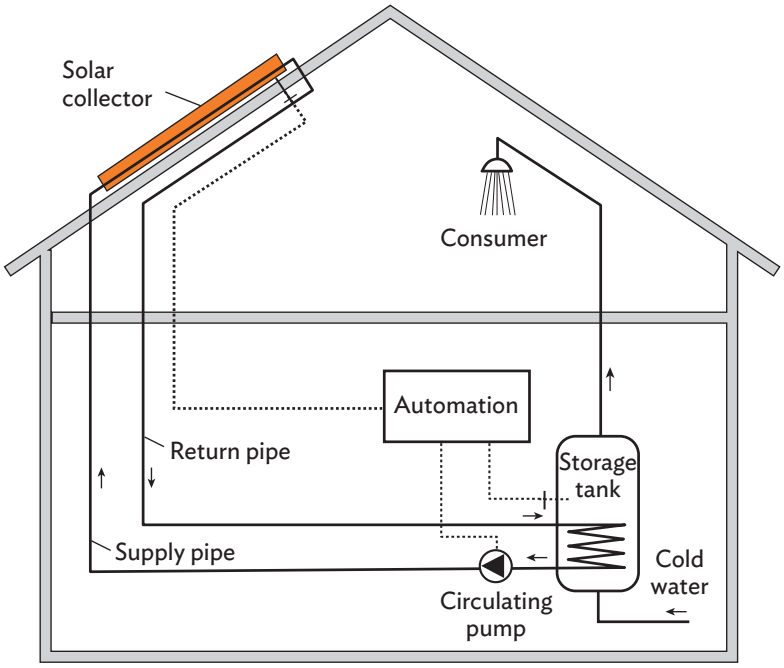
freeze protection. When the drain-down valve is activated by the controller due to the low temperature, it shuts off the water supply to the collector from the tank. The controller simultaneously opens a valve to allow water in the collector to drain away. At the top of the collector, a vacuum breaker is installed to let in air and prevent the backflow of water.

Indirect System

Indirect, closed-loop systems use pumps to circulate the heat transfer fluid through the collectors (Figure 101). Commonly used heat transfer fluids are water and water-antifreeze mixtures (typically propylene glycol). There are two circulation loops in the system: a closed loop of the heat transfer fluid and an open loop of water. The heat transfer fluid circulates within the closed loop and gets heated in the collector. It then transfers the heat through a heat exchanger to the water in the open loop, which flows into the storage tank. The location of the heat exchanger can be either internal or external of the storage tank.

In general, an indirect closed-loop system is more complicated than a direct open-loop system due to the need for a heat exchange. Because of the heat exchanger, the collector loop needs to be pressured and run at slightly higher temperature than a direct open-loop system. With the antifreeze fluid, indirect systems offer the benefit of freeze protection. They can also avoid the risk of overheating which is an issue of direct open-loop systems. Overall, indirect systems are slightly more costly than direct systems. The antifreeze needs to be recharged every 3–5 years, depending on its quality and system operation temperatures.

Figure 101: Indirect Solar Water Heating System



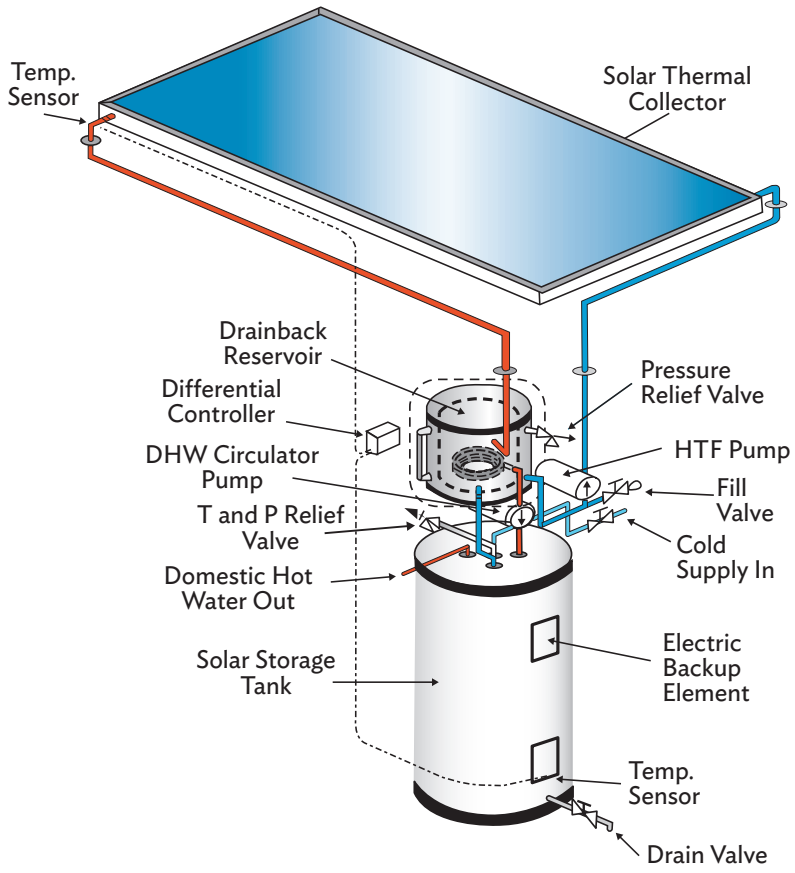
Source: Sarbu, I. and C. Sebarchievici. 2017b. Solar Thermal-Driven Cooling Systems. In I. Sarbu and C. Sebarchievici, eds. *Solar Heating and Cooling Systems – Fundamentals, Experiments and Applications*. Academic Press. pp. 241–313.

Drain-Back System

A drain-back system is a variant of indirect closed-loop systems (Figure 102). It can use water as the heat transfer fluid in the collector loop. This brings the benefit of having no need for recharging, as in the case of systems using antifreeze. A heat exchanger is needed to transfer heat from the water in the collector loop to the domestic water in the open loop. The system features a reservoir tank for the water in the collector loop. When the pump is off, the water in the collector loop drains into the reservoir tank by gravity, thereby avoiding freezing. With temperature monitoring, the system can be turned off when the water in the storage tank is too hot.

A key design consideration of a drain-back system is the appropriate sizing of the reservoir tank, which needs to be large enough to take all the water in the collector and lines when the pump is off. In a pressurized system, the reservoir also serves as an expansion tank, which means it must have a temperature- and pressure-relief valve to protect against excessive pressure. A disadvantage of this system is the heat loss when the pump is off. Also, due to the size of the pump and piping and the requirement for insulation, drain-back systems are normally more expensive than direct open-loop systems.

Figure 102: Drain-Back Solar Water Heating System

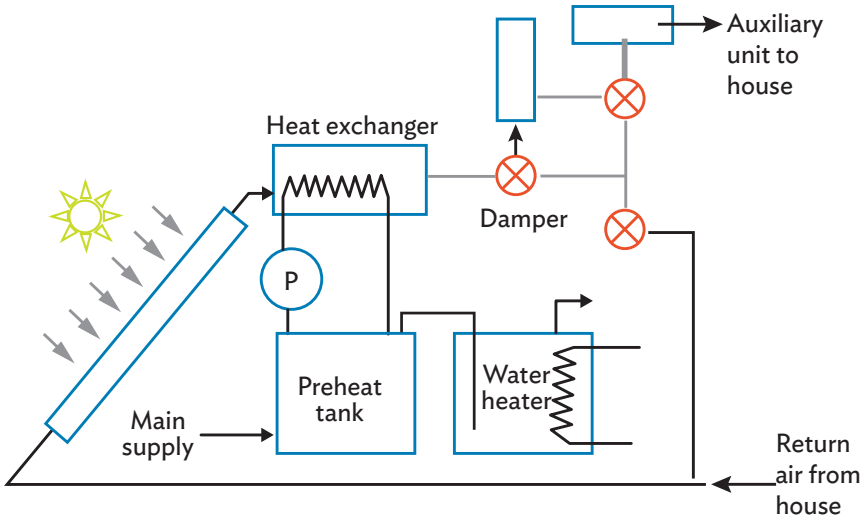


DHW = domestic hot water, HTF = heat transfer fluid.
Source: API Energy. Active Vented System Drain Back Solar Water Heating System. ND.

Air System

Another variant of indirect systems for water heating is the air system, which uses air rather than water or a water-antifreeze mixture as the heat transfer fluid (Figure 103). This helps the system work properly under extreme conditions such as freezing in winter or overheating in summer. As shown in Figure 104, a fan is used to circulate air through the solar collector duct, where the air is heated up. The hot air then transfers heat, through a concentric air-to-water heat exchanger, to the water in the horizontal storage tank. Fans and dampers are integral components of the system that modulate its operation. The system can produce hot water up to 80°C. The system is noncorrosive, requires less maintenance than other systems, and can be used under low temperature conditions. The system, however, has a relatively lower heating capacity and requires a larger area as a result of the use of air as the heat transfer fluid. Also, gradual air leaks will adversely affect system performance.

Figure 103: Solar Air System for Water Heating



Source: Gong, J. and K. Sumathy. 2016. Active Solar Water Heating Systems. In R.Z. Wang and T.S. Ge, eds. *Advances in Solar Heating and Cooling. Elsevier Science*. pp. 203–224.

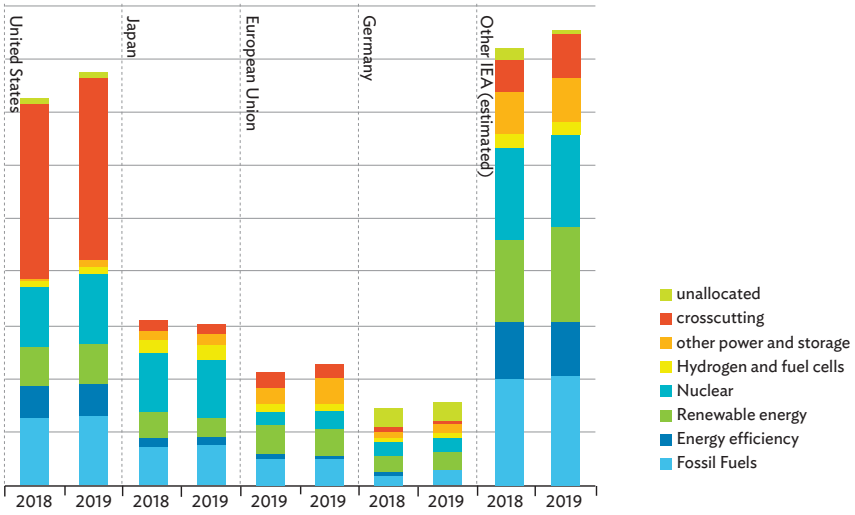
6 FINANCIAL INSTRUMENTS

Current Situation of Energy Efficiency Investment in Buildings

IFC estimates that investment opportunities in the green buildings and building construction sector in emerging markets will amount to $24.7 trillion by 2030, of which $17.8 trillion would be in East, Southeast Asia and the Pacific and $15.7 trillion would be in the residential sector (IFC 2019c). This indicates the magnitude of necessary funding and the need for sustainable business models to be able to guide financial means where they are needed. The current situation in Asia is certainly improving, but annual investment in BEE is still low.

Energy efficiency is key to solving the rising need for energy in the DMCs. With growing GDP, which will nearly triple from its base in 2017 to reach $20 trillion by 2040 in, for example, ASEAN countries, the forecasted demand for energy is expected to rise 2.8% annually from 375 million tons of oil equivalent (Mtoe) in 2017 to 714 Mtoe in 2040 (ACE, GIZ 2020). Judging from the past, it is likely that more power plants are built to meet demand than investments in energy efficiency measures are taken.

Figure 104: Budgets for 2018 and 2019 by Technology in Selected International Energy Agency Member Countries and the European Union



Source: International Energy Agency (IEA). 2021a. 2018 and 2019 Budgets by Technology in Selected IEA Countries and the European Union.

The following subchapters set the frame for understanding the characteristics of financing BEE. It provides the way for individual case diagnosis, which leads to the design of appropriate business models and financial instruments. Financing energy efficiency differs in a couple of ways from traditional financial models. The following part shows the major differences and their impacts.

Nature of Building Energy Efficiency Finance

Investing in savings. Investing in energy efficiency measures anticipates a reduction of future expenses in the form of projected energy costs. Conventionally, investors and banks seek the positive cash flow of an investment to repay a loan or pay a dividend, e.g., by growth in the output of rental space. The concept of financing savings while achieving the same output, although with fewer energy costs, is new. Traditional business models focus on maximizing usable output. For energy efficiency investments, the output occurs in the form of "negawatts," an asset that is not tangible and cannot be taken as collateral. Therefore, the financing of energy savings requires a rethinking process.

Fragmented market. The technical solutions to reduce energy consumption can be different from building to building. The size of the building, its location, the current physical condition, usage, and a number of other factors determine the technical measures that must be taken, their costs, and the amount of possible savings. While there are conventional design methods, practices, and technologies, they vary from a simple switch to an LED light, to building envelopes to space cooling and ventilation. Subsequently, the market from an investor's and banker's point of view is fragmented, consisting of multiple, relatively small modifications, and each individual measure may not be—financially speaking—significant. Transaction costs for banks and investors, however, remain the same regardless of the size of the investment. Thus, multiple small investments are not attractive to most financial providers. It is not only time-consuming, but decision-makers may not have the technical expertise to evaluate each measure's risk level.

Split incentives. An energy efficiency investment is made with the prospect of later savings, i.e., profits. Owners and landlords, however, face the problem that under net lease contracts, energy costs are paid by tenants to the utility, and any investment in energy efficiency would reduce the bill of the tenant but have often no effect on the profit margin of the owner. If the contractual arrangement is based on a gross lease, the owners pay energy expenses, and the tenant has little incentive to correct the energy use, as one would not profit from it. The dilemma[24] that owners do not benefit from their investment is referred to as "split incentives."

Mixed purpose investments. Energy efficiency investments in existing buildings are seldom done solely for the purpose of achieving less energy consumption. Often, it is a replacement investment that had to be done anyway. Buildings will see a refurbishment after 30–40 years due to a change in lifestyle or because equipment is worn out. In most cases, a change in architectural structures, layout, and usage of the building go along with it, and the energy efficiency upgrade is part of the package. In addition, a number of refurbishments may include renewable energy options like solar. The payback period for the part of the investment leading to less energy usage is thus difficult to determine.

Subsidized energy costs. Last but not least important is the fact that in many countries, energy is still subsidized.[25] Energy prices are the most sensitive individual factor to energy efficiency investments. If the true price of energy were paid by consumers, payback periods would be shorter, profits would be higher, and society would accept energy efficiency measures as a useful instrument. It is an often-heard argument, that low-income groups suffer most, if subsidies are canceled. To achieve social acceptance and the right incentives to save energy, subsidies that

[24] Further reading: H. Nie, R. Kemp, Jin-Hua Xu, V. Vasseur, Y. Fan. 2020. Split incentive effects on the adoption of technical and behavioral energy-saving measures in the household sector in Western Europe. *Energy Policy*. 140. p.111424; I. Hamilton. 2021. *Asia launch of online course for Energy Efficiency in Buildings*. International Energy Agency.

[25] Further reading: ADB. 2016. *Fossil Fuel Subsidies in Asia. Trends, Impacts, and Reforms*. Manila.

are harmful to the environment must be redirected and modified. The savings from canceled subsidies can be used to support, e.g., the urban poor to live in more energy-efficient housing estates. Dynamic tariff models can provide allowances for further direct subsidies for selected groups to allow for the affordability of energy.

Rebound effect. Critics of investments in energy efficiency argue that the "rebound effect," meaning that energy efficiency savings are offset by increased use of energy, would render energy efficiency investments impractical. Amplified consumption may stem from

- using energy-consuming services more than before (take-back effect),
- buying additional energy using devices from savings (spending effect), and
- available income is used (also in the case of government-led incentive programs) to increase economic activities and thereby indirectly increase energy demand (the investment effect).

Scientists estimate that in developing countries, a 10% improvement in efficiency might provide "only" a 9% reduction in energy use.[26] Rebound effects are often based on backlog demand. Using more energy at lower costs and securing access to energy is an improvement in the living standards of vulnerable groups in an energy-efficient way. The effect of the energy measure is therefore not nullified but put to proper use.

Box 17: Nature of Energy-Efficiency Finance—Summary

- Unfamiliarity with the concept of investing in savings while achieving the same output
- Fragmented market increase risk perception
- Dilemma of split incentives
- High transaction costs compared to small investment amount
- Very little "pure" energy efficiency investments
- Energy subsidies are obscuring energy efficiency investment profits
- Rebound effects

Source: Author.

Low-Hanging Fruit Versus Deep Renovation

A number of energy efficiency investments have been made in the last few years that have become popular, such as changing light bulbs to LEDs, which typically use about 25%–80% less energy than traditional incandescent lights. Though more expensive, the payback period is short, and given that LEDs last longer, it is very lucrative.

Similarly, the installation of a programmable thermostat that can be adjusted to temperatures according to schedule, the assessment of heating and cooling systems, the insulation of hot water pipes to prevent heat loss, and the replacement of aging and inefficient appliances are reasonable and cheap ways to save energy and achieve short payback periods. Many programs focus on these low-hanging fruits as an incentive and educational instrument to gain broader acceptance of energy efficiency measures.

[26] P. O'Connor. 2015. What is the Rebound Effect? — Energy Efficiency, Part 2. Union of Concerned Scientists.

Box 18: Example of Energy-Efficient Lighting

In a parking lot, 100 400-watt metal halide lamps are installed. They operate 365 days a year for 12 hours at an electricity rate of $0.14 per kilowatt-hour.

Item	Old Lamp	LED
Wattage	400 W	135 W
Energy use, kWh p.a.	175,200	59,130
Energy costs p.a.	$24,528	$8,278
Savings p.a.	$16,250	$17,967
Payback period		2.71 years

kWh = kilowatt-hour, p.a. = per annum, W = watts.

This example covers only electricity savings, additional savings are possible due to build in energy saver programs, which dim the light during the day and brighten up during the night.

Source: Author.

It is suggested specifically that renovation rate and depth should be reinforced. Deep renovation can improve buildings' performance by 30%–50%, which is needed for buildings over 25 years. Deep renovations, including investments in the building envelope, replacement of windows, and changes in space heating and cooling, require larger investment amounts with repayment periods of approximately 15–30 years. These are all useful measures over the life of a building. However, investors expect much faster profits. Therefore, they are hesitant and forgo the opportunity of substantial energy efficiency gains.

An attempt to cut down on long payback periods is to package an energy investment deal with measures that have different payback periods. Profits from quick energy-saving measures are reinvested and shorten the longer payback periods of structural investments. A sculpted repayment schedule requires a strategic and long-term view of investors. The combination of both long- and short-term payback periods is a trade-off, inviting longer-term (and useful) investments into energy efficiency.

Likewise, combining different payback periods makes it easier for the business models of companies specializing in energy efficiency, such as energy service companies (ESCOs). They act as project developers when integrating a project's design, financing, installation, and operational elements. Working with a different set of repayment schedules stabilizes their business model and makes it easier to guarantee a certain output after gaining control over all necessary data.

Box 20: Low-Hanging Fruit Versus Deep Renovation—Summary

Investments with quick payback periods are used as incentives to achieve the popularity of energy efficiency measures. Deep renovation measures require higher investments and thus longer payback periods, which, when mixed with low-hanging fruit can be shortened.

Source: Author.

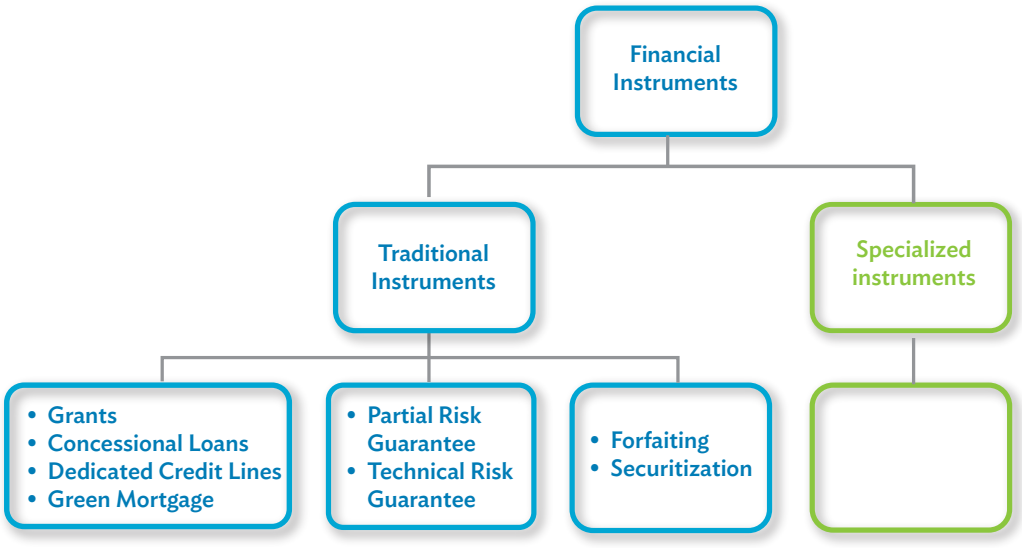
Financial Instruments

The following is meant to be a practical section addressing the question of how best to finance energy efficiency in buildings, what the challenges are, and how best to overcome them. It is based on the understanding that energy efficiency investments in buildings must be economically viable and financially feasible to make sense to tenants, homeowners, developers, and investors alike. The objective of the report is to contribute to opening a sensitive avenue for the transition to a zero-carbon, efficient, and resilient building stock.

To finance energy efficiency in buildings, all commonly known financial instruments are used. They are applied by banks and investors under the same risk assessment scenarios as any other business opportunity. Given the previously discussed lack of information in terms of uncertain cost savings and data to measure performance, financing has been restrained. In response, specialized instruments have evolved that circumvent or mitigate these impediments, such as ESCO models. They also combine traditional financial instruments. The differentiation between specialized financial instruments and business models is not clearly defined. For this handbook, we loosely classify business models as more complex structures that involve financial and nonfinancial instruments.

In the following first traditional instruments (Figure 105) and then specialized instruments (Figure 110) are briefly described, and international best practice examples for their usage are given. The correct use of financial instruments will reinforce political measures.

Figure 105: Overview Financial Instruments (1)



Source: Author.

Traditional Instruments

Grants and Technical Assistance

Grants are funds given for a specific purpose by governments and development banks and are not paid back. They can pay full or part of the costs of predefined investments and are seen as incentives to open markets.[27] Well-known in technical assistance (TA), they are often used to finance capacity development components to cover any additional design costs and demonstration projects involving untested and novel technologies, which is often the case in energy efficiency in buildings. An example is Germany's KfW Development Bank, which provides grants for engineering and construction supervision of energy efficiency measures to cover any additional design costs in existing buildings of up to 50% of costs, up to €4,000 (Dorendorf 2018). Grant finance reduces the costs for building owners. They are often used for a limited period to overcome clearly defined obstacles and to create awareness.

Concessional Loans

On behalf of governments, specialized banks provide loans at better than the prevailing market terms, i.e., with lower interest rates and/or longer maturities for investments that fall within specific guidelines—for example, passive houses. These "soft" loans are often combined with grant finance. For example, investors who follow the regulations of the "KfW energy efficient house" receive concessional loans with interest rates of 1%–2% for 10 to 30 years. The interest rate is among others, determined by the level of efficiency achieved; the higher the level, the lower the interest rate (Kolb 2020). Though the risk stays with the investor, soft loans reduce costs substantially. Good results have been achieved when financing the retrofitting of buildings, especially in the (private) housing sector. Borrowers, however, must be solvent to obtain a loan. If not, they need external finance (see ESCOs). There is no direct link between energy or costs saved and the repayment rate. Loans require collateral, which may be the equipment financed by the loan or other assets such as the customer's mortgage. Concessional lending does not avoid recourse to the lender.

Dedicated Credit Lines

Governments and development banks may decide on a bundle of loan alternatives to support the fragmented buildings and building construction sector. Each of the lines would target a certain market imbalance, and together they would support a larger policy measure. As a bundle, they form a selection of opportunities and have lower transaction costs. Dedicated credit lines are often used to stabilize specific market segments. They may consist of a mixture of concessional loans and grants. Dedicated credit lines are used in on-lending schemes in which commercial banks can build up a steady project pipeline with existing clients. For example, the European Bank for Reconstruction and Development (EBRD) has provided, via their funding vehicle, Green Economy Finance Facilities credit lines to local financial institutions in Bulgaria for on-lending to homeowners. Through Green Economy Finance Facilities, the EBRD offers credit lines to local partner financial institutions for on-lending to small and mid-sized green projects with loans or leasing alternatives. Credit lines are complemented with TA for capacity-raising and project assessments, and occasionally with low-intensity grants to reward end-beneficiaries who opt for advanced technologies.[28] Dedicated credit lines are a cost-efficient instrument; when designed properly, they follow a standardized pattern, may combine several efficiency objects, train the local financial market, and reduce funding shortages. Dedicated credit lines are used in on- lending schemes in which commercial banks can build up a steady pipeline with existing clients. However, on-lending schemes take time to become successful as participating banks need to train their staff and look for suitable clients in an often highly competitive market, which makes pipeline-building a medium-term process.

[27] The report does not include consideration of the impact of current coronavirus disease pandemic as it is still too early to make useful assumptions.

[28] EBRD. *Innovative Financing for Green Building*; further reading: Green Economy Financing Facility. Bulgarian Residential Energy Efficiency Credit Line.

Figure 106: On-Lending Scheme



EE = energy efficiency.
Source: Author.

Green Mortgage

Homeowners or potential home buyers are offered preferential mortgage terms if they can demonstrate that the property for which they are borrowing meets certain environmental standards or if they commit to investing to improve its environmental performance. Preferential terms can be in the form of extended loan maturities, interest rate deductions or in larger loan amounts (Richardson 2020). For example, the Energy Efficient Mortgage Action of the European Union has issued two complementary programs that offer a standardized energy-efficient mortgage using commercial banks to channel private capital to homeowners. The Energy Efficient Mortgages Action Plan. assumes that energy efficiency has a risk mitigation effect for banks as it lowers energy costs for the property and increases the value of the buildings. As a result, banks take on lower risk as usual, thus reducing the cost of capital. The Energy Efficiency Data Protocol and Portal is recording data relating to energy-efficient mortgage assets and allowing connected banks to make reliable risk assessments.[29] The initiative is financially supported by the EU's Horizon 2020 Program.

The combination of market-led data analysis, to which participating stakeholders report, has provided the maximum amount of transparent and relevant information. As the green mortgage program follows a clearly defined standard, the learning curve, monitoring, and valuation of loans reduce transaction costs for financial institutions and, at the same time, become comparable. This allows the bundling of loans, their securitization (see following discussion), the mobilization of an investor base, and the building of an energy-efficient asset pool. Since the administrative effort is substantial, these platforms are best led by independent organizations.

Partial Credit Guarantees

Credit guarantees are designed as a strategy of risk-sharing and mitigation. Partial credit guarantees (PCG) remove the risk from commercial lenders such as banks and financial institutions they do not feel comfortable with. Guarantees may absorb parts or the full debt service, regardless of the background of the default. If no PCG is provided, lenders may abstain from providing loans, or the risk costs would drive interest rates up. For example, ADB offered a credit guarantee to participating partner banks in the PRC in its Energy Efficiency Multiproject Financing Program. The PCG covered the credit risks associated with energy efficiency projects, thereby mobilizing their funds for energy efficiency projects (ADB 2022). A credit risk guarantee is another instrument that can be used in a not-fully matured energy efficiency lending market. It provides confidence to commercial lenders and will, in some cases reduce the interest rate of the borrower. However, a fee for the guarantee will have to be borne by the borrower. It can be used for individual owners as well as for ESCOs.

[29] Energy Efficient Mortgages Action Plan. *Energy-Efficient Mortgages Initiative*.

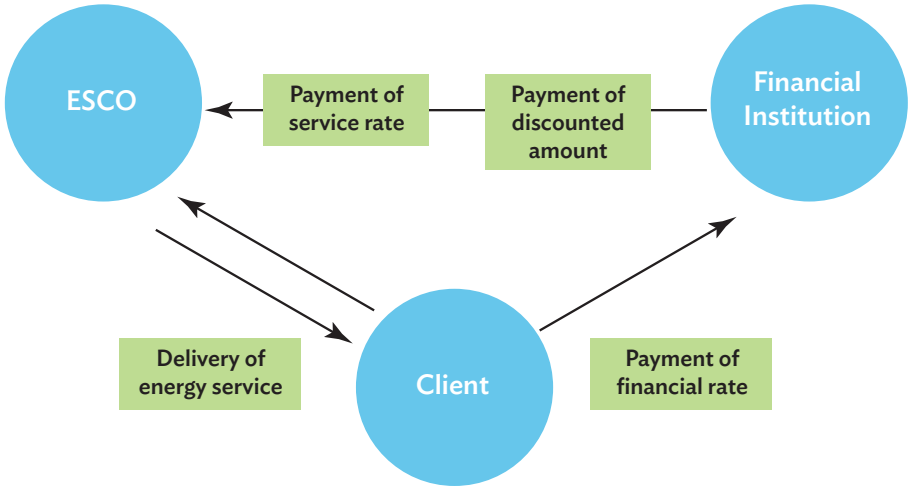
Energy Savings Insurance

The lower the perceived technical risk in energy efficiency, the lower the risk premium the investor must pay. Equipment insurance programs started offering specific insurance coverage for the difference in projected and actual energy savings due to technical defaults. The Energy Savings Insurance ensures guaranteed energy performance. Because of the strong linkage to possible malfunctioning of equipment, it is similar to technical risk insurance. Potential clients are ESCOs, building owners, and even dedicated programs. Eligible equipment is usually limited, such as HVAC, lighting, or building control systems. Programs are developed by governments and development banks to generate confidence in the potential for efficiency savings. When markets mature, commercial insurers also offer such schemes. For example, the Inter-American Development Bank (IDB) facilitates the development of the insurance program in alliance with national development banks. The model offers insurance to SMEs who, under the same program, sign a contract for the supply, installation, and maintenance of equipment and validation by an independent body (IDB 2020). Though the program is designed for SMEs, it also caters to hospitals, commercial buildings, and schools as the equipment eligible under the program is typical for saving energy in buildings, such as lighting and air-conditioning.[30] Those who seek insurance will have to follow stringent standardized procedures as to the equipment covered, the installation process, and the validation of equipment. The interest of the insurer is to control every single step along the way to minimize risks. Deductibles range between 5% and 20% depending on the potential energy savings.

Forfaiting

Known from export finance, the instrument can be used for energy efficiency in buildings as well. It is a means of selling medium- and long-term receivables at a discount to banks or specialized institutions to raise liquidity. ESCOs, who, for example, purchase energy-efficient equipment for their clients through a loan, could sell medium- to long-term debt to a specialized financial institution. By doing so, the ESCO frees its balance sheet of debt and can continue to grow, at the same time, it is still responsible for providing the energy service. The right to claim payments from the client is transferred to the financial institution.

Figure 107: Cash Flow Structure of a Forfaiting Mechanism



ESCO = energy service company.
Source: Author.

[30] Further reading on insurance: Base. Unlocking Investments in Energy Efficiency in Europe.

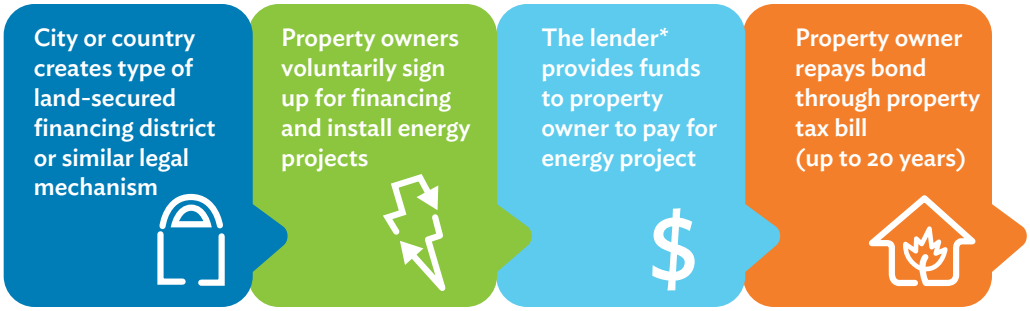
For example, the Save your bUildiNg by SavINg Energy or SUNShINE project in Latvia set up a forfaiting fund that buys receivables after 1–2 years of good performance from an ESCO, whose balance sheet has grown, allowing the ESCO to take on new loans (SUNShINE). Forfaiting comes at a price as it is a nonrecourse purchase of the financial institution, which carries the full risk of non-payment. Therefore, the discount rate the financial institution buys the receivables for depends on the risk the client of the ESCO poses. The better the client, the lower the discount rate.

Securitization

In securitization, the financial institution pools, for example, the receivables and debt from ESCOs and possibly other debt in a special purpose vehicle (SPV) and sells the vehicle to interested investors. The SPV can be a bond or another security (asset-backed security),[31] and investors receive dividends from the principal and interest cash flows collected from the underlying debt (energy savings from energy efficiency measures in the form of the fee the client must pay). Energy savings are thus a sellable asset.[32] For example, The Warehouse for Energy Efficiency Loans (WHEEL), is a public–private partnership, sponsored by the National Association of State Energy Officials of the US, that buys unsecured residential energy efficiency loans that participate in local programs (Clouse 2014). These loans are collected until the portfolio is large enough to bundle it into a bond for sale to institutional investors. Similarly, Deutsche Bank has issued a residential energy efficiency retrofit bond in which the underlying assets to be securitized were receivables from the Property Assessed Clean Energy (PACE) program.

The underlying asset, be it the EPC contract of an ESCO or the receivables from PACE, has a significant influence on the dividend payments of the bond or security. While individual defaults can be better buffered, reducing the risk, the nonstandard contracts of ESCOs make comparability difficult. When all works well, it is a triple-win situation as energy savings at the clients' end are achieved, the ESCO frees its balance sheet of debt and can expand, and investors are able to participate in a truly green instrument. Securitization needs a mature capital market.

Figure 108: Scheme of Property Assessed Clean Energy Program

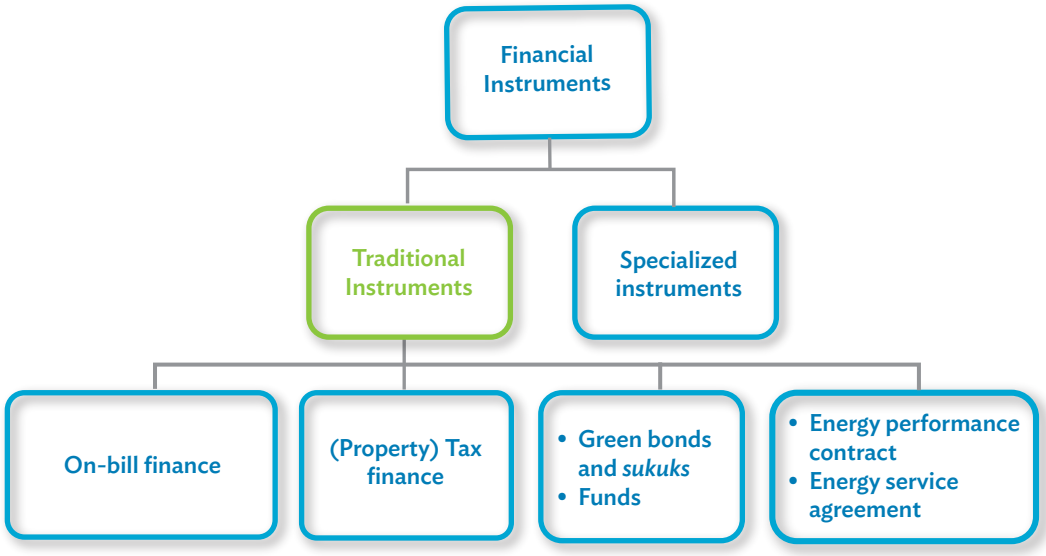


Source: Government of the United States, Department of Energy (US DOE). 2020. Property Assessed Clean Energy Programs.

[31] Securitization belongs to a group called asset backed securities (ABS) meaning a security derived from a pool of underlying assets.
[32] Further reading: Aggregation and Securitization as Key Driver for Energy Efficiency Finance; NRDC. Green Bank Network.

Specialized Instruments

Figure 109: Overview of Financial Instruments (2)



Source: Author.

On-Bill Finance

On-bill finance is another instrument to combat the high up-front costs of energy efficiency measures. Instead of banks, the utility provides funding for the refurbishment, which is paid back via the energy bill. If calculated correctly, the bill will be lower through the energy savings than before, despite the extra payment. There are two different methodologies:

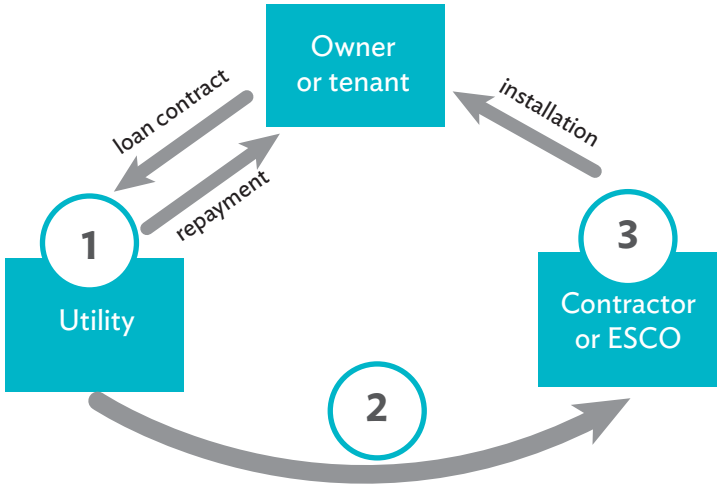
> An on-bill finance involves the utility, which acts as the lender. The customer of the utility receives financing from the utility for an energy efficiency measure and repays the loan through regular payments on an existing utility bill. Usually, this form of finance has zero or very low interest. However, it is legally not linked to the property or the utility meter.
>
> An on-bill tariff, where the building owner also repays the loan via the utility bill, is considered a tariff and, as such, an "essential service," which is linked to the property and part of the tariff. The obligation for repayment stays with the property and is transferred to the next owner if the property is sold.

For example, Rwanda in East Africa is supported by United Nations Environment Programme (UNEP) to replace used cooling equipment in residential homes. The program named R-COOLFI includes not only the replacement of the equipment but also the proper disposal of the used equipment. The loan is repaid through utility bills.[33] On-bill financing is suitable for building owners with little capital at hand. Because of the close relationship between the utility and the contractor, the owner often does not carry the technical risk, because the utility guarantees the

[33] UNEP. Rwanda.

performance. The program can be open to renewable energy measures. A great plus of on-bill finance is that it can be structured in such a manner that the debt is linked to the utility meter and not to the individual owner. This decoupling allows the debt to be transferred to the next owner. The program is driven by the utility, which in turn can be supported by the government.

Figure 110: Structure of On-Bill Financing



ESCO = energy service company.
Source: Author.

Tax Incentives

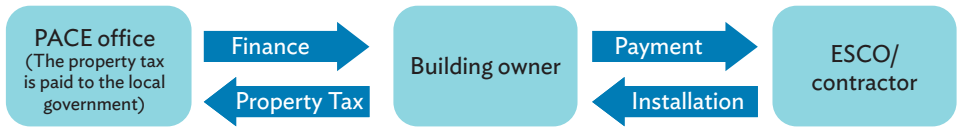
PACE financing is a system used in the US whereby the building owner borrows money for energy efficiency measures and repays the loan via a charge on the property tax. Property tax is linked to the property and not a person or company, and financial arrangements stay with the property even if it is sold. Thus, it allows long-term investments, usually in the range of 10 years or more. The objective is to keep energy savings larger than the charge on the property tax.[34]

For example, the city of Milwaukee wanted to improve the energy efficiency of commercial and industrial buildings by 20%, but lacked capital and had to find a solution for owners who wanted the freedom to sell their property at any time without having to repay a loan. Milwaukee developed a voluntary municipal special charge that is attached to the property, not the owner (US DOE n.d. 2). C-PACE is good for larger projects that require repayment periods of 10 years or more (which do not exceed the lifetime of the equipment in question). It can finance 100%, is transferable to the next owner and overcomes the split incentive situation between landlord and tenant, because the cost savings from the utility bill as well as the property tax surcharge can be shared with the tenant. Most properties are mortgaged, and mortgage providers must usually consent to charges that relate to the asset they cover.

Tax incentives can be more direct and include reductions in import tax duties for energy efficiency equipment and credits for using energy-efficient appliances and equipment.

[34] Energy.gov. Property Assessed Clean Energy Programs. A differentiation is made between C-PACE and R-PACE, depending on who the owner is. C-PACE is for properties that generate income from lease payments of that building, whereas R-PACE is for residential homeowners.

Figure 111: Basic Structure of Property Assessed Taxation



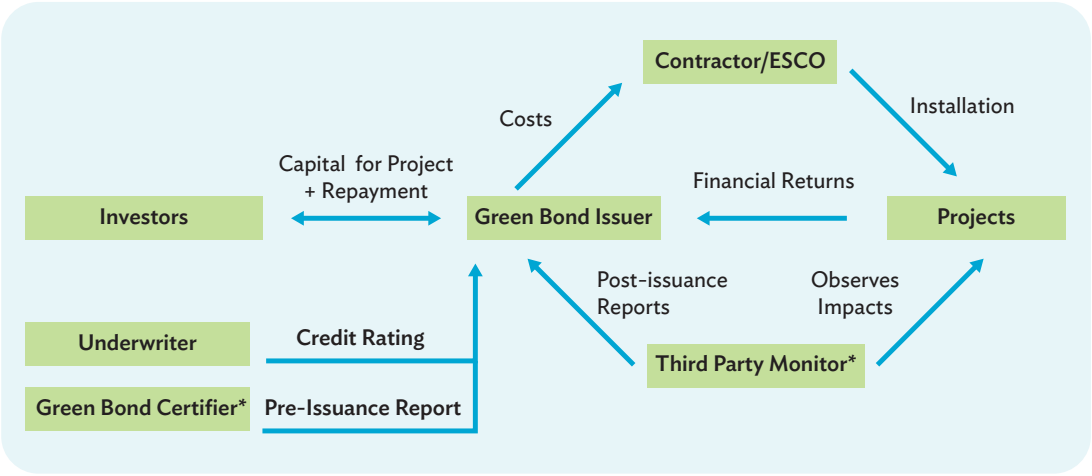
ESCO = energy service company, PACE = property-assessed clean energy.
Source: Author.

Green Bonds and *Sukuks*

To collect funding from private and public sources green bonds and *sukuks* play a growing role in energy efficiency finance. It is a fixed-income debt instrument in which the government or a financial institution (the issuer) borrows money from public and private investors to finance energy efficient projects. The structure does not differ from ordinary bonds and *sukuks* only in that the proceeds of the bond or *sukuk* must be used according to stringent guidelines for energy efficiency investments in buildings. The issuer is responsible for managing the proceeds after selling the bond to investors. They can be used to pay for the energy efficiency services of an ESCO as well as to directly finance energy efficiency equipment.[35]

For example, in 2017, DBS Bank of Singapore launched its first green bond at an amount of $500 million, which was oversubscribed on issuance day. The bond adheres to the Green Bond Principles[36] and may invest in green buildings, sustainable transportation, renewable energy, energy efficiency, waste management, and climate change adaptation projects (Sustainabbonds.com 2017).

Figure 112: Examples of a Green Bond Structure



ESCO = energy service company.
* Note: The same organization can be use to provide pre- and post issuance reports
Source: Government of the United States, Department of Energy (US DOE). n.d.1. Better Buildings Financing Navigator: Green Bonds.

[35] Further reading including other fixed income debt instruments Climate Bonds Initiative. *ASEAN Green Financial Instruments Guide.*
[36] The Green Bond Principles (GBP), updated as of June 2018, is a set of voluntary process guidelines that recommend transparency and disclosure and promote integrity in the development of the green bond market by clarifying the approach for issuance of a green bond. See: ICMA. Green Bond Principles. In addition the not-for-profit organization Climate Bond Initiative-issued Climate Bonds Standard and Certification Scheme. Climate Bonds Standard.

Indonesia, Malaysia, and Singapore are the largest green bond issuers among ASEAN countries. Forty-three percent of green bond proceeds are used for green buildings. However, a few green bonds are solely used for energy efficiency (Azhgaliyeva, Kapoor, and Liu 2020).

The security Commission of Malaysia issued the first green *Sukuk* in 2017. It can be used in support of renewable energy, energy efficiency, natural resources, and community and economic development (ACE and GIZ 2019).

Green bonds are a cost-efficient instrument to finance also smaller energy efficiency projects, though the offering amount needs to be sizable—at least $10 million. It allows the issuer to structure loans with different maturities, repayment periods, and purposes along the predefined guidelines of the bond, or *sukuk*. The fundamental issue with green bonds or *sukuks* is that there is no internationally binding taxonomy, and therefore, at a minimum, a national body needs to be in place to enforce standards across green bond offerings. Possibly, issuers are faced with higher management costs for the bond due to frequent reporting requirements if the bond or *sukuk* follows voluntary standards. These are required by clients to control the proper use of funds.

Funds

The mechanism of an energy efficiency fund is to collect and allocate a pool of money for the purpose of financing energy efficiency in buildings. Sources of funding may come from various parties, the government, development banks, or the private sector. The better the fund is structured and the higher the possible dividends the more money can be leveraged by private investors.[37] Key are clear and plausible investment guidelines, and where to direct the funds. Internationally, there are several examples:

- investing in credit lines (the Thai Energy Efficiency Revolving Fund [EERF], see example below) to overcome funding shortages in the market;
- issuance of guarantees (e.g., Hungary Energy Efficiency Co-Financing Program) (Taylor et al. 2008) to bring confidence in the market and lower investment costs;
- setting up dedicated loan facilities (e.g., Bulgaria Energy Efficiency and Renewable Energy Credit Line [BEERECL]), to cover a whole range of objectives;[38]
- developing private equity funds to invest in, e.g., ESCOs and manufacturers (e.g., ADB Clean Energy Private Equity Investment fund);[39]
- developing early-stage financing funds (e.g., SCAF) to support new technologies and early-stage pipeline building for new ventures (UNEP 2020).

Funds can be fixed-term, meaning once capital is fully utilized, it will be closed, or revolving, meaning they need to be replenished, often from their own revenues. The termination date is then not set by capital extinction, but by any set date in the future.

For example, a "Green Revolving Fund" can accumulate public and private funds that are dedicated to funding energy efficiency in buildings that generate cost savings. Part of those savings is then used to replenish the fund, opening additional funding opportunities for investments in new projects with similar features. The revolving nature creates a continuous funding vehicle, which supports long-term government policies due to the availability of funds and creates confidence in the market as an established instrument. For example, the Thai Energy Efficiency Revolving

[37] Given that the lion's share of funding to combat climate change will need to come from the private sector UNEP made an assessment of leverage ratios and came to the conclusion that typical leverage ratios range from 3 to 15:1. This means an investment from the public side of $10 million could lead to a total of $50 million–$150 million. UNEP. 2008. Public Finance Mechanisms to Mobilise Investment in Climate Change Mitigation. Paris.

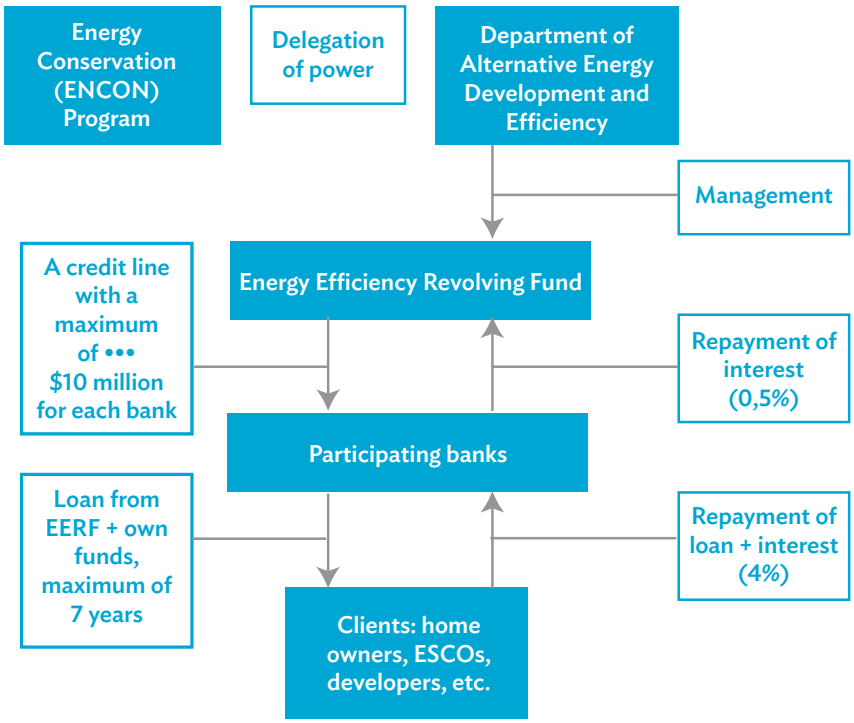
[38] Bulgaria Energy Efficiency and Renewable Energy Credit Line (BEERECL).

[39] Case Study 18: Asia – Clean Energy Private Equity Investment Funds.

Fund (EERF) started in 2003 as part of the framework of the Energy Conservation Program. It was set up to stimulate interest in energy efficiency, encourage local banks to lend to energy efficiency projects, develop a commercially stable market, and help with the deployment of other climate-related programs. The fund's initial capital was provided from the Government of Thailand's budget via revenues from a petroleum tax. As a revolving fund, it is replenishing itself, meaning there is a constant inflow and outflow of funds. The source of the replenishment stems from the interest rate differential banks charge to their clients and the charges banks can lend for.[40]

Funds require a stable institutional background as a general base. To address specific market impediments a clear analysis of the barriers must be made, and a feasible business case must be developed for private capital to come in. Administration costs of funds can be high; however, the cost of capital on an individual basis can be low. Funds need to be managed with transparent guidelines and organized in a lean manner.

Figure 113: Organizational Structure of the Thai Energy Efficiency Fund



EERF = Energy Efficiency Revolving Fund, ESCO = energy service company.
Source: Author.

Energy Performance Contract

The contractual arrangements between an ESCO and a client are called energy performance contracts.[41] They are all built around ESCOs, which, in addition to energy consulting services and equipment supply, can also finance or arrange financing for the operation of energy efficiency measures. Their revenue stream is directly linked to the energy savings achieved, which incentivizes good results. There are three key contract types:

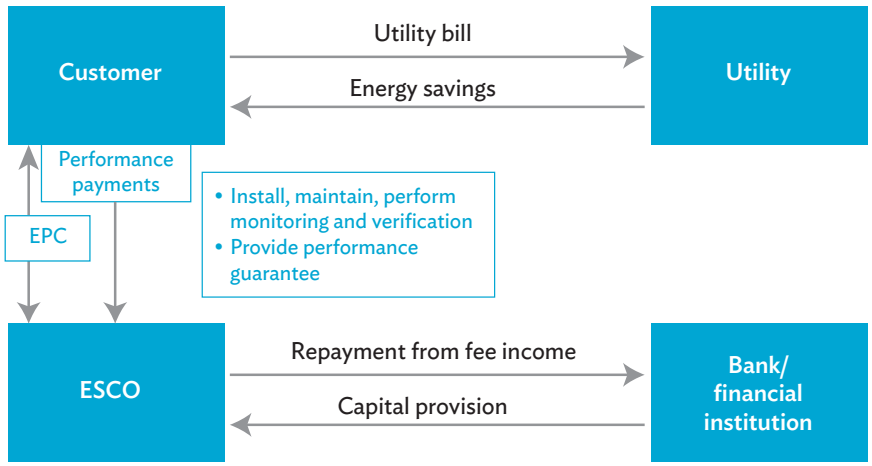
[40] Frankfurt School UNEP Collaborating Center. 2012. *Case Study: The Thai Energy Efficiency Revolving Fund.*
[41] In the US, the Energy Savings Performance Contract (ESPC).

Shared savings. The ESCO assumes the capital costs of installing energy-efficient equipment and shares with the client the energy savings throughout the life of the contract. The ESCO is paid for its services from the cost savings and the client retains the balance. After the contract expires, the energy savings will stay completely with the client. Depending on the contract specifics, the equipment can already be paid off (build–operate–transfer case) or can be bought by the client at market price.

Guaranteed savings. The ESCO guarantees the amount of energy saved after installation of equipment based on a pre-agreed floor price for the energy consumed. This model works well for clients who are skeptical as to the technical performance of the ESCO; however, if energy prices increase, they do not benefit.

Vendor finance. The manufacturer of energy-efficient equipment assumes the role of the ESCO, installs the equipment and is paid from saved energy costs. The vendor assumes the risk of nonperformance. This model works well, when a manufacturer enters a new market, when there is little choice in energy-efficient equipment and when certain efficiency measures (e.g., cooling) should be pushed forward.[42] Many vendors of energy efficiency equipment also offer lease agreements that allow the client to use the equipment without needing to buy it. It's typically part of the EPC. Two types are most common, on-balance sheet capital leases and off-balance sheet operating leases. At the end of the agreement, customers have the option to purchase the equipment at market price, return the equipment, or extend the contract.

Figure 114: Basic Energy Performance Contract Structure



EPC = energy performance contract, ESCO = energy service company.
Source: Author.

The basic design of an EPC[43] is that the owner agrees to an energy efficiency measure; costs, and risks are, however, as much as possible transferred to the ESCO. This puts ESCO financially in a difficult position as their balance sheet is quickly overloaded with several contracts, and it will be difficult to continue to borrow from banks for new investments. An aggregating factor is that the EPC contract is classified as "debt" by banks because it is money owed to the client. It is not seen as a source of income based on its revenue-receiving nature. Lately, new features of EPCs have emerged, emanating from impediments in the market. The way EPCs are assessed has changed, leading to modifications in the regulatory framework. Some examples of adjustments that appear small but may have large implications are as follows:

[42] ADB supports this type in: Southeast Asia Energy Efficiency Project.
[43] Further reading: IEA. 2017. Energy Performance Contracts and SGBC. Green Procurement for Green Buildings.

- Overcome the barrier in the rental housing sector called split incentives
  - If owners are allowed to make EPC fees or a share thereof part of the recoverable housing charges, they may opt for consumption-based cost allocation and reduce their overall cost by implementing more and better energy efficiency equipment. This is legally very often not possible to avoid the shifting of the complete energy efficiency cost to the tenant.
- Broaden the spectrum of energy efficiency measures and lower the financial burden on ESCOs
  - In countries where the value-added tax (VAT) on energy-efficiency appliance and equipment is lowered, ESCOs may be excluded from the benefit, because their overall service is charged. This is why owners often finance the purchase, even though they are limited in their financial capability which in consequence reduces the number of useful energy efficiency measures. The regulations must be amended to allow the purchase of VAT-reduced equipment.[44]
- Make deep renovations more feasible
  - When up-front costs and finance costs are too high to be repaid from energy savings, governments often provide grants or subsidized loans to the owner to pay part of their investment. When an ESCO makes the investment, this support instrument sometimes fails, because the ESCO operates on behalf of the client and only the client is eligible. The claim for subsidies could be made transferable. Attention should be given to the fact that ESCO is a private company, and a transfer can potentially cause market distortion. Transparent financial reporting could mitigate this.
- Facilitating the market for EPCs
  - To build confidence in the ESCO market, public entities are often called on to go ahead. Their motives for not moving ahead are like the ones of the private sector, which are a mixture of ignorance, risk avoidance, and lack of market knowledge. By creating an honest broker as an entity between ESCO and the public entity that facilitates the process, sets standard procedures, and contracts, a service is provided that has upscaling potential and can be replicated, e.g., in other cities.[45]
- Deepening the funding base for ESCOs
  - The pooling of several buildings under one contract has the advantage for the ESCO that if one building fails, the loss can be mitigated by the others, and the overall contract target remains intact. Also, pooling offers the opportunity that different types of interventions can be realized, both low-hanging fruit and deep renovation, as they can be engineered to level off. Houses of the same building owner (e.g., the public sector) could be pooled as well as from different owners.
  - The model can be developed further in the sense that the ESCSO creates an SPV for the pool, which is financed by the savings cash flow. The ESCO provides the initial equity and may attract other equity investors. Because of the diversified risks, banks and other financial institutions are more inclined to lend, giving the entire structure credibility.

The advantage of an EPC contract for any building owner is that two main risks can be transferred to the ESCO. First, there is the risk of borrowing money for the investment, and second, there is the technical performance risk. The assumption of risks by the ESCO opens financing options for the building owner while at the same time improving the technical facilities and value of the building. In family-run businesses, however, the contract duration of an ESCO is deemed to be too long and thus too binding.

[44] In the Republic of Korea, the Building Retrofit Program (BRP) of the Seoul Metropolitan Government allows building owners, tenants as well as ESCOs and energy saving equipment suppliers to apply for loans. Building Retrofit Program.

[45] The Berlin Energy Agency (BEA) was mandated by the Berlin government to support the energy savings partnership program. BEA manages the entire process till the EPC is signed. Meanwhile BEA bundles several public buildings and manages the procurement to offer a larger package to ESCOs. The model has been replicated in other cities and receives competition from the private sector. See also chapter business models at BEA.

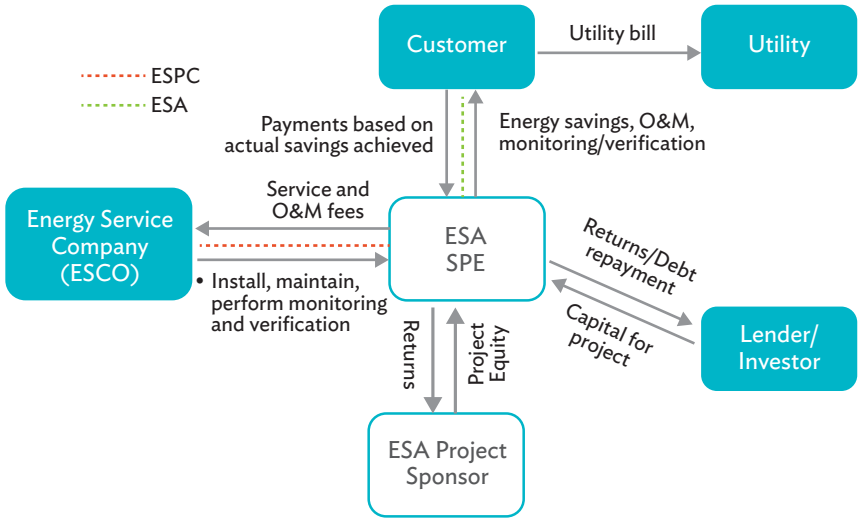
Energy Service Agreement

Widely seen as the sister to a project finance-type power purchase agreement (PPA) in the power sector, energy service agreements (ESAs) are an off-balance sheet financing solution that allows the building owner to undertake energy efficiency projects with zero up-front capital expenditures. What makes it similar to a PPA is that once the project is operational, the customer pays a service charge based on the actual savings achieved ("negawatts"). It can be a percentage of the customer's utility rate or a fixed amount per kilowatt-hour saved. The latter can be a hedge against an increase in utility tariffs.

The ESA provider develops, finances, owns, operates, and maintains the energy efficiency measures during the term of the ESA, employing an ESCO to do the installation, measurement, verification, etc. Depending on the contract structure, the customer may purchase the equipment at the end of the contract at the market price or renew the contract and receive yet again new equipment. For each new contract, the ESA provider establishes an SPV for which funding sources, like in a typical project finance structure, come from equity and debt providers. They are repaid from the revenue streams the customer pays for energy savings, possible tax rebates, and other supporting measures. The cost of funding depends strongly on the credibility of the ESA provider and the ESCO.[46]

For example, Metrus Energy, a private company that develops and finances sustainable energy projects at commercial, industrial, and institutional facilities, signed an energy service agreement with Kuakini Medical Center in Hawaii for a new central chiller plant, an LED lighting retrofit, boiler plant upgrades, variable-frequency drives, and an energy management system. The investment amount was fully financed by Metrus and repaid by energy savings, with zero capital expenditure for the client. The contract tenure was 10 years; annually, $1.18 million and 3,234 $MtCO_2$ were saved with initial investments of $5.96 million.[47]

Figure 115: Basic Structure of an Energy Service Agreement Model



ESA = energy service agreement, ESPC = energy savings performance contracting , O&M = operation and maintenance, SPE = special purpose entity.

Source: WSGR. 2014. *Innovations and Opportunities in Energy Efficiency Finance.* New York.

[46] Further reading: U.S. Department of Energy. Better Buildings.

[47] METRUS.

ESAs build on the successful PPA model in project finance, where third-party project developers and investors provide the up-front capital for energy efficiency improvements, which is repaid over time by the customer through energy savings. Because the ESA provider is paid based on the amount saved, there is an incentive to implement newer technology to maximize revenues. As in project finance, smaller energy efficiency projects (below the $1 million annual energy expenditure threshold) have difficulties using private sector funding, as the amount is deemed too small for the structural costs of an ESA. Because ESAs deliver stabilized utility costs without capital expenditure at no performance risk for the client, they are a practical instrument for multi-use commercial buildings such as shopping centers and warehouses, as well as for office buildings. The ESA fee is for operational costs, which are usually tax-deductible.

Carbon Finance

According to the UNFCCC, "carbon pricing curbs greenhouse gas emissions by placing a fee on emitting and/or offering an incentive for emitting less. The price signal created shifts in consumption and investment patterns, making economic development compatible with climate protection." (UNFCCC 2022). Carbon pricing instruments come in three forms, whereby, worldwide, mostly hybrids are used:[48]

- **Emission trading systems**. A limit is set for participating entities, such as buildings on the emissions that can be emitted. If the building emits more than the allowance, owners must buy additional emission units at the market to offset the exceeding greenhouse gas emissions. The owner can also sell if the building emission are less. The idea is that refurbishment is cheaper than buying credits at market rates. The price is set based on supply and demand.[49]
- **Emission reduction funds.** The government sets up a fund, usually financed by the taxpayer, that buys or sells emission units for eligible projects.[50]
- **Carbon tax**. A tax is applied to the use of fossil fuels making their use more expensive. The price signal would be felt not only in the buildings and building construction sector but throughout the entire economy. No minimum greenhouse gas emissions can be guaranteed for the ETS and emission reduction fund, but it allows for additional tax income to be used for energy efficiency projects.[51]

For example, in Germany, a new price on greenhouse gas emissions in the transport and buildings and building construction sectors from 2021 is applied. It exists in parallel to the EU–ETS trading system and covers a number of those emissions currently not included there. The tax is on heating oil, natural gas, gasoline, and diesel, which both sectors use heavily, contributing more than one-third of greenhouse gases in 2020 in Germany.

The government sets an annual total emissions limit for transport and heating fuels ("cap and trade" system). For the first 5 years, the price is fixed, starting at €25 per allowance (ton of CO_2 equivalent) and going up to €55 in 2025. For 2026, allowances will be auctioned within a price corridor of €55–€65. From 2027 onward, a market price is foreseen. Emission allowances then become fully transferable and can be traded. The government expects revenues in the amount of €40 billion in the first 4 years, which will be used for relief measures for citizens and industry, and for climate action support programs. The government expects the price to save 3.1 $MtCO_2$ in 2025, 7.7 million tons in 2030, and 12.4 million tons in 2035. To avoid carbon leakage, the government also issued a regulation that provides compensation for certain industries. It is supposed to prevent harmful industries from moving production abroad (Wettengel 2021).

48 Further reading: World Bank. State and Trends of Carbon Pricing 2021.
49 The PRC has set up a national ETS system. Further information: IEA. China's Emissions Trading Scheme.
50 Australia has introduced an emission reduction fund. Further reading: Government of Australia. ACCU Scheme.
51 For examples on carbon tax in use: Center for Climate and Energy Solutions. Carbon Tax Basics.

Considering its long-term investment cycles, fragmented ownership structure, and persisting non-economic barriers, a carbon price is part of the solution to reduce greenhouse gas emissions in the buildings and building construction sector. It must, however, be accompanied by other measures. The long-term nature of a carbon tax system and the reliability of price increases can, in addition, make way for urgently needed deep renovation, as pay-off periods will drop. The price volatility of a market-based ETC. system may not offer a reliable price forecast for investors; however,
it incentivizes the introduction of greenhouse gas reduction measures.

Any sort of carbon finance system needs to be implemented at the end of the user, be it building owners or those who supervise the energy use. The implementation needs technical and financial run-up time. While neither system is perfect, a mixture of both can address a larger variety of impediments.

7 BUSINESS MODELS

Latvian Baltic Energy Efficiency Facility

Independent of the type of building, the following features are important to determine methodologies for business models:

- Age: newly built or existing buildings that need retrofitting
- Ownership: who pays for the energy efficiency measure?
- Beneficiaries: whose energy bill will be reduced?
- Risk takers: who takes what risk?
- Usage: some building types have limited energy usage, some 24/7.

Background

Latvia is one of the countries that performed well after the fall of the Soviet Union and became an EU member only five years after gaining independence. The Ministry of Economics is responsible for energy and energy efficiency. Four main policies have been issued in the past years based on the Latvian Law on Energy Performance of Buildings of 2013, of which the Latvian Energy Strategy 2030 is most important for energy efficiency in buildings. It proposes an average energy intensity of 100 kWh/m^2.

Latvian building stock in the multi-family sector is old and constructed mainly in the period from 1941 to 1990. Many of these Soviet-style buildings have been privatized, so 83% are in the hands of individual families. All of them need to agree to energy efficiency measures. Many of the buildings slowly fall apart because the owners do not have enough capital for renovations. There are about 39,000 multi-family buildings covering a total floor space of about 55,000 m^2. Average energy consumption for heating is around 160–180 kWh/m^2.

Prior to the Latvian Baltic Energy Efficiency Facility (LABEEF),[52] a private ESCO called RenEsco[53] started out renovating 15 multi-family homes based on EPC contracts. Buildings are typically connected to district heating.

[52] Key words: deep renovation of multi-family buildings, support of long-term finance of ESCOs through a combination of financial instruments (forfaiting and on-bill finance), model possibly replicable in former Soviet Union countries, finance platform transferable to other type of buildings. Source and further reading:

- European Commission. *Energy.*
- Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) *LABEEF in Latvia*.
- K. Jörling, M. Schäfer. 2018. LABEEF in Latvia.
- SUNSHINE: EPC for deep renovation of condominiums, forfeiting fund for ESCOs Latvia. (Youtube)
- Funding for Future. Building a Green Future: Investment that Will Make an Impact.

LABEEF has been replicated in Bulgaria (D. Dukov. 2010. *Accessible Financing Instruments for Energy Efficiency and Renewable Energy Projects.* International Energy Efficiency Forum. Astana, Kazakhstan. 28–30 September.) and is planned in other countries in Europe.

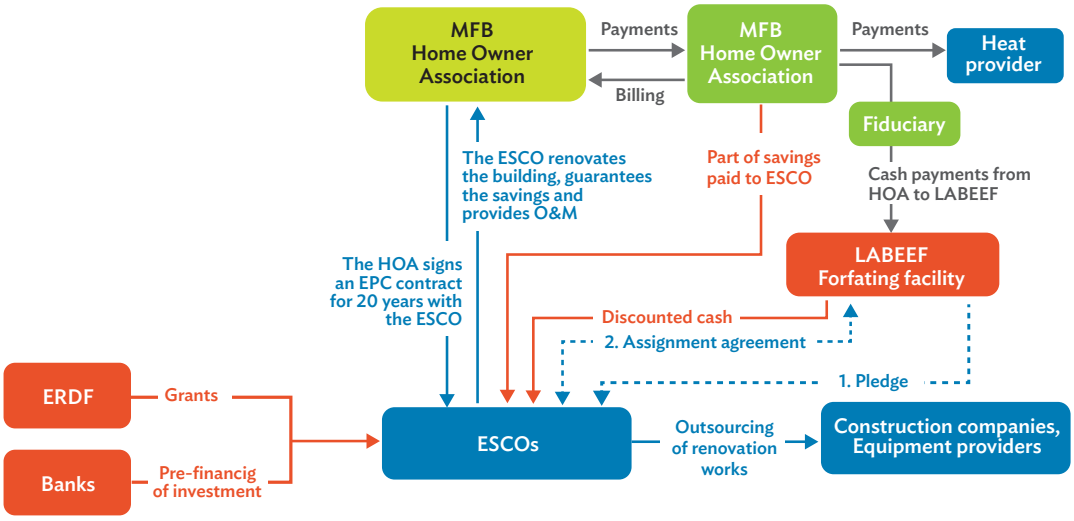
[53] RenEsco. RenEsco Ltd. was founded in 2008 to develop and implement energy efficiency projects for residential housing.

Therefore, the renovation targeted the building envelope, heat distribution pipes, heat control, and energy management. The measures were eligible to a 40% grant from the European Regional Development Fund.

EPC contracts were signed for 20 years. The average payback period was 9–10 years (including the grant), whereby an on-bill finance model was used. Homeowners paid the same amount throughout the contract period and accepted an increase of 15% on their energy bill. RenEsco received a fee based on the amount of saved energy from a house maintenance company. The benefit to homeowners was not only energy savings of 45%–65%, but also an increase in value of the apartment, estimated to be 20%–30% in a building, with an extended lifetime of about 30 years or more.

RenEsco received funding from a local commercial bank of up to 60%, which was backed by a third-party guarantee from the Dutch Housing Institute of 40%. No further collaterals was provided. It soon became clear that the balance sheet of RenEsco filled up and no further EPC contracts could be signed, even though the payment morale of homeowners was very high. This led to the creation of SUNShINE (Save your bUildiNg by savINg Energy), a project funded by the EU-Horizon2020 platform, which led to LABEEF.

Figure 116: Latvian Baltic Energy Efficiency Facility Scheme—Combination of On-Bill Finance and Forfaiting (SUNShINE)



EPC = energy performance certificate, ERDF = European Regional Development Fund, ESCO = energy service company, HOA = home owner association, LABEEF = Latvian Building Energy Efficiency Fund, MFB = multifamily buildings, O&M = operations and maintenance.

Source: SUNSHINE. N.D. SUNSHINE

Basic Model

LABEEF was founded in 2016 in support of the Latvian ESCO business. It aims at reducing energy use in prefabricated Soviet-style multi-family buildings with diverse ownership based on EPCs.

The facility has a fund size of €30,000,000. It receives capital in the form of a loan from the EBRD and technical support from the EU Horizon project. Funding for Future B.V., a management company, is a shareholder in LABEEF.

LABEEF's objective is to modernize 20% of multi-family buildings by 2022, which is currently projected to result in the saving of 21 kg CO_2e/m^2. It is estimated that €7,600 is needed to avoid 1 ton of CO_2 emissions in the first year after renovation. This may go down to €250 per ton when considering the extended lifetime of the building due to renovation. In addition, an information technology (IT) platform is created to simplify administrative work such as applications, templates, and reporting, as well as provide financial, technical, and economic tools and training. The structure of the facility is lean and works without a delivery unit.

ESCOs sign 20-year EPCs with the building owners[54] and finance the refurbishment measures with bank loans. Once measures are implemented and their guaranteed savings verified—usually after 1.5–2 years—LABEEF forfeits the EPC contracts and receives EPC fees from building owners until the contract terminates. Please also refer to Figure 119. ESCOs receive discounted cash for their future receivables, minus an amount for operation and maintenance and a guarantee. The mechanism allows the ESCO to take on new EPCs as their balance sheet is cleared of debt. On the other side, ESCOs are incentivized to continue delivering good-quality work, as they will otherwise not receive any payments for their efforts. For the first 1.5-2 years 100% of the risk stays with the ESCO; for the remaining 18 years, the risk is shared between the two of them, with LABEEF taking 80% of the net capital expenditure receivables and the ESCO 20%.

Success Factors

The success of the platform LABEEF is first, energy savings, which are achieved through the renovation of multi-family homes. Second, LABEEF frees up long-term finance by taking on long-term risks. Third, the facility provides standardized and internationally accepted procedures. Fourth, the project learned from previous experience and built on it. Below are some of the success factors in more detail:

- A challenge for multi-family-owned buildings is to receive the commitment of all owners. Even though the need to act may have been obvious, owners were severely short of capital. The acceptance of homeowners has been achieved, probably due to a mixture of factors:
    - They were approached by a professional company and did not need to organize anything on their own.
    - The additional amount of 15% on their energy bill did not touch any savings and was manageable and stable for the entire period.
    - Homeowners did not directly sign any contracts. In case of difficulties, they could approach the house management company, which they knew and trusted.
    - Because no individual contract was signed, homeowners could sell their apartments at any time. The increased energy fee is attached to the apartment and transferred to the new owner.
    - The value of their apartments increased, as did the quality of their housing conditions.
- The structure of the facility is based on earlier experience, involves long-term stakeholders, and is lean.
    - RenEsco has worked before in the sector, and the creation of LABEEF is a back-to-back consequence of direct experience that helped to gain confidence at every angle and with all stakeholders.
    - Most stakeholders were approached at a very early stage. It helped to shape the structure and individual mechanisms to match each party's requirements. Therefore, processing was carried out with few adjustments contributing to a stable working environment and trust.
    - EPCs, contracts, procedures, and standards thus follow international standards, which helped to gain investors' confidence.

[54] Or by proxy with the homeowners' association.

- The IT platform is also open to businesses that do not operate under the LABEEF umbrella, carrying standardized procedures even beyond the LABEEF border, meaning that the EPCs are replicable.
- The structure works without a project delivery unit. Each organizational division is directly responsible for a certain part of the internal value chain of the project. Thus, all participating organizations are directly linked and part of the success. It also keeps admin and transaction costs down.

- Even though Latvia has a history of corruption in the buildings and building construction sector, the use of a fiduciary system supports transparency and good governance.
- LABEEF is a market-based instrument. Eventually, it will work without public support. This may have increased investors' confidence.

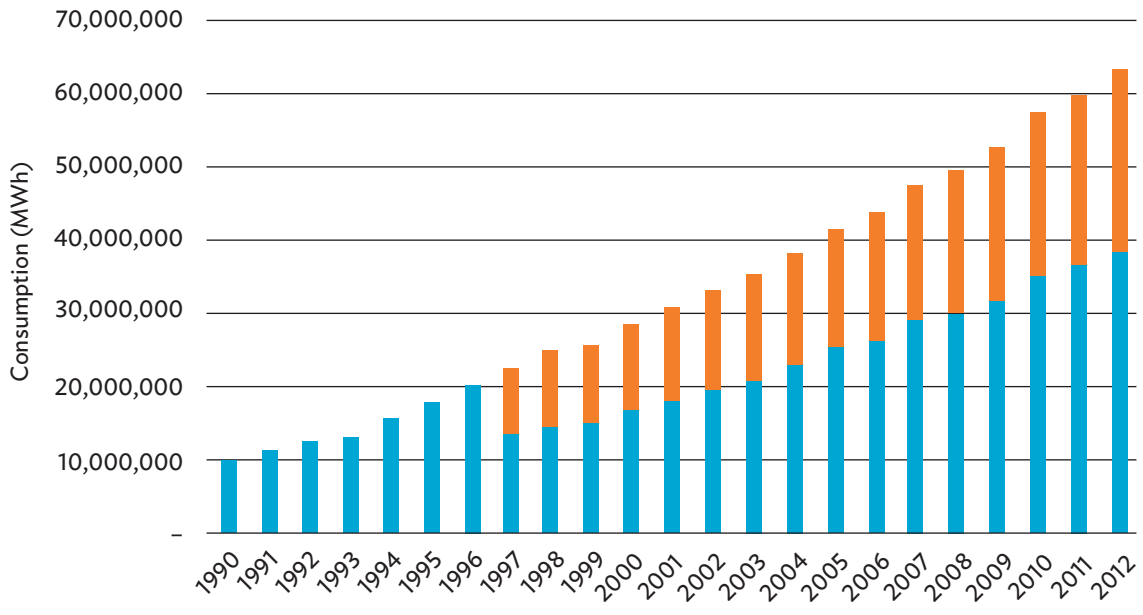
The long-term development and experience in the market have created a new sector in building construction as well as in maintenance and most likely led to new jobs. The more people who work in the sector, the more accepted renovations of buildings get.

Building Sector Energy Efficiency Project, Malaysia

Background

Malaysia wanted to reduce energy consumption by 40% in 2020 based on consumption patterns from 2003. One of the main consumers is the buildings and building construction sector, with commercial and government buildings ahead of residential buildings.

Figure 117: Commercial and Residential Electricity Consumption in Malaysia from 1990 to 2012



MWh = megawatt-hours.

Source: International Conference on Energy Efficiency in Buildings. 2015. *Implementing Energy Efficiency in Buildings*. 17–18 December. p. 78.

During the preparation period of the Building Sector Energy Efficiency Project (BSEEP),[55] the following main barriers were identified:

- **Fragmented institutional and regulatory environment.** At the time of the establishment of the fund, the responsibility for energy efficiency lay with the Ministry for Energy, Green Technology and Water (KeTTHA), which had a number of implementing agencies, whose scope of work was not aligned. This led to gaps in policy execution and interference. At the same time, the Ministry of Housing and Local Government had the mandate to regulate building energy design. As is the situation in Malaysia, the bylaws were never fully implemented by the federal and lower levels, as they are not mandatory. Also, the execution was not supervised.
- **No adoption of action plan.** When KeTTHA drafted an energy efficiency action plan in 2013, it was only for 10 years. This provided insufficient planning security for the industry and investors. The plan was based on voluntary reduction based on the thought that if people know how energy can be saved they will do it. This assumption proved to be unsustainable. At the same time, the action plan was issued, and the Sustainable Consumption and Production Plan for Malaysia's 11th Five-Year Plan came into light, supported by the Switch Asia program, creating an overlap of activities.
- **No database.** Despite Malaysia being able and permitted to collect individual consumption data of buildings, it has done so only irregularly. Therefore, the effect of policy and support activities cannot be measured.
- **Limited access to finance.** While there are some successful measures by the government to support energy efficiency in buildings, the financial sector fails to provide finance to the private sector. The reasons are not unique to Malaysia. Banks and financial institutions lack experience in evaluating energy efficiency projects. The concept of financing future savings translated into banking language means that decision-makers must accept future cash flows instead of collateral. This, as can be seen in the much more popular field of project finance, has always been a stumbling block. Third, and not less well-known, is the high transaction costs for relatively small-sized loans compounded by a much more complex financial transaction.

Basic Model

Under the responsibility of Jabatan Kerja Raya (Public Works Department), the agency, under the Ministry of Works and financed by GEF BSEEP, aimed at enhancing the energy conservation design of new buildings and reducing the energy use in existing ones. The project closed in December 2015. It had five components that relate to the barriers identified:

(i) institutional capacity development,
(ii) policy development and regulatory framework,
(iii) energy efficiency finance capacity improvement,
(iv) information and awareness enhancement, and
(v) BEE demonstrations.

[55] Key words: transfer of knowledge from Europe (Croatia) to Asia (Malaysia) and lessons learned; commercial buildings and government sector; new and existing buildings. Sources and further reading:

- UNDP. 2018. Terminal Evaluation for the Building Sector Energy Efficiency Project.
- M. Ahmad. 2011. Introduction to Building Sector Energy Efficiency Project (BSEEP). 14 December. Renaissance Hotel, Malaysia.
- United Nations Development Programme (UNDP). Project Document: Malaysia.

Connecting policy, regulatory, and financial objectives were to be linked to specific outcomes, which for the financial part was the availability of financial and institutional support for initiatives on energy efficiency building technology applications.

The outcomes were formulated to be:

- For 1: Clear and effective monitoring system
- For 2: Implementation of, and compliance to, favorable policies that encourage the application of energy efficiency technologies and practices in the country's buildings and building construction sector
- For 3: Availability of financial and Institutional support for initiatives on energy efficiency applications
- For 4: Enhanced awareness of the government, public, and the buildings and building construction sector on energy efficiency building technology applications
- For 5: Improved confidence in the feasibility, performance, energy, environmental and economic benefits of energy-efficient building technology applications.

The outcomes were then broken down into specific outputs. The situation in Malaysia is not untypical for many countries: a number of laws, regulations, financial support instruments, and fiscal incentives exist; they are not linked to a coherent strategy. Malaysia had a number of governmental financial support programs, which, however, were not sufficiently effective due to an uncoordinated approach between policy, regulation, and financial measures. They have since been combined and renewed.[56]

Under the project it was also proposed to

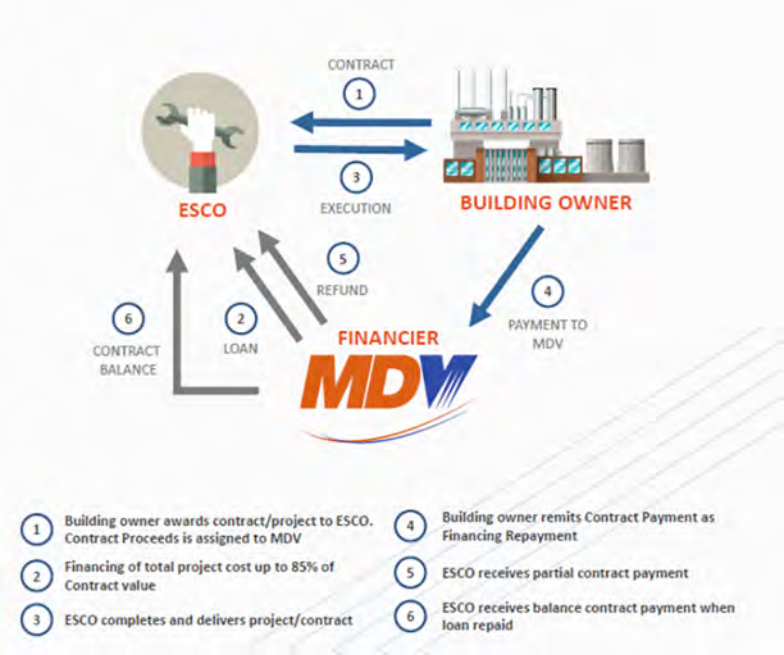
- Establish a dedicated credit line for EPC contracts
- Establish an on-bill finance scheme for commercial building retrofits
- Establish an on-bill finance scheme for household appliances

As a result, an Energy Performance Contracting Fund was provided by Malaysian Debt Ventures (MDV), a corporation under the Minister of Finance, in 2016 with a fund size of RM200 million. In addition, a credit guarantee fund of RM15.8 million from the Ministry of Energy, Green Technology and Water and a RM2 million contribution from the JKR BSEEP, funded by the United Nations Development Programme-Global Environment Facility. Altogether, $52 million was supplied in support of ESCOs implementing energy-efficient projects in the buildings and building construction sector. It combines typical ESCO business with on-bill finance and opens up a spectrum of financing alternatives.

Figure 118 describes the simple mechanism of an ESCO model funded by MDV. Figure 119 shows how, in the next step, MDV as the financing vehicle is secured by a guarantee facility funded by KeTTHA and BSEEP. MDV does the management of the guarantee facility (CGC) in-house. In addition, KeTTHA provides another facility to reduce interest rates for ESCOs from 8% to 7%, thus profiling the repayment scheme. Also, this facility is managed by MDV.

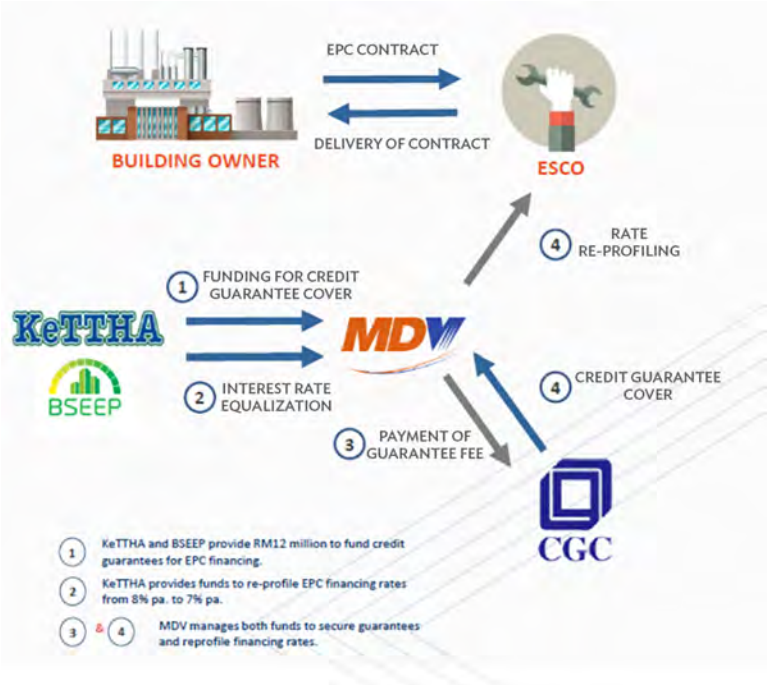
[56] The Green Investment Tax allowance (GITA) and the Green Investment Tax Exemption (GITE).

Figure 118: Malaysian Debt Ventures Fund Scheme



ESCO = energy saving company, MDV = Malaysian Debt Ventures.
Source: Malaysia Debt Ventures Berhad. 2017. The Energy Performance Contacting (EPC) Fund by Malaysia Debt Ventures.

Figure 119: Basic Malaysian Debt Ventures Fund Financial Incentive Scheme



BSEEP = Building Sector Energy Efficiency Project, CGC = Credit Guarantee Corporation, EPC = Energy Performance Contacting, ESCO = energy saving company, KeTTHA = Ministry for Energy, Green Technology and Water (Malaysia), MDV = Malaysian Debt Ventures.
Source: Malaysia Debt Ventures Berhad. 2017. The Energy Performance Contacting (EPC) Fund by Malaysia Debt Ventures.

Success Factors

- Review of tariff policy: removal of primary fuel subsidies to reflect true economic and market costs allowed gradually increasing electricity tariffs.
- BSEEP developed better ties and communication channels between various actors, such as Jabatan Kerja Raya (Public Works Department) and KeTTHA, which helped mending the fragmented sector and apply an integrated approach to energy efficiency in buildings.
- The work of ESCOs is based on newly established and supervised policy and regulatory measures developed under BSEEP, such as BEE codes (MS1525), the application of MEPs, and the disclosure of building energy intensity (BEI). The development of technical measures created synergies between policy and economic instruments. It also gave banks and financial institutions a standard they could tick off when assessing loan proposals.
- The credit guarantee facility is set up as a market-based instrument that covers and leverages private sector funding, while directly supporting public sector funding.
- Balancing policy, regulatory, fiscal, and financial instruments.
- Saving costs by building on the experience of the Croatian Environment Protection and Energy Efficiency Fund. Due to the involvement of the United Nations Development Programme (UNDP) in the project, which supported a similar project in Croatia, parallels were drawn. The energy management system developed by UNDP Croatia was transferred and customized to meet the needs of Malaysia. It facilitates the linkages with existing databases and information systems developed by different ministries and thus can be used to enforce the management and supervision of energy efficiency regulations.

Figure 120: Building Sector Energy Efficiency Project Fiscal and Financial Measures

Technical	Fiscal	Financial
• MS 1525 • MEPS • BEI	• economic audit grants • gross floor area incentive scheme	• economic audit grants • gross floor area incentive scheme

BEI = building energy intensity; MEPS = minimum energy performance standard; MS = Malaysian Standard.
Source: Author.

Super-Energy Saving Company: Berlin Energy Agency

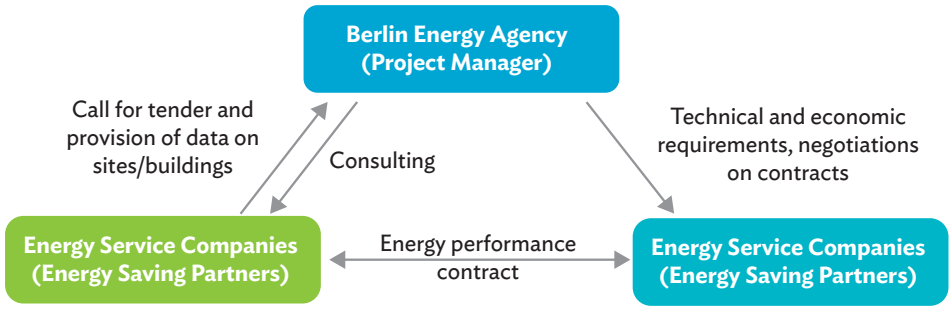
Background

In the early 1990s, the city of Berlin faced high energy bills for its public buildings, but public budgets were reduced also due to the reunification of Germany. Energy costs were created mainly by the cost of heating and lighting adding to the disadvantages of an aging building stock. Berlin Energy Agency (BEA) was established in 1992 with equal shareholdings by four partners, two of which are utilities (Vattenfall Wärme Berlin and private sector GASAG AG), KfW Development Bank and the Federal State of Berlin. Together with the Berlin Senate, BEA developed the Energy Savings Partnership (ESP) and acted as the manager. The objective was to reduce energy consumption by 26%, reduce CO_2 emissions and develop EPCs for large public buildings such as schools, office buildings, and prisons.

Basic Model

Under the ESP, BEA[57] facilitates as an independent advisor retrofit by acting as the arranger between a pool of (public) buildings and ESCOs. It thereby overcomes technical and economic knowledge gaps on the part of the public building owners, which may impact their interest in such savings.

Figure 121: Main Stakeholders of the Energy Savings Program



Source: Adapted from Buildings Energy Efficiency Policies. 2012. *Energy Agencies for the Promotion of Energy Efficiency and RES*. 16 March.

The main components of the ESP are as follows:

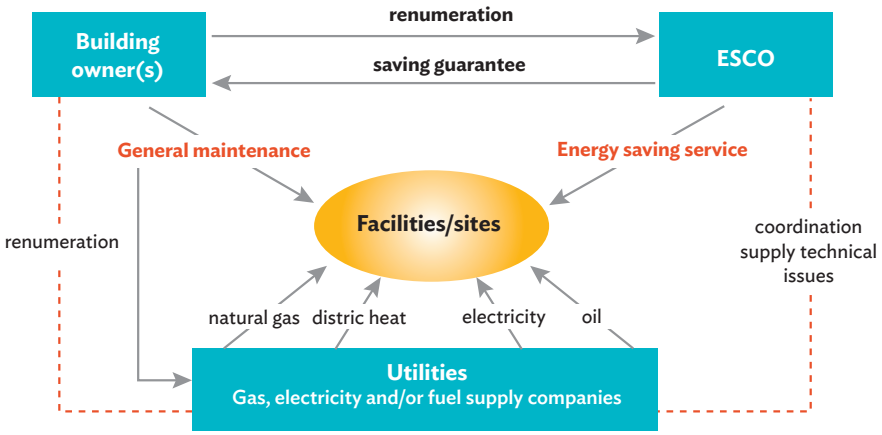
- Building owners may pool several buildings. Required is a total energy bill of approximately $270,000 annually. It allows building owners to club together bigger and smaller projects such as universities with small daycare centers.
  - Buildings cannot be sold over the next 10 years after signing of the contract.
  - BEA must see a certain minimum savings potential.
  - The building must be in use with a similar occupancy rate for 3 years and for the period of the contract.
  - No limitation on retrofitting heating, cooling, and ventilation systems.
- BEA sets the baseline, analyzes the technical necessities on behalf of the building owner, helps to set up the bidding documents, and guides though the tendering process. Because of the market overview BEA will also supports in the negotiation of the financial terms of the contract. Later it will monitor the implementation.
- All participating ESCOs must be accredited.
- According to the EPC contract at least 25% cost savings are targeted, of which 6% go back to the city government and the remainder is used to finance the investments, i.e., the building owners do not pay for the retrofit.
- Average payback periods are between 8–12 years.
- Amounts exceeding the guaranteed cost savings go to the ESCOs.

[57] Key words: possible roles for energy agencies, PPP-led program, public sector develops best practice examples, pooling of buildings to save costs, replication potential in other countries.

Sources and further reading:
- New York City Global Partners. 2011. *Best Practice: Public-Private Partnership for Building Retrofits*.
- BEA. Energy Performance Contracting.
- Achim Neuhäuser. 2012. *Energy Agencies for the Promotion of Energy Efficiency and RES. Buildings Energy Efficiency Policies*. 16 March.

In Berlin, more than 25 pools are in operation involving more than 15 different ESCOs, which have at least 100 subcontractors. These are often regional companies that gain experience in the safe framework of an expert led program. Energy savings range between 25% and 32%.[58] The partnership has now opened to commercial buildings.

Figure 122: Basic Structure of the Energy Savings Partnership



ESCO = energy service company.
Source: NYC. 2011. Best Practice: Public–Private Partnership for Building Retrofits.

Success Factors

- The setup of BEA, with four equal shareholders, brings in political will, technical expertise, and private sector thinking.
- BEA is an expert company providing independent advice and acting as an honest broker between stakeholders.
- A stable legal and regulatory framework on which enforceable standards, EPCs, and tenders were based eases the implementation of the ESP as a program.
- Transparent and standardized procedures.
- Kick-starting ESCO business and/or EPC contracts with public support.
- Guaranteed savings are for building owners, and savings are used to finance investment costs; therefore, there is no direct financing burden for building owners.
- Ability to club buildings into one contract, allowing larger building complexes to participate.
- Success on the public buildings and building construction sector side incentivized also larger private owners to participate.

Further References

In India, ADB has provided loans to Energy Efficiency Services Limited (EESL), which is a public-owned super-ESCO, to expand energy efficiency investments in India. EESL was established in 2009 as a joint venture of four public sector undertakings of the Ministry of Power to pursue large-scale energy efficiency investments, providing a comprehensive package of project design, implementation, monitoring, and investment. ADB's loans in 2016 and 2019 were directed to investments in efficient lighting and appliances, smart meters, distributed solar PV, and electric vehicles.

[58] Established energy savings figures are old. As of 2012, over 1,500 buildings had been retrofitted, leading to a CO_2 reduction of 70,000 metric tons per annum. It has led to $74 million in private investments and financial savings of approximately $14.3 million, which represented 26% of the total energy bill.

8 CONCLUSION

The handbook provides a wealth of technical information for energy efficiency practitioners in the buildings and building construction sector, covering a wide range of policies, technologies, financial instruments, incentives, information and awareness mechanisms, strategies, plans, roadmaps, and business models. An energy-efficient building will reduce energy costs for the building owner, create a higher asset value, improve the health, comfort, and well-being of the residents, and support poverty reduction.

The buildings and building construction sector offers significant opportunities for improving energy efficiency and reducing greenhouse gas emissions, as well as enhancing energy security, affordability, and resilience. The energy demand and emissions from the buildings and building construction sector are expected to grow rapidly in the coming decades, especially in developing countries, driven by population growth, urbanization, economic development, and rising living standards. There are various barriers that hinder the uptake of energy-efficient technologies and practices in the buildings and building construction sector, such as lack of information, awareness, and skills, high up-front costs, split incentives, and regulatory gaps. To overcome these barriers, a comprehensive and integrated approach is needed, combining technical, policy, regulatory, financial, and behavioral measures, as well as stakeholder engagement and collaboration.

First, to accelerate the adoption of energy efficiency in the buildings and building construction sector (both new and existing buildings), it is imperative that governments reconsider the use of inefficient fossil fuel subsidies, improve availability and access to building energy use data, set national energy efficiency targets for buildings, and enable local governments to adopt and effectively enforce mandatory building energy codes. The energy performance of buildings can be improved by applying passive design principles, optimizing building envelopes, using efficient HVAC systems, lighting, appliances, and equipment, integrating renewable energy sources, and implementing smart building management systems and controls. The choice and combination of these technologies and practices depend on various factors, such as climate, building type, function, occupancy, user behavior, and cost-effectiveness. The energy savings potential of these technologies and practices can vary significantly across regions and building segments, but in general, they can achieve a 30%–80% reduction in energy consumption compared to conventional buildings.

Second, green building certification and energy labeling can help building owners identify buildings that go beyond the national standards and assist the government in providing incentives to cover the incremental costs or even expedite the permitting process of green buildings. The main types of incentives for stimulating energy efficiency investments in buildings include fiscal incentives (such as tax credits, rebates, subsidies, and grants), financial incentives (such as preferential loans, guarantees, and green bonds), and nonfinancial incentives (such as recognition, awards, and public procurement). The design and implementation of these policy and regulatory frameworks and incentives require careful consideration of the local context, stakeholder interests, institutional capacities, and monitoring and evaluation mechanisms.

Third, capacity building of government staff and the private sector will be important to ensure there is a sufficient skilled workforce to deliver and invest in sustainable and efficient buildings in the country. Energy efficiency can contribute significantly to job creation, particularly in building retrofits. The adoption of energy-efficient technologies and practices requires adequate technical capacity, quality assurance, performance monitoring, and feedback mechanisms, as well as user education and engagement. Project development and financing are key steps for realizing energy efficiency investments in the buildings and building construction sector, which involve identifying, assessing, and prioritizing opportunities, preparing bankable project proposals, and securing adequate and affordable sources of funding. The main challenges for project development and financing of energy efficiency investments in the buildings and building construction sector include lack of data and benchmarks, high transaction costs, low profitability and long payback periods, perceived risks and uncertainties, and limited access to capital and credit. To address these challenges, various tools and methodologies can be used, such as energy audits, energy performance contracting, measurement, and verification, ESCOs, and blended finance. The main sources of funding for energy efficiency investments in the buildings and building construction sector include public funds, private funds, and multilateral and bilateral funds, which can be mobilized and leveraged through different instruments and mechanisms, such as grants, loans, equity, guarantees, and carbon finance.

Fourth, it is essential to have enhanced information and awareness on energy efficiency policies and technologies at different levels of government, including building owners, developers, real estate companies, and even the banking and utility sectors. This handbook aims to raise awareness of BEE measures, provide a better understanding of the potential, proven technologies, and financing instruments applicable to this sector, and foster project opportunities within DMCs. To address this point, ADB has prepared this handbook as its contribution to opening a sensible avenue for the transition to a zero-carbon, efficient, and resilient building stock.

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A STUDY ON THE ENERGY CONSUMPTION OF THE ELECTRICAL AND ELECTRONIC HOUSEHOLD AND OFFICE EQUIPMENT IN STANDBY AND OFF-MODE

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Abstract. ***The most recent generation of the electrical and electronic household and office equipment is far more efficient than its predecessor, but it is still improvable. The smart equipment, when it is used, adds the advantages of the supplementary control functions with the requirements of beeing electrically supplied. By interconnecting the smart devices in a data network, some of the energy consumption occurs even in the non-active states. These states, either a "stand-by" mode or an "off-line" mode, according to the European Committee directives, imposes maximum limits for the electricity consumption, thus an eco-design of the electrical and electronic equipment. The impact of these eco-design requirements on household appliances and office equipment with repercussions in their operation and use, as well as the energy and environmental effects, are dealt in this paper, based on a case study.***

Keywords - low energy consumption, efficiency, eco-design requirements, standby mode

1. INTRODUCTION

A general feature of household and office electrical and electronic equipment is that it consumes electricity in on-mode and both standby mode or off-mode. These categories of consumption are regulated by Council Regulation (EC), no. 1275/2008 of 17.12.2008 [1], which imposes eco-design requirements for standby consumption, as amended by Regulation (EC) no. 801/2013 [2], on eco-design requirements for household appliances in relation to the standby mode.

According to the EC regulations [1], [2]:
- active "on-mode" of operation is the state in which an equipment is connected to the electrical grid and performs the main functions for which it was designed,
-"stand-by mode" of operation is the state in which an equipment is connected to the electrical grid and provides only the reactivation function with/or without the indication (display) of status information or other information,
-'off-mode' means the condition in which the equipment is connected to the electrical grid and does not perform any function'.

It should be noted that the standby mode is an electricity consumer and in accordance with EC regulations [1] and [2], the power consumed in stand-by mode must be not more than 1W. For some household and office equipment, stand-by mode is necessary, e.g. the sleep mode operation on laptops and printers, LAN and Wi-Fi network equipment or alarm systems, but for a fairly wide range of devices, the stand-by mode is not necessary, as in this state of operation the equipment does not perform functions for which it was created, i.e.: air conditioning, television, electric ovens, when the consumed electricity is considered a loss of energy.

According to the Monitoring Report on the Implementation of the National Energy Efficiency Action Plan, Section P7 – Energy Efficiency in the Residential Sector [4], it is noted that in Romania, as a result of the alignment with European Union (EU) directives and an increase in living standards, energy consumption in the residential sector has also increased against the background of the continuous increase in the volume of household and office products purchased (predominantly of minimum energy class A and "smart").

Power losses in standby mode at the equipment level of approximately 1 W seem to be insignificant, but multiplied by the large number of equipment and standby operating time make the energy loss significant and especially unjustified, and as a result of the increasing trend of purchased household appliances, energy losses in the standby mode will also increase.

In this paper, an impact analysis was carried out on a modern residential building with a normal occupancy level, in order to implement the community eco-design requirements on electricity consumption in the off-mode and standby mode of household and office electrical and electronic equipment.

Significant energy losses identified in standby operation mode, amounting to 34% of the total annual energy consumption of the residential building studied, which require substantial action to be taken with regard to:
- the energy class of equipment to be purchased on the market,
- identifying and implementing measures to reduce standby consumption and,
- changing people's behaviour versus using household and office equipment.

2. ACTUAL SITUATION IN THE EUROPEAN UNION

The rules governing the standby and off-mode consumption in the EU are the EC Regulation, no. 801/2013 on eco-design requirements for household appliances, amending EC Regulation, no. 801/2013 on the design requirements of household appliances, 1275/2008, relative to the standby electrical consumption with information/display state of maximum 1W and consumption in off-mode and standby with reactivation of maximum 0.5W. Particularly, in Romania, according to our knowledge, there are no specific rules to reduce the electricity consumption of household and office equipment in standby and off-mode modes. Only a few information-education activities initiated by ANRE (Romanian National Energy Regulatory Authority) were carried out. At European level, measures to increase the energy efficiency have replaced the old household and office equipment with higher energy-class ones. A matter of great importance is that the new generation home appliances are more energy efficient than their predecessors. They are of the smart type or even 5G generation type and are equipped with additional functions that require to be connected to the electrical grid and interconnected to each other over the LAN or 5G network, during the period when they are not actively operating.

Currently, according to [3], based on recent measurements carried out in about 1300 households across the EU, the average annual electricity consumption in standby mode was found to be almost 7% of the total annual energy consumption per household. Further, the International Energy Agency (IEA) estimates a 15% increase in the standby energy consumption by 2030 [5], [6]. With the objective of measurements of energy loss in standby and off-mode [7], the SELINA project has been launched by ISR - Coimbra University (Portugal). It was geared towards characterising the EU market in terms of standby consumption and off-mode mode of new household and office electrical and electronic equipment, which is sold on the market. The study was carried out on 6318 equipment on a geographically diverse sample of 12 EU Member States between 2009 and 2010, before and after the entry into force of Regulation (EC) 1275/2008 [1] on standby and off-mode energy consumption [7]. Power consumption was recorded in the standby mode and off-modes, in compliance with the requirements of Regulation (EC), no. 1493/1999, 1275/2008 (1W/2W) and EU Regulation, no. 801/2013 (0.5W /1W), showing the percentage of products above the regulatory threshold imposed in 2010 and 2013.

It was found that 18.5% of the equipment does not meet the EU regulatory threshold of 1 W for the off-mode electricity consumption. When measurements are compared to the 0.5 W threshold of 2013, this percentage increases to 41.5%. In terms of standby consumption, 31% of the measured products did not meet the EU regulatory limit for the 2010 threshold. When measured values are compared to the 2013 limit, the number of products above the EU regulatory target increases to 66.4% (Figure 1).

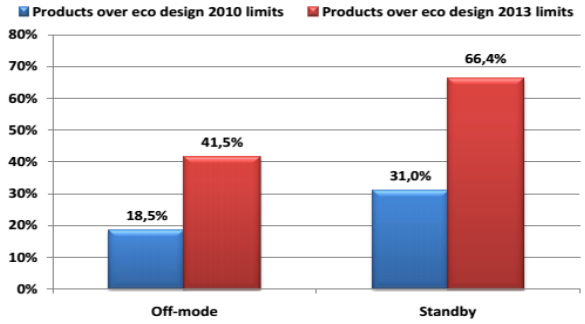


Figure 1. Equipment in the EU with overconsumption [7]

According to [8], for the years 2005 and 2010, the electricity consumption in the EU for standby and off-mode modes is of the scale of those presented in Figure 2. For 2010, the study estimated that equipment, worth around EUR 3.7 billion, has been installed in the EU, which has standby/off-mode modes, leading to a standby/off-mode electricity consumption of almost 50 TWh, corresponding to electricity costs of around EUR 7 billion and 20 million tonnes of CO2 emissions (Figure 1). Combined with other measures to reduce consumption as a result of the purchase of higher energy class equipment (A, A++, etc.) an energy saving of 194 TWh, equivalent to EUR 26.4 trillion and a reduction in CO2 emissions of 77.6 million tonnes [8] was expected for 2020.

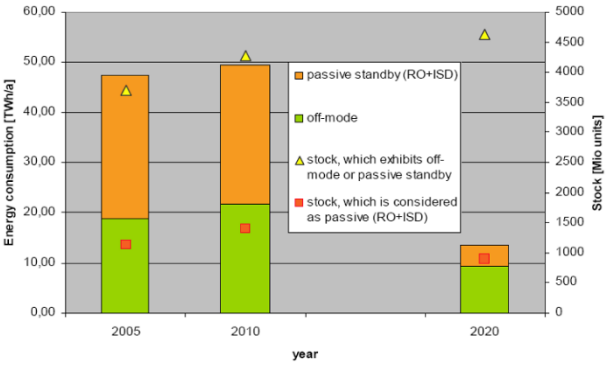


Figure 2. Evolution of the energy consumption in the EU in standby/off-mode and assuming a level of energy consumption 0.5W / 1.0W in 2020 [7], [8]

The commission also named and proposed the consume types 'Hard off-switch' or '0 Watt off-mode' for some equipment. But complying with electromagnetic compatibility and other technical requirements, consumptions of 0.1 – 0.3W cannot be technically avoided and 0W consumptions cannot be technically achievable with the maintenance of minimum electromagnetic compatibility requirements [8]. So the target of "0 Watt" will remain a desiderate.

The design process, manufacturing, purchase of household and office equipment don't keep up with the eco-design requirements imposed by the Regulations (EC), no. 1275/2008 and EU, no. 801/2013. It is estimated that, in

present (Figure 3) we should consume 10% of total household energy consumption [6].

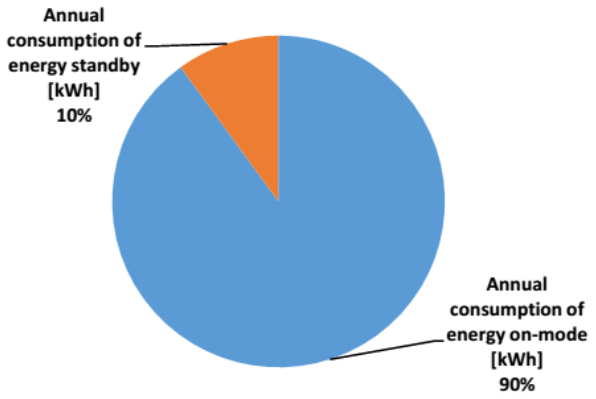


Figure 3. Estimated energy consumption by IEA for 2020 [6]

3. ENERGY CONSUMPTION OF THE ELECTRICAL AND ELECTRONIC EQUIPMENT IN A RESIDENTIAL BUILDING

An impact analysis of the implementation of community eco-design requirements on energy consumption in the off-mode and standby mode of the household and office electrical and electronic equipment was carried out. The systematic investigation has been included every consumer, which was connected to the power grid of the residential building, electrical consumers were grouped into two categories:
a) electric lighting lamps: fluorescent low-pressure mercury vapour tubes and low-pressure mercury fluorescent economical lamps, and
b) household and office appliances: air conditioning, gas-fired power plant, smart TVs, media box, refrigerators, freezer, washing machine, microwave, electric cooking oven, hood, coffee expressor, dust vacuum cleaner, iron, hairdryer, radio, HI-FI combine, smart phones, laptop, tablet, printer and internet modem. All household and office appliances are energy class A and A+ and are manufactured between 2012 – 2019.

By energy consumptions, the energy consumers were highlighted in the active on-mode of operation as well as in the "standby" mode of operation. No household and office consumer analysed shall have a switch intended to be switched off. Switching off mode can be done by physically disconnecting from the grid, where this manoeuvre is available. All consumers destined for electric lighting have only two operating conditions: active on-mode and off-mode (by disconnecting with switches on lighting circuits). So, the power consumption in standby mode is given only by the home appliances and the office consumers.

Following the analysis carried out for consumption, in active and standby operating regimes, and the degree of use of household and office equipment, the most representative situations are:
- high-power appliances, but with a seasonal use of 1.7%, e.g. an air conditioner which standbys a very low current (8.1mA) compared to the current consumed in active mode (2.2A) but, due to the very low use of 1.7% given the seasonal use, an annual standby consumption (15.14 kWh) is achieved compared to active consumption (70.66 kWh),
- smart TVs of low power, with daily use and an unreasonably high standby current (0.11A), almost third part of the current consumed in the active mode (0.29A). Due to the high standby consumption at a daily use of 20%, it results in an annual standby consumption of 175.86 kWh higher than the active operating energy of 92.51 kWh.

There is an exaggerated and unjustified annual energy consumption for some categories of household and office equipment, which requires measures for increasing their efficiency. Based on direct performed measurements for each household and office consumer, and corroborated with the occupancy rate of dwelling (two persons as an example), the daily, weekly, monthly and annual operating schedules (on/standby/off) of each consumer household appliances and each lamp, were determined:
- annual energy consumption in the active mode of operation E_{mod_activ} amounting to 2714.47 kWh,
- annual energy consumption in standby $E_{standby}$ mode of 1385.95 kWh,
- total annual energy consumption, amounting to 4100.42 kWh.

The share of consumption by groups of household appliances, from the total household consumption is presented in Figure 4, and the separation of consumption in the two active and standby modes is shown in Figure 5.

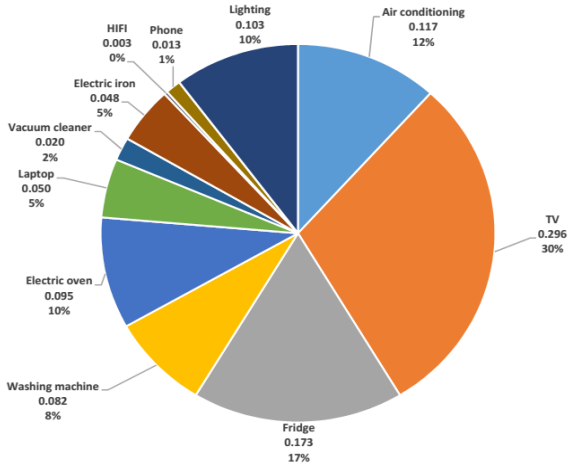


Figure 4. Energy consumption by groups of household appliances

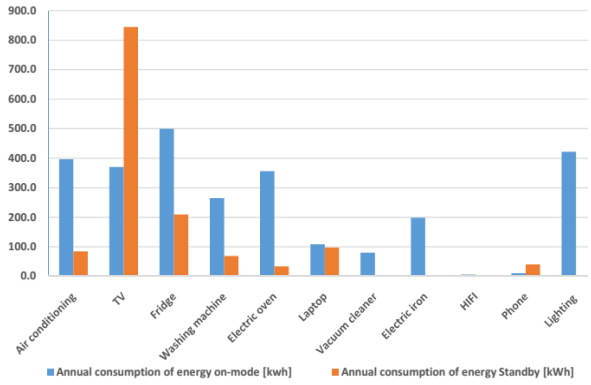


Figure 5. Energy consumption in active and standby modes of household and office equipment

On the data taken in this study, an excess consumption of 34% (Figure 6) was found to be unreasonably high and a serious discrepancy from the estimated European average consumption in this segment for 2020, amounting to 10% of total energy consumption per place of residential consumption (according to the IEA [6]). In terms of standby consumption, immediate measures are needed to reduce consumption by identifying solutions to modernise and implement a flexible energy consumption control system for household and office equipment related to residential construction.

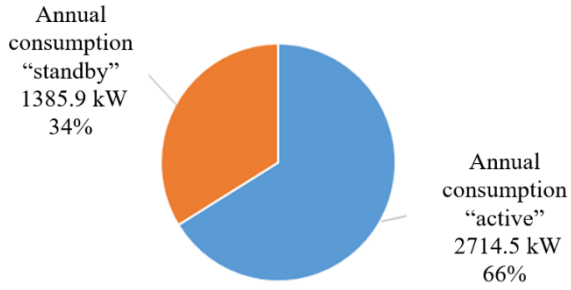


Figure 6. Annual energy consumption in standby and active modes for residential building equipment

Minimizing the loss of energy consumed by the household and office equipment is possible by implementing of a flexible system of control of operating conditions: active (ON), standby (pending) and off-mode (off). The lighting installation is not upgraded because all lamps have only two operating states: on-mode (active) and off-mode. In the off-mode state there are no electricity consumptions. The solution adopted was to add in the electrical installation, directly to the socket (without the lighting installation), appropriate devices for modernising the electrical installations, related to an already inhabited residential construction, without making significant constructive changes to the existing electrical installation. These devices are accessible on the market and with an easy way of installation between the household appliance and the power supply, with parameters in the range 16A, 230V, 3600W, of several types: adapter sockets with ON-OFF switch, ON/OFF adapter sockets with WiFi remote control 433.9MHz, ON/OFF "smart-home" adapter sockets integrated into the 2.4GHz WiFi network with smart phone control on Android, programmable switch ON/OFF, ON/OFF switch with twilight light sensor, ON/OFF switch of the "standby killer" type or according to the "Energy Saver" standard. As a principle of operation, these switches are added between the household appliance and the power socket and interrupt the consumer's power supply by remote, manual or automatically and independently (with a twilight sensor or timer). In this way, the standby mode is forced to become off-mode) and standby consumption is significantly reduced or completely eliminated.

The electrical energy assessment carried out on a domestic electrical installation, after modernisation has revealed the following:

- the distribution of the energy consumption by groups of household appliances in the total household consumption has been changed (Figure 7),
- reduced consumption in standby, obviously for smart TVs, (Figure 8),
- annual energy consumption in the active operating mode (including household lighting energy) E_{mod_activM} of 2760.4 kWh has shown a very small increase.
- annual energy consumption in the standby mode $E_{standbyM}$ decreased to 589.6 kWh, i.e. from 34% of total energy consumption (initial consumption) to 18% after modernisation (Figure 9).
- total annual electricity consumption E_{i_M} decreased to 3350 kWh.

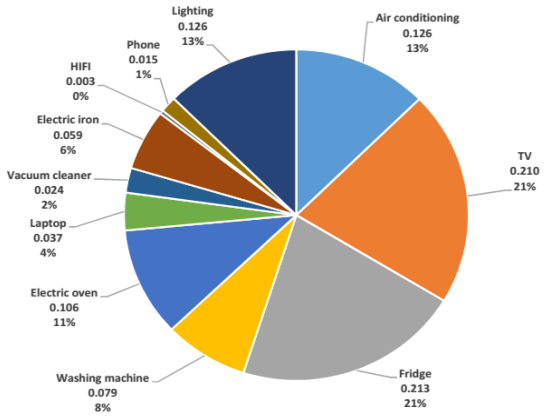


Figure 7. Energy consumption by groups of appliances after modernisation

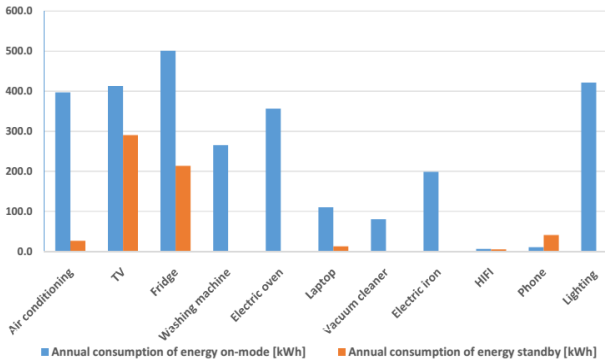


Figure 8. Annual energy consumption, by consumer groups, in the active mode and standby of operation after modernisation

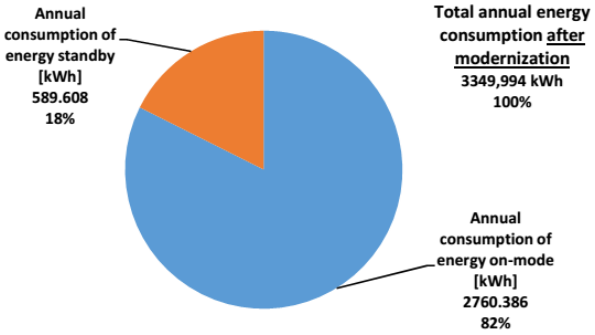


Figure 9. Annual energy consumption in standby mode and active mode relative to all consumption, after modernisation

The energy consumption, when the electrical installation is modernised with controlled ON/OFF switches is shown in Figure 10.

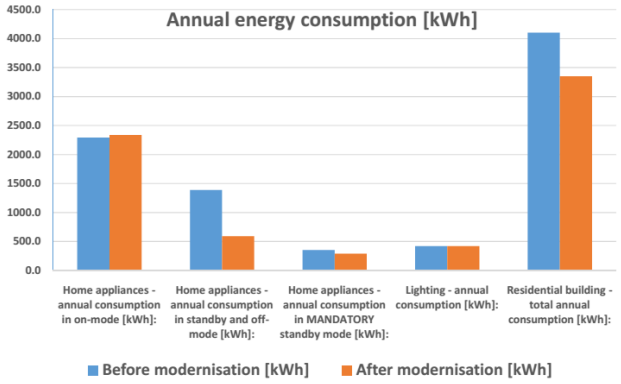


Figure 10. Evolution of energy consumption as a result of the electrical installation modernisation

4. CONCLUSIONS

The energy assessment has found that some of the household and office appliances correspond to the energy consumption in the standby operating regime, covered by Regulation (EC), no. 1275/2008, as amended by Regulation (EC), no. 801/2013. For a range of household and office equipment, standby mode is considered necessary, but for a fairly wide range of standby equipment, it is not necessary. In the standby mode of operation some of the electrical and electronic equipment does not perform the functions for which they were created, e.g.: air conditioning, TVs, electric ovens, etc., and the electricity consumed is considered a waste of energy. For other equipment, e.g. smart TVs, the energy consumption in standby mode is unreasonably high.

For the residential building studied, by taking measures to reduce standby consumption, consumption reductions can be made from 35% to 18% of the total consumption, i.e. a reductions of 750.4 kWh per year. In addition to the financial effects, this reduction has a environmental beneficial effect, because, according to the estimations of the EU member countries [3], this reduction in the annual energy consumption means a reducing of the CO2 emissions into the atmosphere by 0.218 tonnes per year (for a dwelling/year at a conversion rate for 2018 of 289.85 g CO2/kWh).

The standby and off-mode energy consumption of 18% of the total consumption on residential construction exceeds the EU's 2020 estimate of 10%, but it is still an improvement from the initial situation.

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[7] SELINA - Grant agreement No. IEE/07/563/SI2.499206 –„Standby and Off-Mode Energy Losses In New Appliances Measured in Shops", contractor: ISR - Coimbra University (Portugalia), ISBN: 978-972-8822-21-7, 2010.

[8] DG TREN Impact Assessment. 18/12/2008 - Document accompanying the Commission Regulation, implementing Directive 2005/32 / EC on eco-design requirements for the standby and off-mode consumption of electrical and electronic equipment for household and office use. Brussels: no., 18/12/2008. SEC (2008) 3071.

PVSYST
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PVSYST 7

Stand Alone



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INTRODUCTION

This document is the first chapter on the basic aspects of simulation for stand-alone systems.

More tutorials on different features of PVsyst are in preparation and will be added in the future. The complete reference manual for PVsyst is the online help that is accessible from the program through the “Help” entry in the menu, by pressing the F1 key or by clicking on the help icons  inside the windows and dialogs.

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Chapter 1: Basic Approach - My First Project

1.1 First contact with PVsyst

Stand-alone systems are always organized around a battery storage. A PV array charges the battery or directly delivers its power to the user. Therefore, the daily profile of the user's needs (consumption) should be well defined (i.e., in hourly values).

On the hour, the simulation performs a balance between the PV production (depending on the irradiance) and the user's needs. The difference should be derived in the battery, either positively (charge) or negatively (discharge).

This energy balance is controlled by a controller. The role of the controller is to handle the energy flow, mainly for the protection of the battery:

- When the battery is full, the PV array should be disconnected.
- When the battery is empty, the user should be disconnected.

Moreover, the controller may manage the starting of an eventual back-up generator (Genset), when the battery is empty, and the solar gain is not sufficient.

In any case, the reconnection will be performed with a specific hysteresis, depending on the state of charge (SOC) of the battery.

Very little stand-alone systems (SHS: Solar Home Systems):

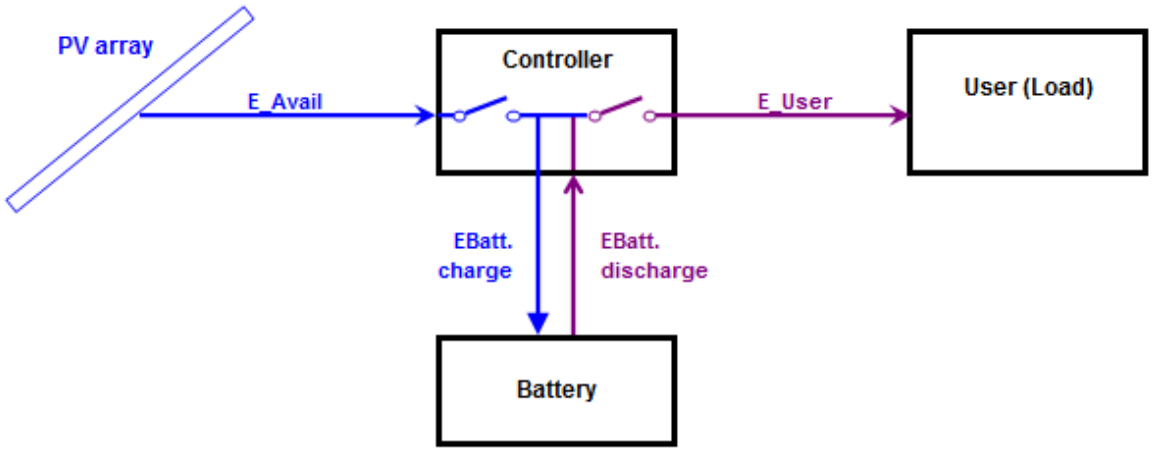


Figure 1: Very little stand-alone systems.

This concerns small systems (50 to 200 Wp) with a very limited consumption (some lights, radio-TV, computer, no fridge).

With these simple systems, the PV array (one or few modules) is usually connected directly to the battery, without power conditioning. This implies that the PV modules should be "12V" or "24V" modules, i.e., with 36 or 72 cells.

This type of installation is managed by simple controllers, acting either by disconnecting the battery, or short-circuiting the PV modules when the battery is full. These controllers have always the ability to control the load when the battery is empty.

Medium power systems (small household, communications):

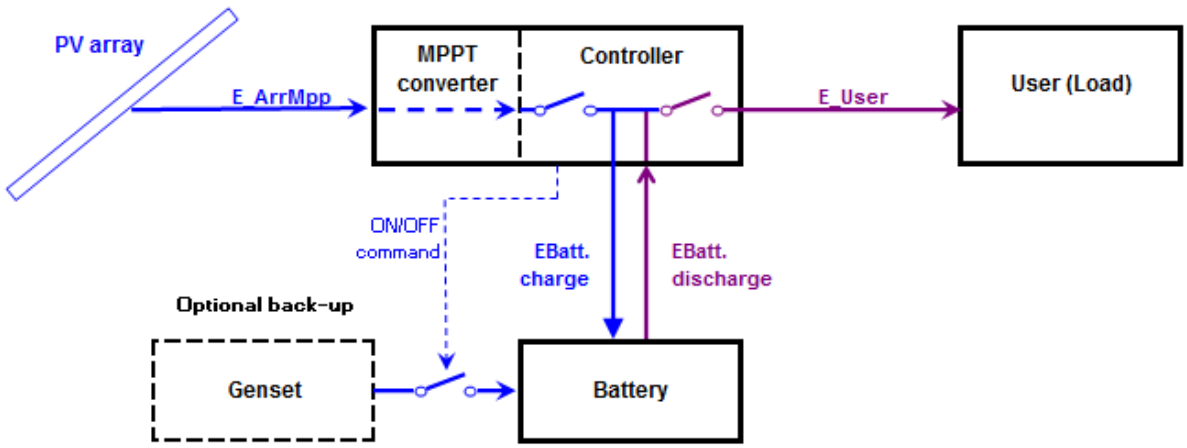


Figure 2: Medium power systems.

These systems are usually ranged between 200 Wp and 2 kWp.

The controller includes a power conditioning unit that can perform the maximum Power Tracking on the PV array. Therefore, the PV array voltage is no longer related to the Battery pack voltage. Most of the time, the controller is also able to ensure the load control, with a limited current capability (usually of the order of the charging current).

These installations may power lighting, fridges, washing machines, dishwashers, small electro-tools, etc. These may also be used in some small remote communication stations.

The energy may be used as DC energy or fed as AC energy through an inverter ("Battery inverter").

Currently, PVsyst does not implement the inverter. The Load is specified as energy, whichever way it will be used.

Such systems may - rarely - be supported by a back-up generator in case of lack of energy. If automatic, the Genset start/stop command should be managed by the controller.

High power systems (Household, communication relays, isolated little industry, etc)

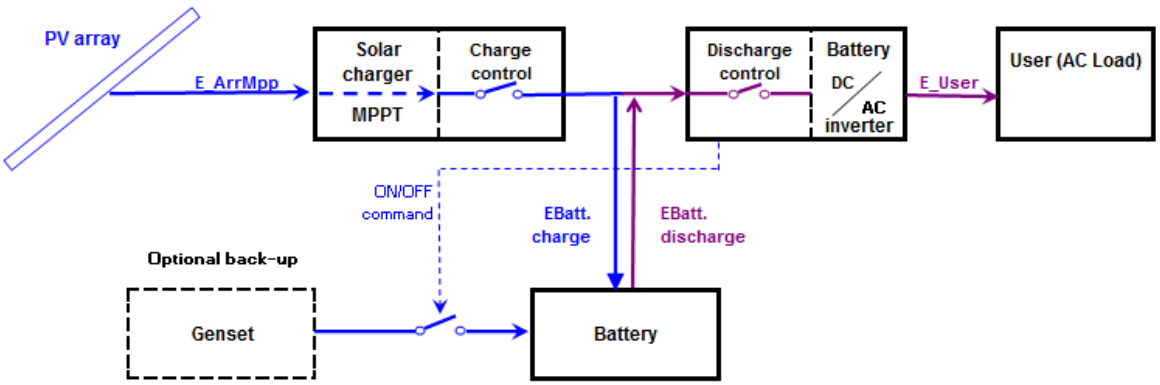


Figure 3: High power systems.

These may be stand-alone systems of 2 kWp to several dozens of kWp.

Such installations use one (or several) “Solar chargers", equipped with MPPT converters, and DC/AC battery inverters.

The controller is not a single device anymore: the charging control is ensured by the Solar charger (sometimes several in parallel) and the discharge control by the inverter. The inverter should also manage the back-up generator if any.

In PVsyst, we consider the Solar Charger as the “Controller for Stand Alone" component. For historical reasons (and simplification), this PVsyst component has also to control the discharge and the back-up generator. But as the parameters for these functions are not defined within the "Solar charger" physical devices (data sheets), the internal parameters for these controls (maximum current, thresholds, etc) will remain in the dialog of this component, but their values will be defined within the system. Their initial values will be adapted from the system configuration and will be modifiable according to the real Inverter used, or other control device.

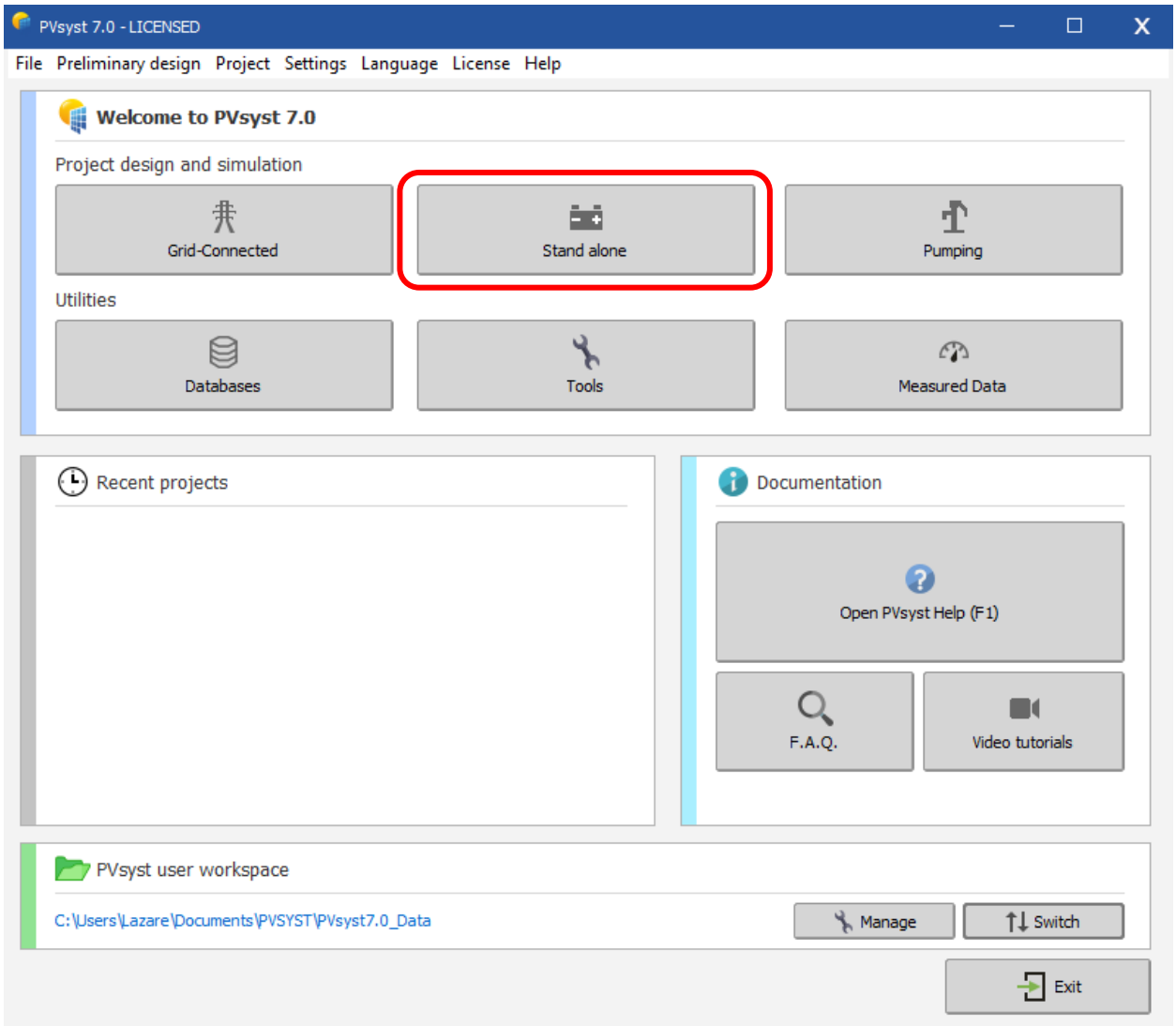


Figure 4: Starting a stand-alone project.

Stand-Alone system procedure – A step-by-step guide to define stand-alone system in PVsyst.

Step 1:

Similarly to any PVsyst system, you have to specify the orientation of the PV array.

Step 2:

You will be asked to define the user's needs.

By default, for small systems, this is proposed as a list of domestic appliances and their consumption (may be seasonal or monthly).

For industrial or bigger systems, you have many possibilities to define a load profile (including by a list of hourly values).

Step 3:

The Pre-sizing tool (on top) gives advice about the required Battery bank and PV array power.

The calculation is based on your meteorological files and above definitions. You should define:

- the required autonomy (usually around 4 days),
- the acceptable probability that the needs are not covered by the system (PLOL: "Probability of Loss of Load),
- the nominal voltage of the battery bank.

The program will then perform a system sizing, in a similar way as in the "Pre-sizing" section.

You also have a button for a more refined sizing studies for different meteorological distributions, or according to the PLOL parameter.

Step 4:

Define the battery pack by choosing a battery model ("Storage" page).

The program will propose the number of batteries in series and in parallel according to the suggestions obtained in the previous pre-sizing tool.

You should also define the operating temperature conditions for the batteries, according to your system implementation.

Step 5:

Define the array configuration and control strategy ("PV array" page) by:

- Acknowledging the pre-sizing propositions (planned power or available area),
- Choosing a PV module model in the database,
- Choosing the control strategy (direct coupling, MPPT or DCDC converter).

You are advised to start by choosing the "Universal controller" to get rid of the specific control conditions.

The program determines the number of modules in series and in parallel according to the battery voltage or MPPT conditions and required PV power.

1.2 Define Orientation

1.2.1 Creating the first (basic) variant for this project

After defining the site and the meteorological input of the project, you can proceed to create the first Variant. You will notice that in the beginning there are 2 buttons marked in red: “Orientation” and “User’s needs”.

The red color signifies that this variant of the project is not yet ready for simulation: additional input is required. Basic parameters that need to be defined for any of the variants, and not yet specified are the orientation of solar panels, User’s needs, type and number of PV modules, type and number of batteries that will be used.

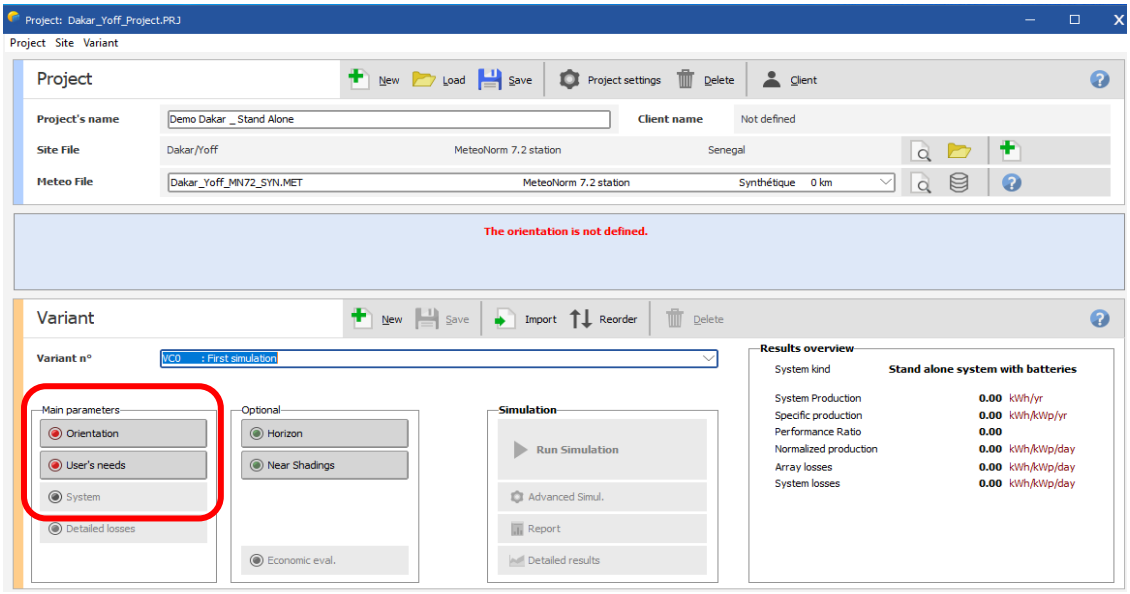


Figure 5: Basic parameters to be defined.

Firstly, you need to click on the “Orientation” Button:



Figure 6 : Orientation dialog.

This tool aims at showing the best suited orientation for a PV system or what you lose when not optimally oriented.

The Transposition Factor is the ratio of the incident irradiation on the plane to the horizontal irradiation, i.e., what you gain (or lose) when tilting the collector plane.

Now, please observe that the optimization of the orientation depends on the planned use of the PV energy. For Stand-Alone systems, the relevant solar yield for sizing the system may be, for example, the winter months for a house or industrial system, or some specific months for leisure appliances.

Therefore, this tool gives the possibility to choose the optimization period by year, winter, summer, or chosen months.

Moreover, the optimization may depend on specific far-shading conditions (mountains): you can define a horizon line, and this will usually result in an azimuth displacement.

Quick optimizing tool in the "Orientation" part:

When choosing the (fixed) plane orientation, an information panel indicates the corresponding Transposition Factor, the difference (loss) with respect to the optimum orientation, and the available irradiation on this tilted plane.

A graph of the Transposition Factor in terms of the plane tilt and azimuth will indicate your actual choice with a violet circle on the curves, showing at once where you are positioned in terms of the optimum.

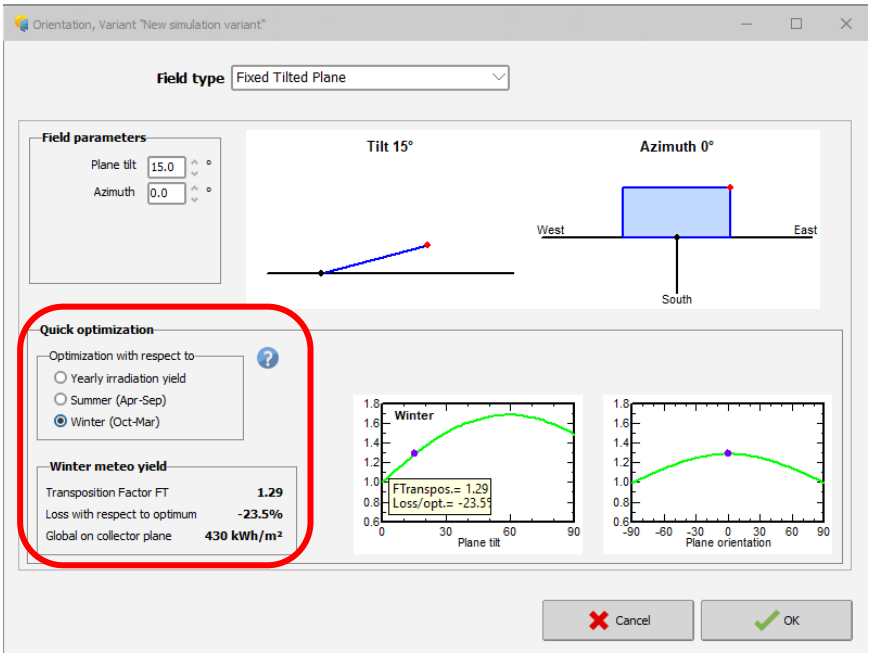


Figure 7: Orientation quick optimization tool.

1.3 Definition of User's needs

Now, we need to define the User's needs.

Several options are available:

- Use of a consumption profile available in the database.
- Import a consumption profile in CSV format.
- Use the user's needs definition interface.

1.3.1 Basic definition

We will use the user requirements definition interface to give you keys to customize the definition of your energy needs.

To complete your energy needs, you must in any case click on the "User's needs" button.

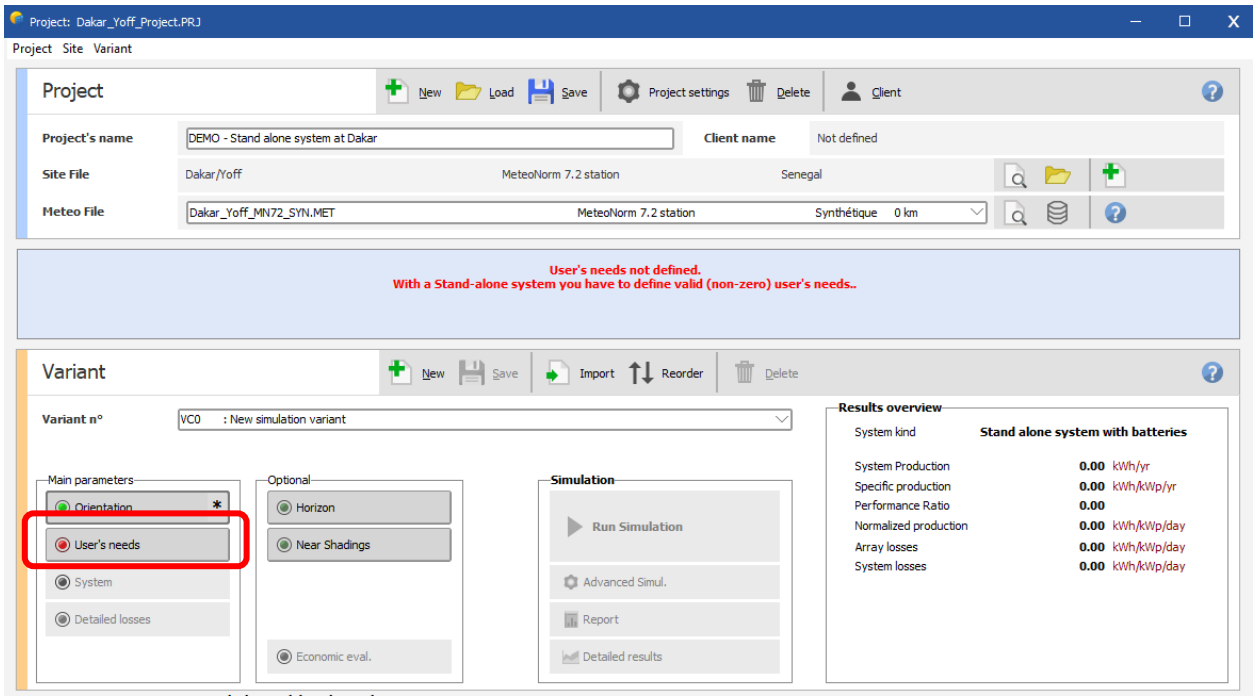


Figure 8: Defining the user's needs.

Once the "User's needs" menu is open, start by defining the frequency of your needs.

You can choose the distribution of your consumption between: Years, Seasons or Months.

Also, you can choose the number of days in week of your consumption.

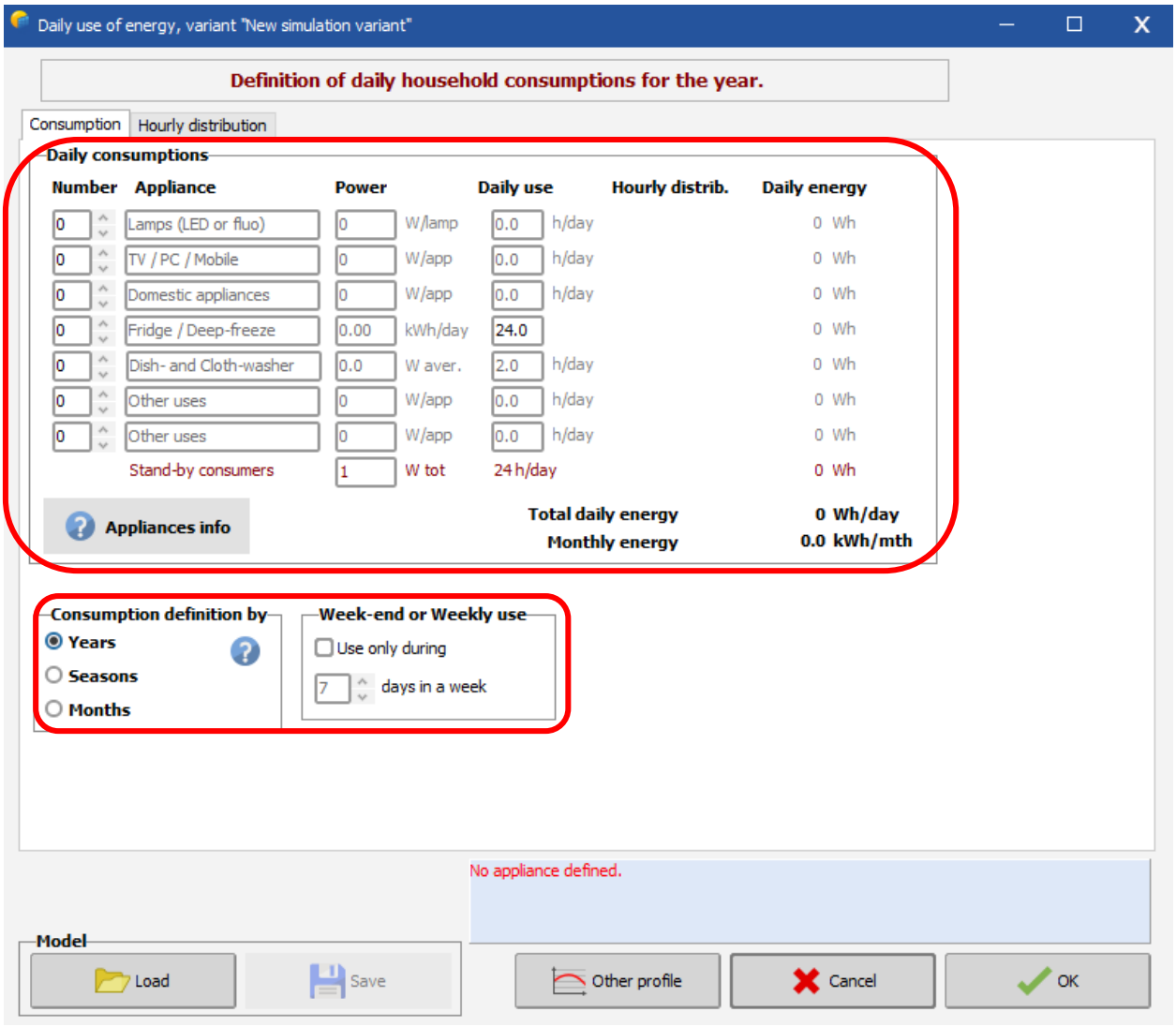


Figure 9: Consumption tab in the user's needs dialog.

The next step is to complete the table of daily consumption.

To do so, you will need to define the:

- number of appliances corresponding to the designation,
- unit power in Watts,
- the daily operating time.

You can modify / customize the name of each device in the “Appliance” section.

Please note that we are not talking about unit power, but the energy consumed (in kWh / day).

Once the definition of your energy requirements is complete, you have a balance sheet of the total daily and monthly energy consumed by your devices.

You can see that we have added 24 Watts on 24 hours a day for the Stand-By consumers. In fact, when your devices are off, very often a standby or other lamps remains on. It is therefore necessary to define this consumption in order to achieve a dimensioning closest to reality.

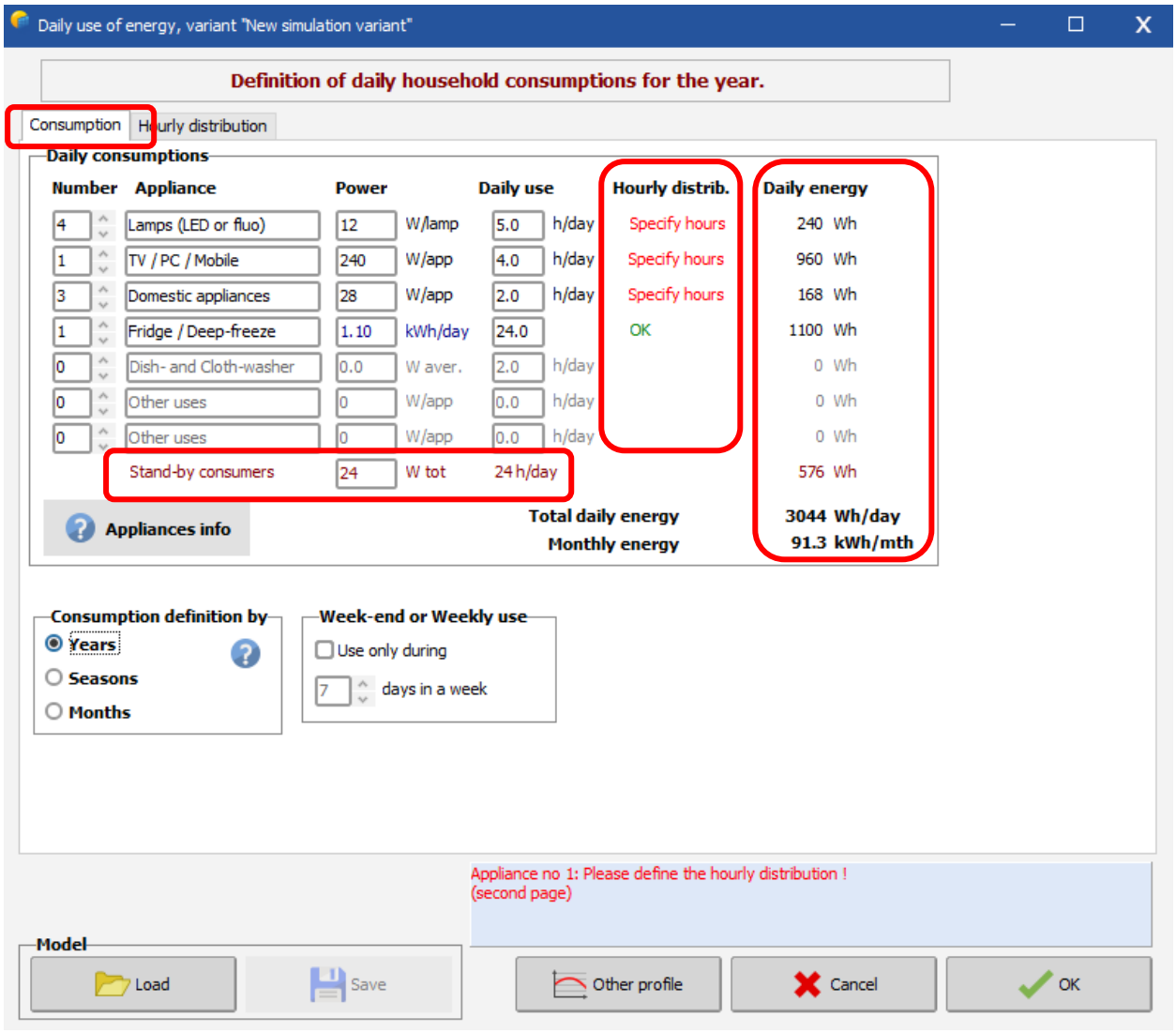


Figure 10: Definition of daily household consumptions for the year.

Several error messages in red indicate that you are still yet to finish defining your “User’s needs”.

In fact, now that you have defined the devices and their power, you must enter the operating time slots for these devices.

It is important that these time slots are correctly completed because it is with these elements that the sizing of the photovoltaic field and the battery pack will be calculated by the “pre-sizing” tool.

When you click on the “hourly distribution” tab, the respective watch dials for your devices will be empty.

Only the dial for the refrigeration systems will be completed beforehand (obviously modifiable according to your project).

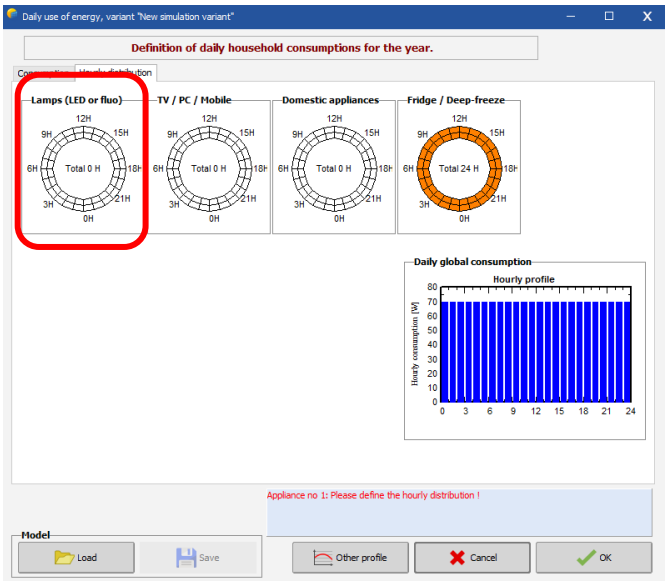


Figure 11: Defining the hourly distribution of each appliance.

Each dial is made up of 48 sections. Each section represents 30 min of the day. Left-click to define a schedule or a time range, and right-click to delete a schedule or a time range.

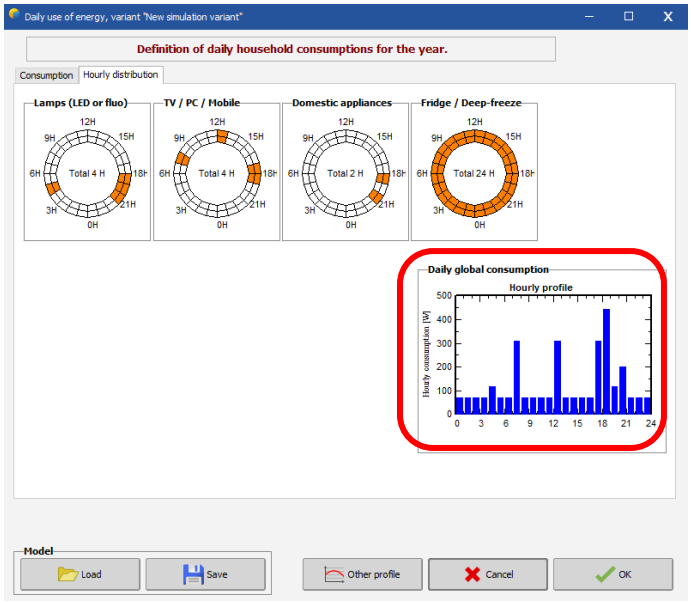


Figure 12: Daily consumption graph.

When you add a time slot, a graph corresponding to your daily consumption profile is automatically constructed.

Also, if the value of the operating hour positioned in the dials does not correspond to the daily use defined in the “Consumption” tab, the value defined in the dials in the “Hourly distribution” tab will be used for calculations.

Once the hourly distribution has been completed, you can return to the “Consumption” tab to check if a change in value has been made and if no error message appears.

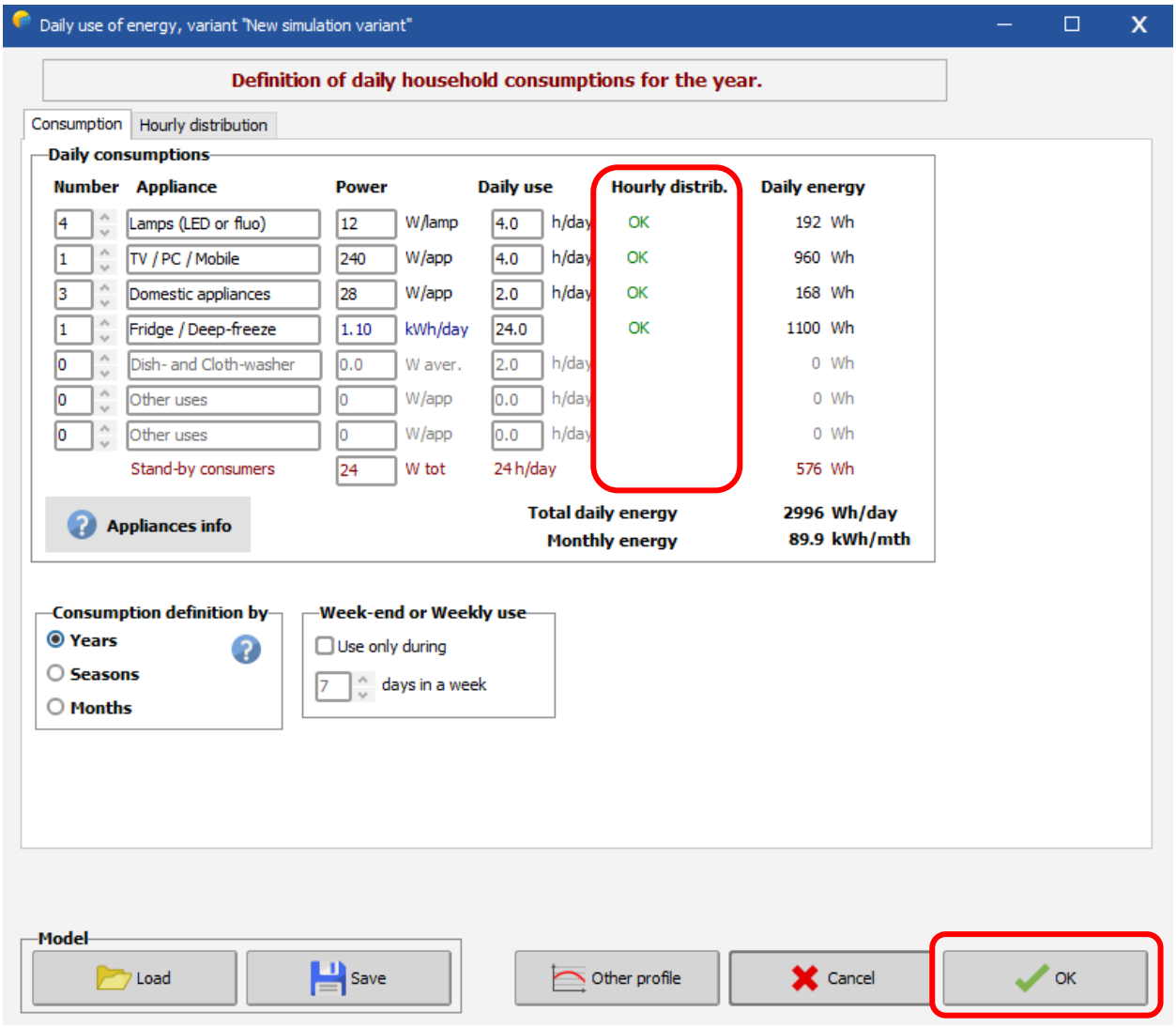


Figure 13: Finalization of consumption definition.

When there is no longer a red message or an error message, you can validate this information by clicking OK. All these input parameters will be displayed in the final PDF report.

1.3.2 Other profile

Another way to define the consumption of the receivers is by importing a database in the CSV format. This can be done by clicking on the "Other profile" button, that gives you access to the table shown in **Erreur ! Source du renvoi introuvable.**.

Here, you can define your consumption by:

- Loading a model,
- Fixing constant consumption,
- Defining the monthly values,
- Defining the daily profiles,
- Defining household consumers,
- Loading values from a CSV hourly / daily file.

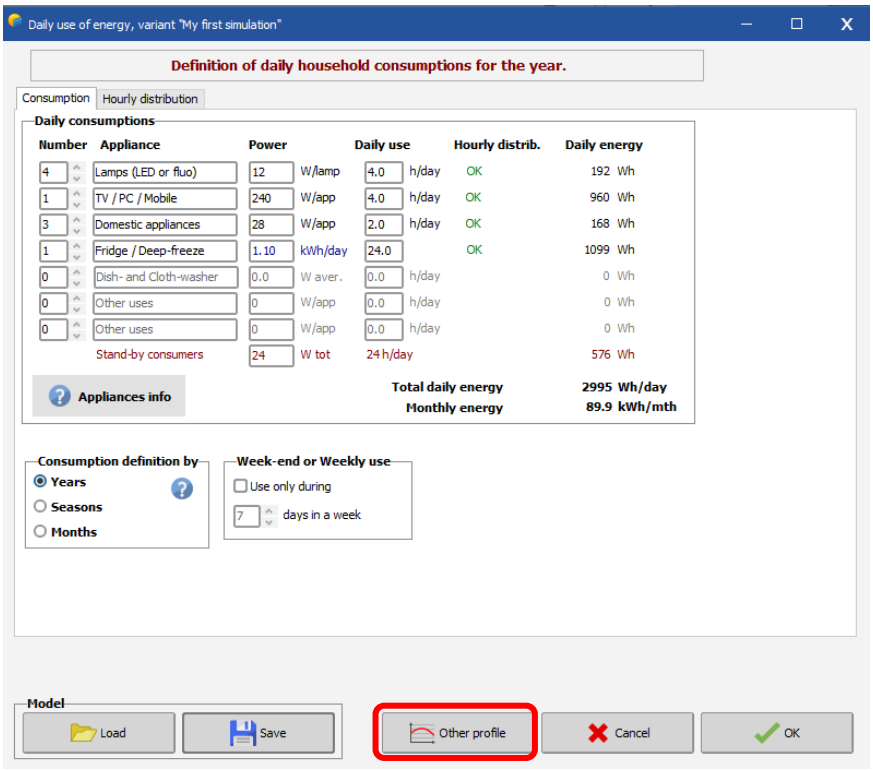


Figure 154: Defining consumption of receivers through "other profile".

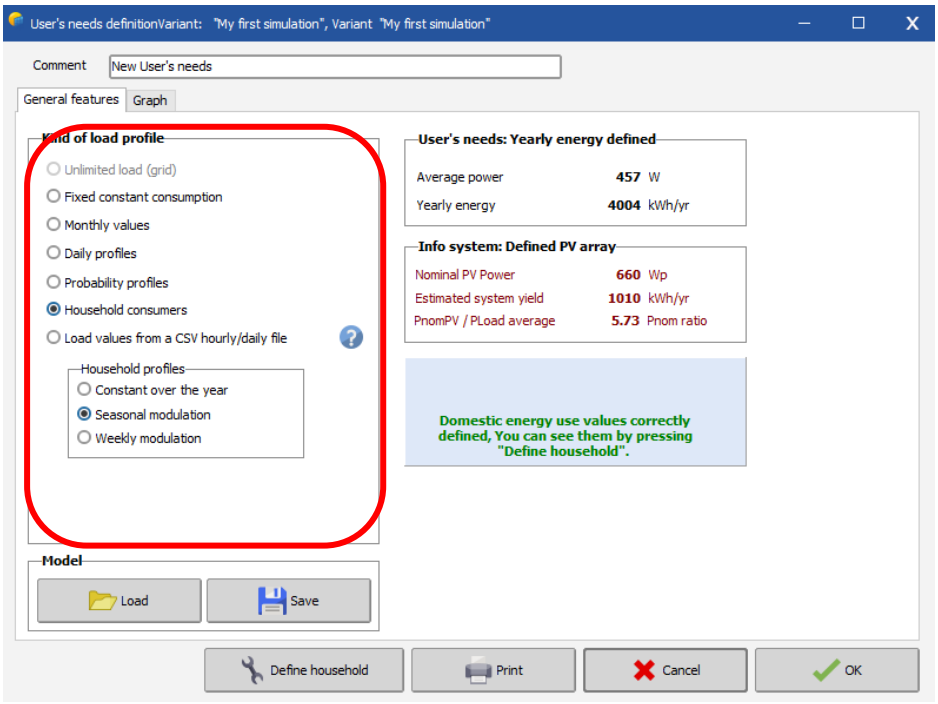


Figure 145: Loading profiles.

<u>Load values from a CSV hourly / daily file:</u>

The most flexible way to define a custom load profile is to input it as an ASCII (CSV) hourly file.

Hourly Parameters file

The input source file should be prepared in a spreadsheet program (like MS-EXCEL), in the CSV-format (Comma Separated Values, separator may be semicolons or commas).

You can find a template named «PARAMS_Hourly_Template.CSV":

- Either in the program's location, usually C:\ program files (x86) \ PVsyst7.x \ DataRO \ PVsyst7.0_Data \ Templates \
- Or in your workspace C: \ users \ YourSession \ PVsyst7.0_Data \ Templates \

In the latter case you should update/reload this file using «Files > Workspace > reload templates» in the main menu.
When modified, you will put your data file in your workspace \"user"\ PVsyst7.0_Data \ user Hourly Params \.

PVsyst standard format for hourly parameters

The required format to import hourly parameters in PVsyst is the following:

- Text file (CSV format with commas or semicolons) written in ANSI (not UTF8).
- All lines beginning by # are comments, ignored.
- The blank lines are ignored.
- The first line without # holds the column title. It should begin by “date” and “P Load” for an hourly load power (other keywords for other parameters will be defined in the future).
- Second line: units of the data in this column, will be read and interpreted by the program.
- In sub-hourly data, specifying [kW] will be interpreted as powers (values will be averaged within the hour step), and [kWh] will be energies (values will be added within the hour).
- First column of data and hour EXCEL format (both European DD/MM/YY hh:mm or US MM/DD/YY hh:mm formats are recognized).
- Other columns: values according to the column title and units.
- The file should contain all hours of a generic year (from 01/01 at 0h00 to 31/12 at 23:00). The year is ignored.
- These dates/hours are not related to the real dates of your input meteorological file: they are for each hour of a generic year.
- Time label = beginning of the year.

Use of the file

After carefully preparing this file, the “Hourly Parameter" dialog will ask to choose it in your workspace \ UserHourlyParams\, or anywhere else.

The file content will appear, so that you can check it.

The program will also check its validity and give some integrated values so you can analyze it with plots.

The dialog will ask if you want to:

- Read the file at the time of the simulation (may be useful for batch mode),
- Read the file immediately and store it internally in your calculation version as input parameters for the simulation

Sub-hourly data

It is also possible to read sub-hourly data (for example Load profiles in 15-minutes steps).

Once the type of profile and the load are defined, you can click on "graph" to view the profile of your load.

On the abscissa axis, you will find the hours of operation per day by default.

On the ordinate axis, you will find the power of the load (previously defined).

You can change some display settings for the graph above:

- Values,
- Units,
- Number of Day.

Once all the data entered is set up and verified, you can validate it and continue your project by clicking on the "OK" button.

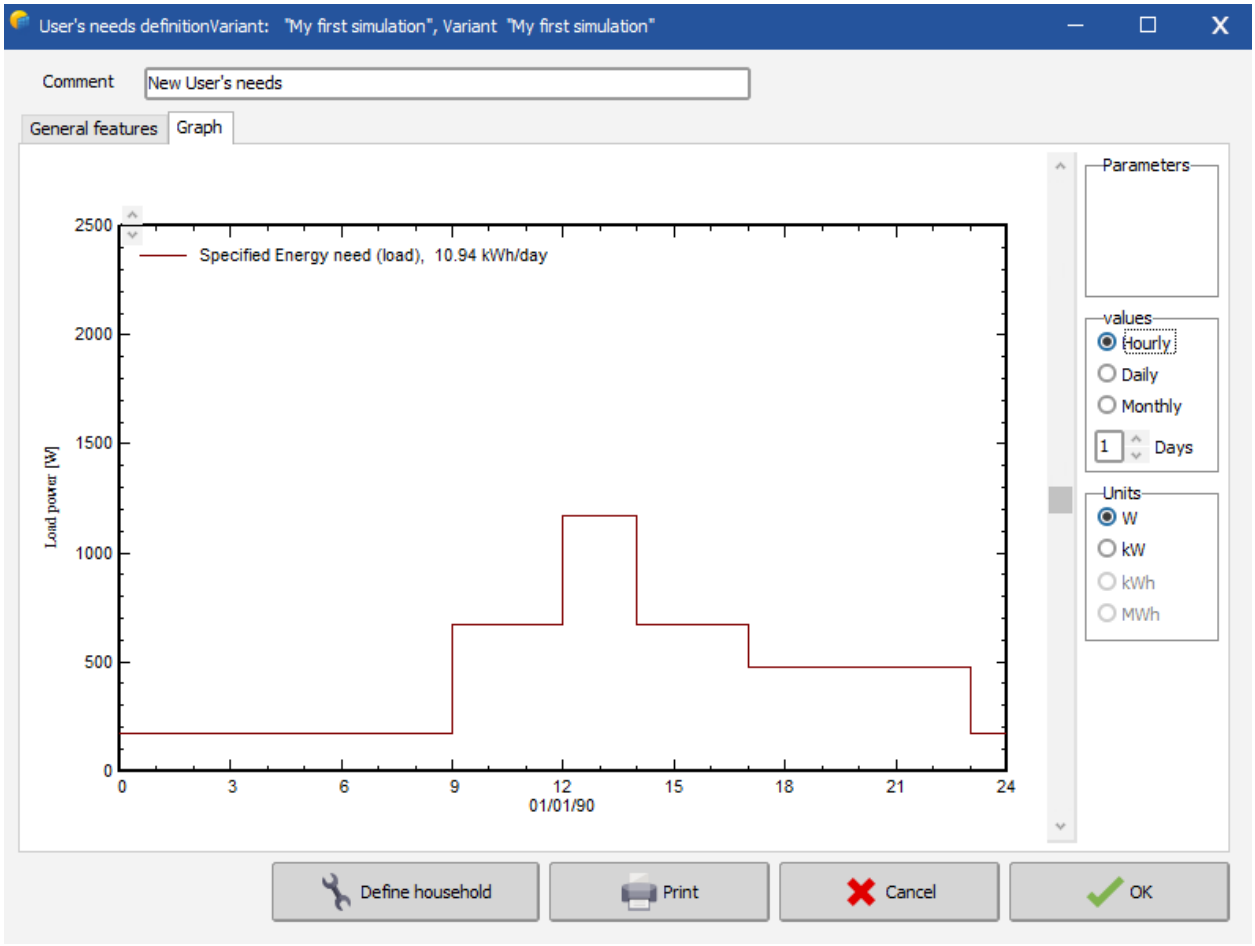


Figure 16: Graph of load power data in terms of hours.

1.4 Define the System

Once you defined the system orientation and your user's needs, the "System" tab will turn red which means that you can click on it to define your electrical system.

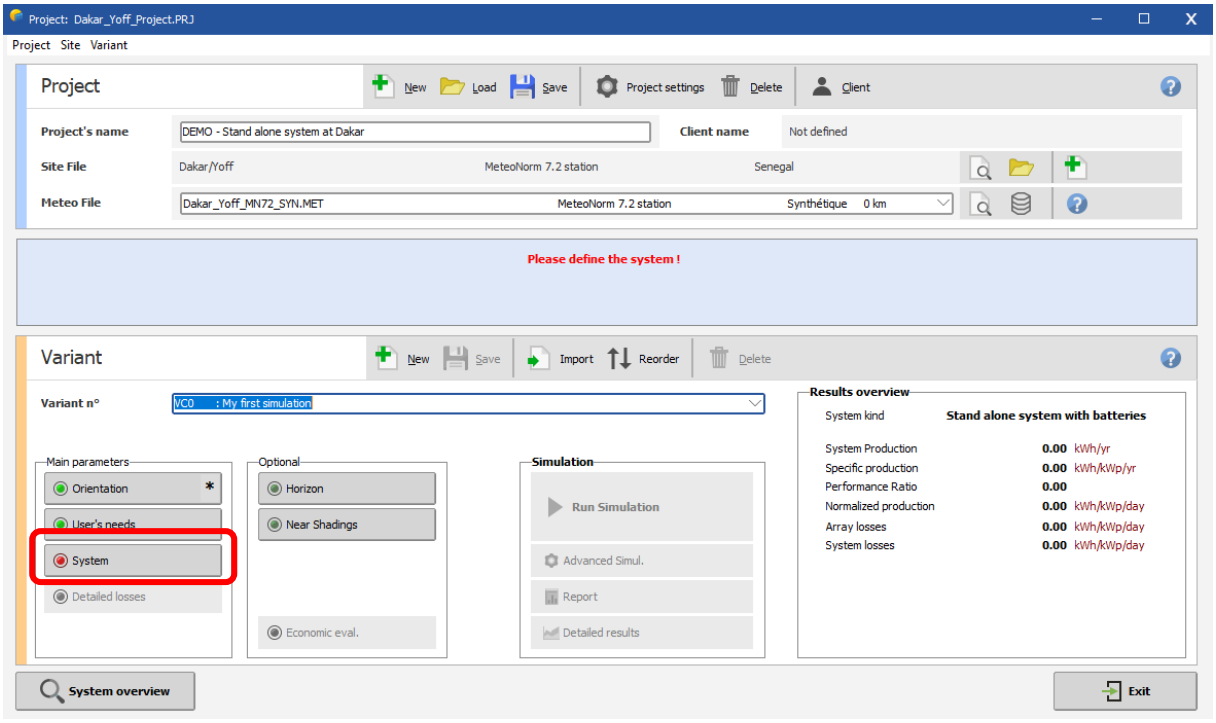


Figure 17: System definition.

In the "System" dialog, you must define the:

- characteristics of the battery pack,
- characteristics of the photovoltaic field,
- characteristics of the charge / discharge regulator.

You can add optional generator system via the "Back-up" tab.

The first tab in the "Systems" dialog contains several important information, such as:

- Pre-Sizing,
- Battery Set,
- Operating battery temperature.

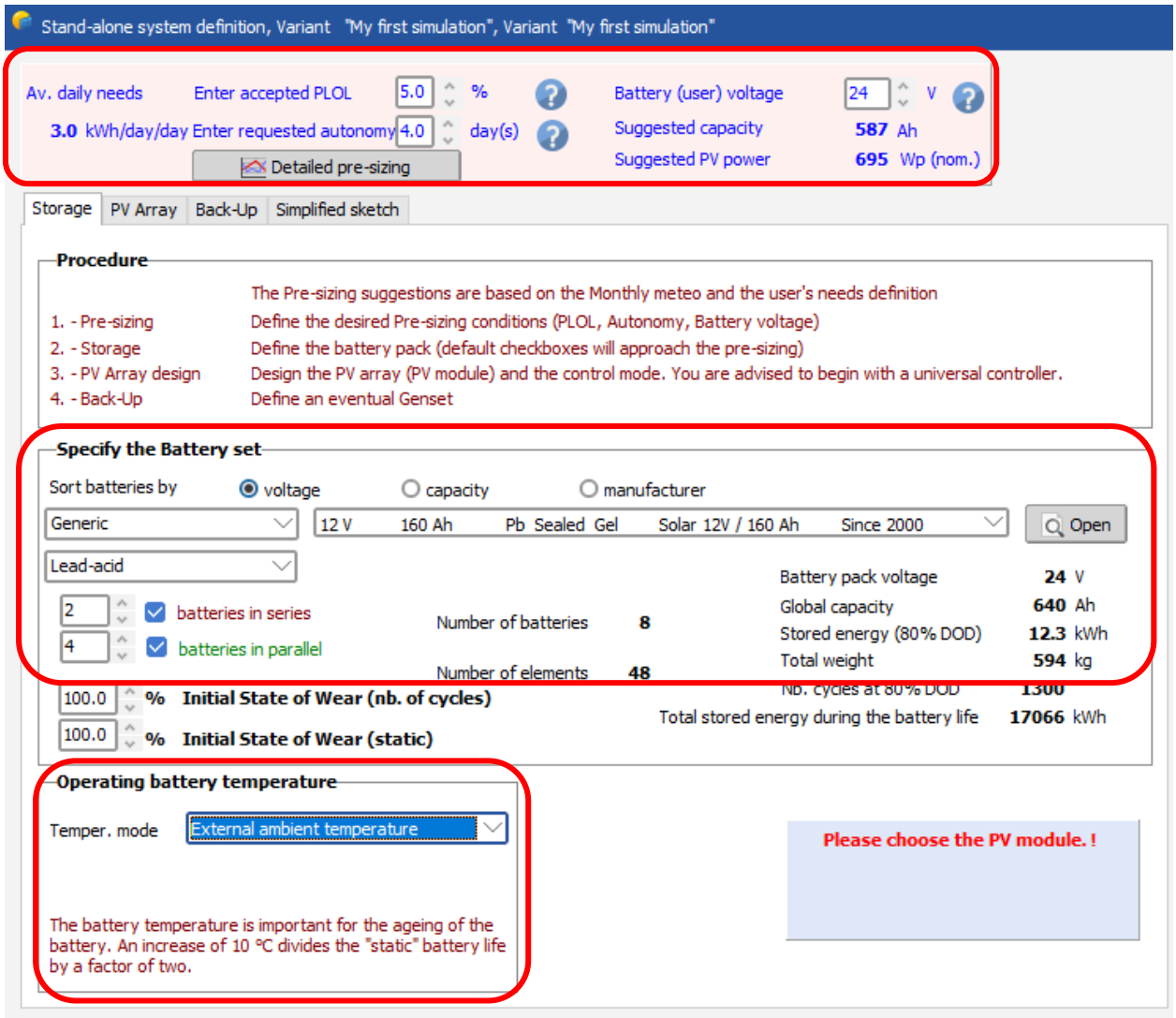


Figure 18: Defining the system's storage.

The Pre-Sizing tool calculates two pieces of information, the:

- Suggested capacity (battery),
- Suggested PV Power.

PLOL in percentage (%):

This value is the probability that the user's needs cannot be supplied (i.e., the time fraction when the battery is disconnected due to the "Low charge" regulator security).

It may be understood as the complement of the "Solar fraction" (although it is described in terms of time rather than energy). During the sizing process, the LOL requirement allows to determine the PV array size needed, for a given battery capacity.

The LOL is calculated using a simplified and fast yearly simulation: the program splits the monthly meteorological values into a realistic random sequence of 365 days (according to Collares-Pereira model), each day being divided into 3 periods: morning - day (with solar gains) - and evening. Then, it performs a day-by-day balance and reports the daily system state, in order to accumulate a realistic "LOL" yearly value.

This process is repeated with different PV-array sizes, in order to find the exact PV size matching the required "LOL".

Requested Autonomy in days:

In the Pre-sizing process, the proposed battery pack capacity is determined according to the required autonomy of the system, given in days.

The autonomy is defined as the time for which the load can be met with the battery alone, without any solar inputs, starting of course from a "fully charged" battery state. With non-constant loads (seasonal or monthly definition, weekly use), this is accounted as the worst-case scenario over the year.

The calculation takes the minimum SOC disconnecting threshold and the battery "energy efficiency" into account. It also has to apply a capacity correction, as this mode of use usually occurs at a rather slow discharge rate (therefore corresponding about to the C100 capacity definition, i.e., with discharge in about 100 hours); when the nominal capacity of the batteries in the PVsyst database is defined as the C10 value. The C100/C10 ratio is usually in the order of 120% to 130%.

These 3 sizing parameters are adjustable in the "Hidden parameter".

NB: When defining a very large autonomy, the global system optimization process will choose the "minimum" PV size which just meets the required "LOL".

This may lead to a very low average State of Charge value over large periods of the year, which is quite damaging for the battery.

Battery (user) voltage:

In a stand-alone PV system with direct coupling to the user (without inverter), the battery voltage determines the distribution voltage. Nowadays, many DC appliances can be found in 24V as well as in 12V. this choice should be made according to the system and/or appliance's power, as well as the extension of the planned distribution grid to minimize the ohmic wiring losses.

This choice should be made at the early planning stage of an installation, since the existing appliance voltage usually cannot be changed, and voltage translators will be expensive and not 100% efficient.

The rated distribution values could be chosen according to the following criteria (inverter supposed directly connected on the battery pack):

- 12V - small systems for lighting and TV:
  - Appliance max power: < 300 W.
  - Corresponding current:25 A.
  - Inverter: about < 1 kW.

- 24V - medium size, household with fridge and little appliances, or wiring extension to more than 10 m:
  - Appliance max power: < 1000 W.
  - Corresponding current: 42 A.
  - Inverter: about < 5 kW.

- 48V - special industrial or agricultural use:
  - Appliance max power: < 3 kW.
  - Corresponding current: 62 A.
  - Inverter: about < 15 kW.

Higher powers require either high DC voltages (special appliances) or AC feeding through inverter.
NB: In a battery pack, when a cell is weaker than the other ones, it will drain out faster.

As all the cells are connected in series, i.e., with the same current, it may encounter deep discharges, or even reverse polarization (the forced current may reverse the polarity, like for the Hot spot in a PV array).

This will still further damage this bad cell. In the same way, during charging, as the capacity is lowered, the overcharging conditions will produce gassing before the other cells, leading to loss of electrolyte.

Therefore, in high voltage battery packs, in absence of a careful maintenance or compensating strategies, the risk of failure is strongly increased.

Pre-sizing Help tool:

With this tool, you can define a maximum surface or power that you want to install.

When a value is defined in one of the two boxes, the software will make a wiring suggestion via the PV Array Design tool.

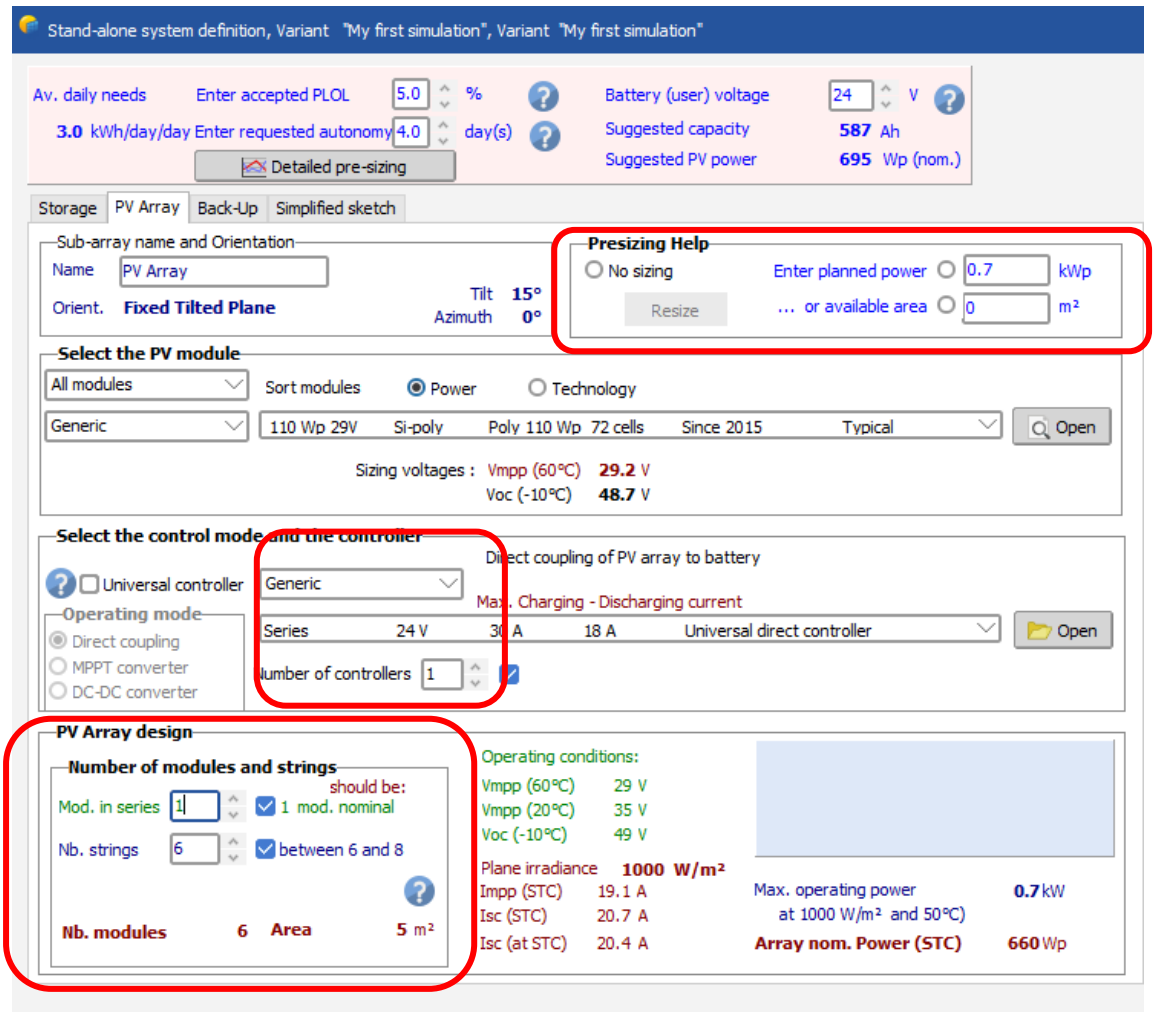


Figure 19: Presizing help tool.

Universal controller:

During the early stage of the study for a stand-alone system, the main issues are the global system sizing, i.e., the determination of the Battery pack, the PV array power, in terms of the user's needs and the meteorological conditions. After the quick pre-sizing evaluation, the results (PLOL, unused energy) must be assessed with a detailed hourly simulation.

The exact regulator strategy does not matter. To get rid of the control constraints, PVsyst introduces a general purpose "generic" universal controller, for the 3 different strategies: Direct coupling, MPPT converter or DCDC converter.

During the sizing process (specification of the battery pack and PV array), these special devices will adapt their parameters to the system, in order to always stay compatible with a normal behavior without control losses during the hourly simulation.

The main parameters to be adapted are:

- The control thresholds: their default values are specified in the "Hidden parameters" in terms of SOC. But you can change them for threshold's dependency studies and eventually define them in terms of Battery voltage.
- Temperature corrections for the battery voltage thresholds.
- With Power conditioning units, the input Voltages and Power according to the modules of the array, as well as the efficiency curve. The efficiency values (Euro and Max efficiencies) may be explicitly modified.
- The maximum Charging, Load and Back-up currents.
- Management of the back-up control if a Genset is specified.

All these parameters are stored in your calculation variant, therefore also keeping your modifications.

If you want to keep a specific configuration for further use, you can always save this Universal converter with the present parameters. In this case, please give it a significant name to the Manufacturer and Model parameters. You are advised to save it under a name like "Manufacturer_Model.RLT in your own database.

1.5 Executing the first simulation

On the Project's dashboard, all buttons are now green (occasionally orange) or off.

The "Run simulation" button is activated and we can click on it.

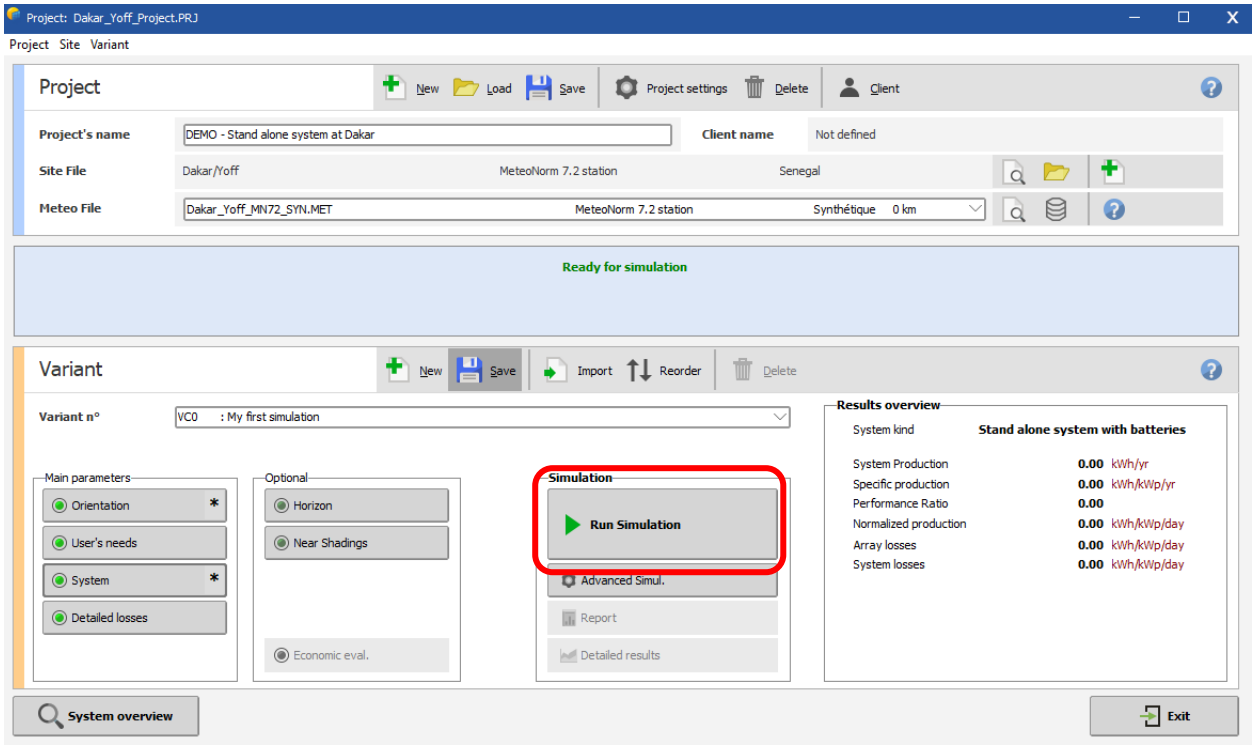


Figure 20: Run simulation.

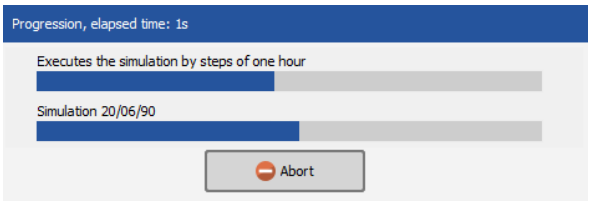


Figure 21: Progress bar.

A progress bar will appear, indicating how much of the simulation is still to be performed. Upon completion, you will be directed to the "Results" dialog.

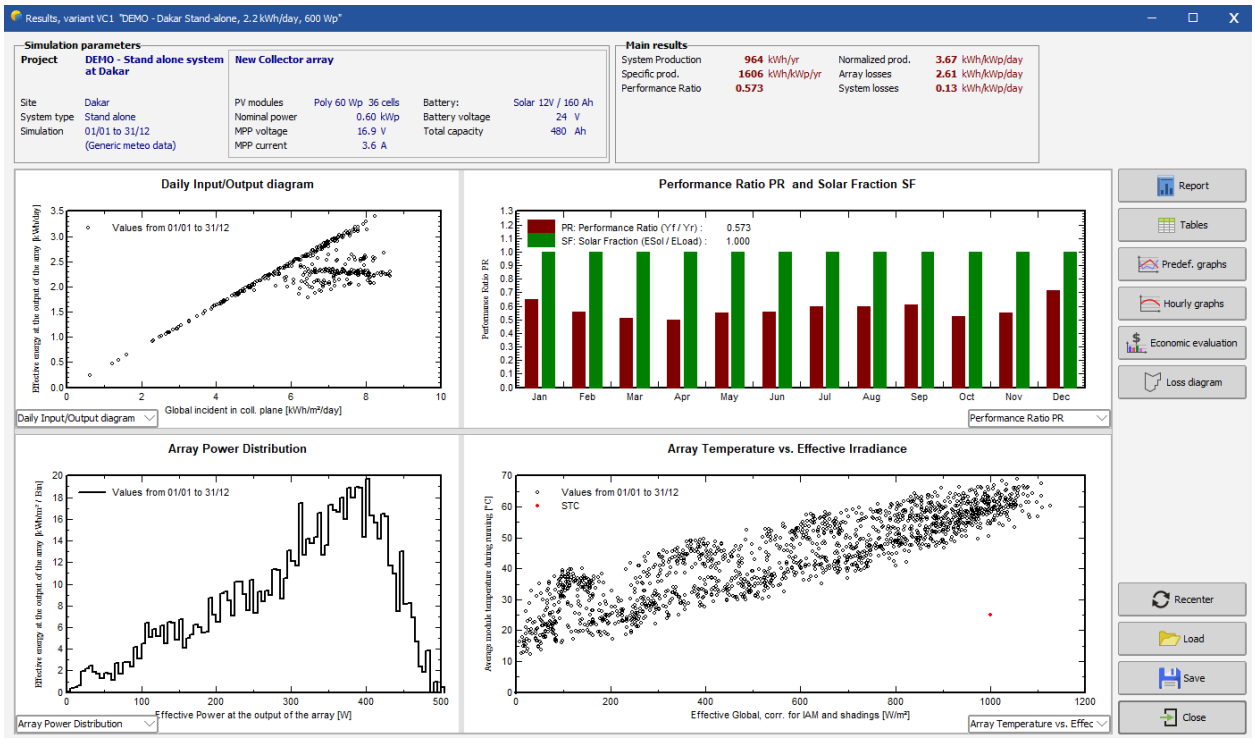
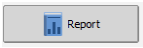


Figure 22: Results dialog.

On the top of the dialog is a summary of the simulation parameters that you should give a quick check to make sure that you made no obvious mistake in the input parameters. On its' right is a frame with six values that summarize at one glance the main results of the simulation. They only give a very rough picture of the results and are there to quickly spot obvious mistakes or to get a first impression of a change or a comparison between variants of the project.

The main information of the simulation results is gathered in the report. The other buttons give access to complementary tables and graphs for a deeper analysis of the simulation results. For now, we will ignore them. When you click on 

, you will get the complete report, which for this first simple variant consists of 7 pages (for simulations with more detail you can get up to 11 pages of report). In this report you will find:

Cover page: Various aspects of the simulation project and variant name including the PVsyst version number and information about the system kind, size and location

Second page: A high level summary of the project system and results of the simulation variant. A fully defined geographical site and meteo properties. Table of contents of the report is also provided.

Third page: General underlying parameter of the simulation: the system kind, plane orientation, general information about shadings (horizon and near shadings), components used and array configuration, loss parameters.

Fourth page: A detailed information on the user's need where the consumption of each households are presented in tables according to the season, and graph on the hourly distribution is illustrated on the bottom of the page.

Detailed User's needs

Daily household consumers, Seasonal modulation, average = 2.2 kWh/day

Summer (Jun-Aug)

	Number	Power	Use	Energy
		W	Hour/day	Wh/day
Lamps (LED or fluo)	6	18W/lamp	4.0	432
TV / PC / Mobile	1	75W/app	3.0	225
Domestic appliances	1	200W/app	1.0	200
Fridge / Deep-freeze	1		24	1001
Stand-by consumers			24.0	144
Total daily energy				2002Wh/day

Autumn (Sep-Nov)

	Number	Power	Use	Energy
		W	Hour/day	Wh/day
Lamps (LED or fluo)	6	18W/lamp	5.0	540
TV / PC / Mobile	1	75W/app	4.0	300
Domestic appliances	1	200W/app	1.0	200
Fridge / Deep-freeze	1		24	1001
Stand-by consumers			24.0	144
Total daily energy				2185Wh/day

Winter (Dec-Feb)

	Number	Power	Use	Energy
		W	Hour/day	Wh/day
Lamps (LED or fluo)	6	18W/lamp	6.0	648
TV / PC / Mobile	1	75W/app	6.0	450
Domestic appliances	1	200W/app	1.0	200
Fridge / Deep-freeze	1		24	1001
Stand-by consumers			24.0	144
Total daily energy				2443Wh/day

Spring (Mar-May)

	Number	Power	Use	Energy
		W	Hour/day	Wh/day
Lamps (LED or fluo)	6	18W/lamp	5.0	540
TV / PC / Mobile	1	75W/app	4.0	300
Domestic appliances	1	200W/app	1.0	200
Fridge / Deep-freeze	1		24	1001
Stand-by consumers			24.0	144
Total daily energy				2185Wh/day

Hourly distribution

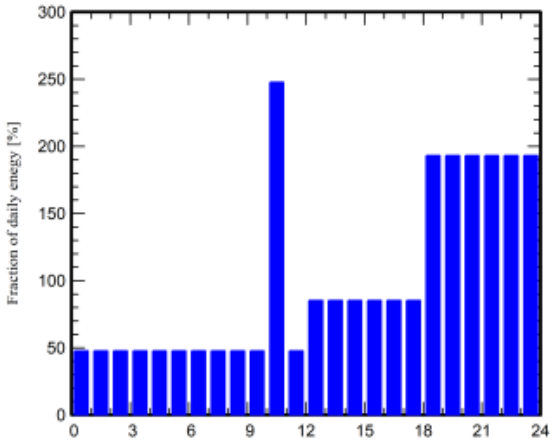


Figure 23: Detailed user's needs and hourly distribution.

Fifth page: This page displays the main results of the simulation, starting by defining three relevant quantities:

- System production,
- Loss of Load,
- Battery aging.

Main results

System Production			
Available Energy	963.9 kWh/year	Specific production	1606 kWh/kWp/year
Used Energy	803.8 kWh/year	Performance Ratio PR	57.30 %
Excess (unused)	132.4 kWh/year	Solar Fraction SF	100.00 %
Loss of Load		**Battery aging (State of Wear)**	
Time Fraction	0.0 %	Cycles SOW	97.4 %
Missing Energy	0.0 kWh/year	Static SOW	90.0 %
		Battery lifetime	10.0 years

Figure 24: Main results of the simulation.

The monthly graphs are also presented below where the graph on the left represents the normalized production and the one on the right represents the performance ratio.

The bottom of this page consists of a table with the main variables, given as monthly values and the overall yearly value. The yearly value can be an average like the temperature, or a sum, like the irradiation or energies. The meaning of the different variables is the following:

- GlobHor: Global irradiation in the horizontal plane. This is our meteorological input value.
- GlobEff: Ambient (dry-bulb) average temperature. This is also our meteorological input value.
- E_Avail: Available Solar Energy.
- EUnused: Unused energy (battery full).
- E_Miss: Missing energy.
- E_User: Energy supplied to the user.
- E_Load: Energy need of the user (Load).
- SolFrac: Solar fraction (EUsed / ELoad).

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac ratio
January	165.9	183.8	78.91	0.00	0.000	75.73	75.73	1.000
February	181.6	192.7	83.92	9.19	0.000	68.40	68.40	1.000
March	211.1	209.7	92.05	20.95	0.000	67.73	67.73	1.000
April	223.9	208.1	91.34	23.02	0.000	65.54	65.54	1.000
May	218.7	192.3	84.25	16.02	0.000	67.73	67.73	1.000
June	196.4	169.5	74.29	9.65	0.000	60.05	60.05	1.000
July	184.7	162.0	71.00	7.08	0.000	62.06	62.06	1.000
August	180.3	164.3	71.87	8.06	0.000	62.06	62.06	1.000
September	175.4	168.9	73.80	6.99	0.000	65.54	65.54	1.000
October	198.0	204.4	89.48	17.91	0.000	67.73	67.73	1.000
November	170.4	186.7	81.68	13.21	0.000	65.54	65.54	1.000
December	150.1	166.6	71.26	0.30	0.000	75.73	75.73	1.000
Year	2256.5	2209.0	963.85	132.38	0.000	803.84	803.84	1.000

Figure 25: Monthly graphs in main results.

Sixth page: The PVsyst arrow loss diagram, showing an energetic balance and all losses along the system. This is a powerful indicator of the quality of your system, and will immediately indicate the sizing errors, if any. This is the PVsyst way of reporting the systems' behavior, with all detailed losses. This diagram is very useful for the analysis of the design choices and should be used when comparing systems or variants of the same project.

Note that there are different types of arrows on the diagram: The outward facing arrows represent losses of energy from the simulation. The size of the arrows is proportional to the loss amount of the system. The inward facing arrows represent energy gained of the system and the percentage are noted with a positive sign (+).

The report can be sent to a printer or copied to the clipboard.

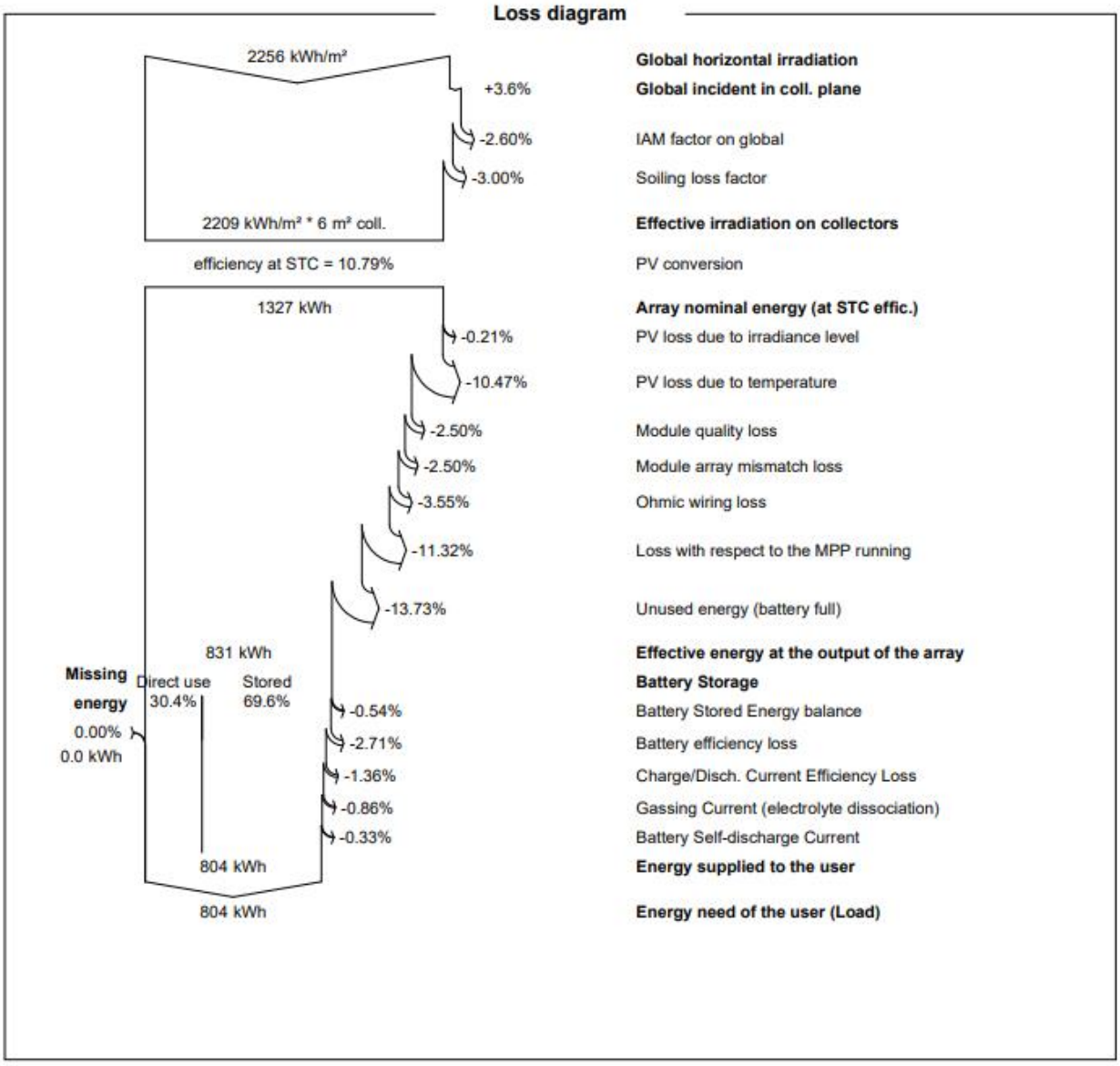


Figure 26: Arrow loss diagram.

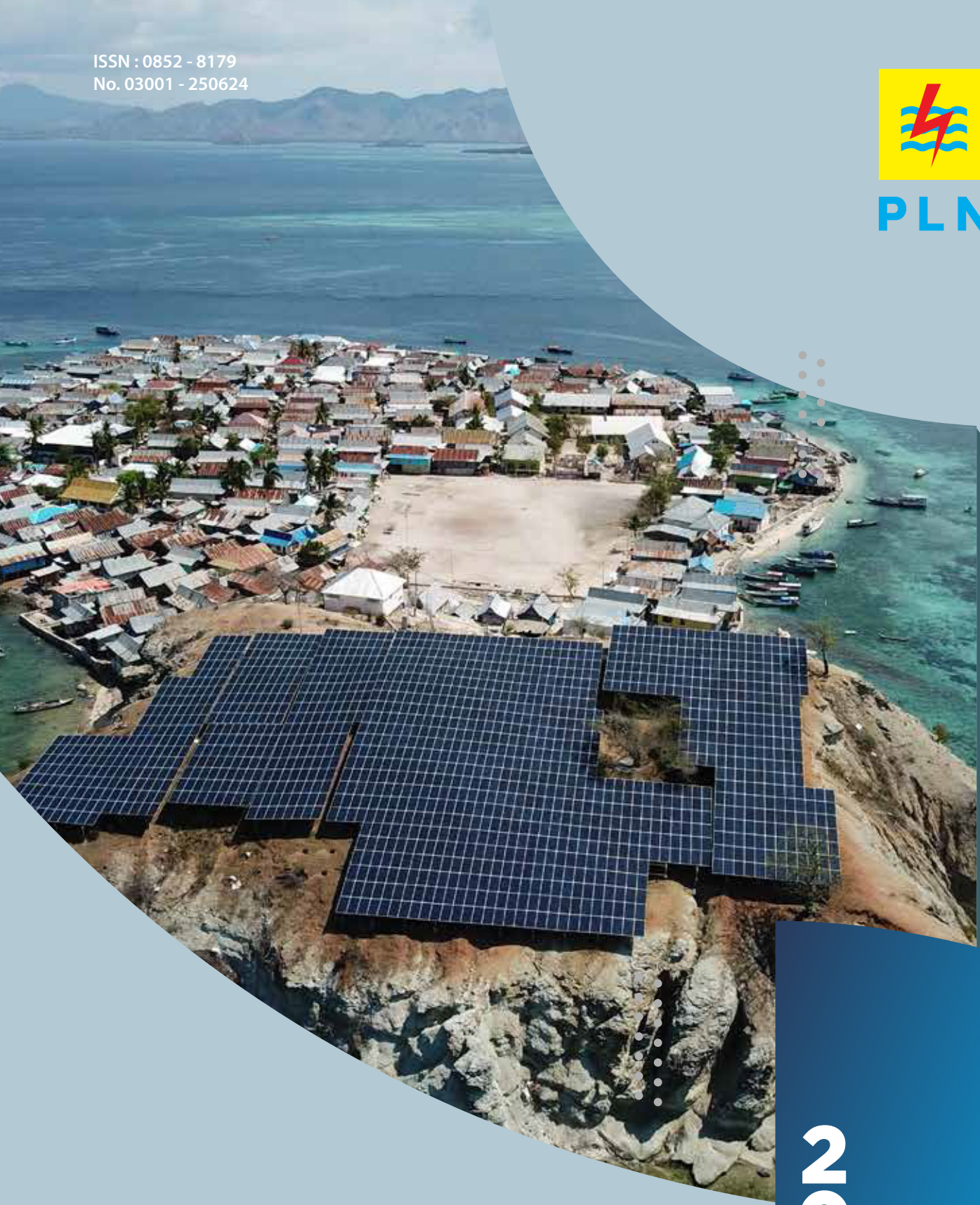
Seventh page: Special graphs on the simulation. Daily input/output diagram and the distribution of power injected to the grid are shown.

1.6 Conclusion

In this document, we demonstrated the basic approach to run a first simulation project for stand-alone system project on PVsyst using an example, starting from the project specifications, defining its variants to executing and analyzing the results on the report.

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PLN



STATISTIK PLN 2023



STATISTIK PLN 2023

Kata Pengantar

Buku Statistik PLN 2023 diterbitkan dengan maksud memberikan informasi kepada publik mengenai pencapaian kinerja perusahaan selama tahun 2023 dan tahun-tahun sebelumnya.

Data yang disajikan merupakan gabungan antara data PLN Holding, Subholding, dan Anak Perusahaan, serta dilengkapi pula dengan beberapa grafik untuk memudahkan pembaca.

Kami sangat mengharapkan saran dan kritik yang membangun untuk meningkatkan penyajian Buku Statistik PLN selanjutnya.

Jakarta, Juni 2024

PT PLN (Persero)

1. Pembangkitan Tenaga Listrik

Kapasitas Terpasang

Pada akhir Desember 2023, total kapasitas terpasang dan jumlah unit pembangkit PLN (unit Pembangkit PLN Group) mencapai 45.095,19 MW dan 6.446 unit, dengan 31.202,08 MW (65,29%) berada di Jawa.

Total kapasitas terpasang mengalami peningkatan sebesar 0,34% dibandingkan dengan akhir Desember 2022. Persentase kapasitas terpasang per jenis pembangkit sebagai berikut :

PLTU 20.439,90 MW (28,01%), PLTGU 12.089,10 MW (16,57%), PLTD 3.521,21 MW (4,83%), PLTMG 2.071,31 MW (2,84%), PLTA 3.142,85 MW (4,31%), PLTM dan PLTMH 454,27 (0,62%), PLTG 2.763,97 MW (3,79%), PLTP 579,26 MW (0,79%), PLT Surya, PLT Bayu dan PLT Biomas 33,32 MW (0,04%).

Adapun total kapasitas terpasang nasional termasuk pembangkit sewa dan IPP adalah 72.976,30 MW.

Beban Puncak)*

Beban puncak pada tahun 2023 mencapai 58.282,48 MW, mengalami kenaikan sebesar 39,43% dibandingkan tahun sebelumnya. Beban puncak sistem interkoneksi Jawa Bali mencapai 40.223,47 MW, dan beban puncak sistem di luar Jawa Bali mencapai 18.059,01 MW.

Produksi dan Pembelian Tenaga Listrik

Selama tahun 2023, jumlah energi listrik produksi sendiri dan sewa sebesar 183.980,89 GWh.

Dari jumlah tersebut, 17,28% diproduksi oleh PLN Holding, dan 82,72% diproduksi Subholding yaitu PLN Indonesia Power, PLN Nusantara Power dan Anak Perusahaan PT PLN Batam.

Produksi total PLN (termasuk pembelian dari luar PLN) pada tahun 2023 sebesar 323.320,62 GWh. Dari produksi total PLN tersebut, energi listrik yang dibeli dari luar PLN sebesar 139.339,73 GWh (43,10%). Pembelian energi listrik tersebut meningkat 15.156,46 GWh atau 12,20% dibandingkan tahun sebelumnya.

2. Transmisi dan Distribusi

Pada akhir tahun 2023, total panjang jaringan transmisi mencapai 87.691,48 kms, yang terdiri atas jaringan 500 kV sepanjang 7.194,43 kms, 275 kV sepanjang 4.572,67 kms, 150 kV sepanjang 69.075,92 kms, 70 kV sepanjang 6.747,14 kms dan 25 & 30 kV sepanjang 101,33 kms.

Total panjang jaringan distribusi sepanjang 1.048.183,16 kms, terdiri atas JTM sepanjang 438.900,17 kms dan JTR sepanjang 609.282,99 kms.

Kapasitas terpasang trafo gardu induk sebesar 180.164,65 MVA, meningkat 11,65% dari tahun sebelumnya. Jumlah trafo gardu induk sebanyak 2.712 unit, terdiri atas trafo sistem 500 kV sebanyak 90 unit, sistem 275 kV sebanyak 49 unit, sistem 150 kV sebanyak 2.264 unit, sistem 70 kV sebanyak 307 unit dan sistem < 30 kV sebanyak 2 unit.

Kapasitas terpasang trafo gardu distribusi sebesar 66.716,23 MVA, mengalami peningkatan sebesar 1,95% dari tahun sebelumnya. Jumlah trafo gardu distribusi sebanyak 558.994 unit, mengalami peningkatan sebesar 1,48% dari tahun sebelumnya.

**) Beban Puncak Pembangkit PLN, Sewa, dan IPP*

3. Penjualan Tenaga Listrik

Jumlah energi listrik terjual pada tahun 2023 sebesar 288.435,78 GWh. Kelompok pelanggan industri mengkonsumsi 88.587,68 GWh (30,71%), rumah tangga 122.339,69 GWh (42,41%), bisnis 57.112,00 GWh (19,80%), dan lainnya (sosial, gedung pemerintah dan penerangan jalan umum) 20.396,41 GWh (7,07%).

Jumlah pelanggan pada akhir tahun 2023 sebesar 89.153.278 pelanggan meningkat 4,11% dari akhir tahun 2022.

Harga jual listrik rata-rata per kWh berdasarkan data AP2T selama tahun 2023 sebesar Rp1.155,47/kWh lebih tinggi dari tahun sebelumnya sebesar Rp1.137,26/kWh.

4. Susut Energi

Selama tahun 2023, susut energi sebesar 8,57%, terdiri dari susut transmisi 2,01% dan susut distribusi 6,71%. Susut energi tahun 2023 lebih baik dibandingkan tahun 2022 yaitu sebesar 8,72% (polarisasi negatif).

5. Rasio Elektrifikasi

Dengan pertumbuhan jumlah pelanggan rumah tangga dari 78.328.012*) pelanggan pada akhir tahun 2022 menjadi 81.556.202*) pelanggan pada akhir tahun 2023, maka rasio elektrifikasi menjadi sebesar 98,33%**).

6. Keuangan

Selama tahun 2023 jumlah pendapatan operasi mencapai Rp487.384.064 juta yang terdiri dari pendapatan penjualan tenaga listrik sebesar Rp333.191.062 juta, Pendapatan biaya penyambungan Rp1.288.284 juta. Subsidi pemerintah Rp68.636.731 juta, pendapatan kompensasi Rp73.991.897 juta, dan pendapatan lain-lain sebesar Rp10.276.090 juta.

Jumlah biaya operasi sebesar Rp440.183.990 juta, dengan demikian laba bersih tahun berjalan sebesar Rp22.071.458 juta mengalami kenaikan 53,12% dari tahun 2022 yaitu sebesar Rp14.414.720 juta.

Total aset mencapai sebesar Rp1.670.639.704 juta, naik 1,98% dari tahun 2022.

7. Sumber Daya Manusia

Jumlah pegawai PLN pada akhir Desember 2023 sebanyak 51.245 orang. Produktivitas pegawai pada tahun 2023 mencapai 5.628,56 MWh/pegawai dan 1.740 pelanggan/pegawai.

**) Termasuk Pelanggan Alat Penyalur Daya Listrik (APDAL)*
***) Tidak termasuk pelanggan non PLN*

1. Rumus yang digunakan dalam buku ini adalah sebagai berikut.

   1.1. Faktor kapasitas (*capacity factor*) *)

$$\frac{\Sigma \text{ kWh produksi bruto per tahun}}{\Sigma \text{ kW kapasitas terpasang x 8.760 jam}} \times 100\%$$

   kWh produksi bruto, adalah energi (kWh) yang dibangkitkan oleh generator sebelum dikurangi energi pemakaian sendiri (untuk peralatan bantu, penerangan sentral dan lain-lain), atau produksi energi listrik yang diukur pada terminal generator.

   Kapasitas terpasang, adalah kapasitas suatu unit pembangkit sebagaimana tertera pada papan nama (*name plate*) dari generator atau mesin penggerak utama (*prime mover*), dipilih mana yang lebih kecil. Khusus untuk PLTG, kapasitas terpasangnya adalah sebagaimana tertera pada papan nama berdasarkan *base-load*, bukan berdasarkan *peak-load*.

   1.2. Faktor beban (*load factor*)*)

$$\frac{\Sigma \text{ kWh produksi total per tahun}}{\Sigma \text{ kW beban puncak x 8.760 jam}} \times 100\%$$

   kWh produksi total, adalah jumlah dari kWh produksi sendiri dari pembangkit yang ada pada satuan PLN yang bersangkutan, dan kWh yang diterima dari satuan PLN lain, ditambah kWh pembelian dari luar PLN dan sewa genset (jika ada).

   Beban puncak, adalah beban tertinggi setiap sistem yang pernah dicapai pada tahun kalender yang bersangkutan.

   1.3. Faktor permintaan (*demand factor*)

$$\frac{\Sigma \text{ kW beban puncak}}{\Sigma \text{ kVA tersambung x cos } \varphi} \times 100\%$$

   cos φ = 0,8

**) SE Dir. PLN Nomor 006/PST/88*

1.4. Susut energi (*energy losses*)

$$\frac{\Sigma \text{ kWh hilang di jaringan transmisi} + \Sigma \text{ kWh hilang di jaringan distribusi}}{\Sigma \text{ kWh produksi netto}} \times 100\%$$

kWh produksi netto, adalah jumlah kWh produksi sendiri dari pembangkit yang ada pada satuan PLN yang bersangkutan, ditambah kWh yang diterima dari satuan PLN lain, ditambah kWh pembelian dari luar PLN dan sewa genset (jika ada), dikurangi pemakaian sendiri sentral.

kWh hilang di jaringan transmisi (susut transmisi), adalah kWh produksi netto, dikurangi kWh pemakaian sendiri gardu induk, dikurangi kWh yang dikirimkan ke satuan unit PLN lain dan luar PLN, dikurangi kWh yang dikirimkan ke distribusi.

kWh hilang di jaringan distribusi (susut distribusi), adalah kWh yang dikirimkan ke distribusi, dikurangi kWh pemakaian sendiri gardu distribusi, dikurangi kWh terjual.

1.5. SAIDI (*System Average Interruption Duration Index*) **)

$$\frac{\Sigma \text{ (Lama pelanggan padam x Jumlah pelanggan yang mengalami pemadaman)}}{\text{Jumlah pelanggan}}$$

1.6. SAIFI (*System Average Interruption Frequency Index*) **)

$$\frac{\Sigma \text{ (Pelanggan yang mengalami pemadaman)}}{\text{Jumlah pelanggan}}$$

**) Pemadaman di jaringan distribusi yang dirasakan oleh pelanggan, termasuk yang diakibatkan oleh gangguan atau pemeliharaan di sisi pembangkitan maupun transmisi. (SE Direksi PLN No. SE.031.E/471/PST/1993).

1.7. SOD (*System Outage Duration*) : $\frac{\text{Lama gangguan yang menyebabkan pemadaman}}{\text{100 kms transmisi}}$

Lama keluar sistem (*System Outage Duration*), adalah indikator kinerja lama gangguan yang menyebabkan pemadaman sistem transmisi pada titik pelayanan, dengan satuan jam/100 kms.

1.8. SOF (*System Outage Frequency*) : $\frac{\text{Jumlah gangguan yang menyebabkan pemadaman}}{\text{100 kms transmisi}}$

Jumlah keluar sistem (*System Outage Frequency*), adalah indikator kinerja jumlah gangguan yang menyebabkan pemadaman sistem transmisi pada titik pelayanan, dengan satuan kali/100 kms.

2. Pengelompokan data

2.1. Data pembangkitan

Data PLTA sudah termasuk data PLTM (Pusat Listrik Tenaga Mini/Mikro Hidro) yaitu pembangkit listrik tenaga air dengan satuan (unit) pembangkit berkapasitas 1.000 kW ke bawah (sesuai dengan Surat Edaran No. 006/PST/88).

2.2. Data pelanggan menurut golongan tarif

2.2.1. Menurut kelompok pelanggan

Kelompok **rumah tangga**, adalah penjumlahan golongan tarif S-1, R-1, R-2, dan R-3.
Kelompok **bisnis**, adalah penjumlahan golongan tarif B-1, B-2, B-3, T, C dan tarif Multiguna/Layanan Khusus.
Kelompok **industri**, adalah penjumlahan golongan tarif I-1, I-2, I-3, dan I-4.
Kelompok **sosial**, adalah penjumlahan golongan tarif S-2, dan S-3.
Kelompok **gedung kantor pemerintah**, adalah penjumlahan golongan tarif P-1 dan P-2.
Kelompok **penerangan jalan umum**, adalah golongan tarif P-3.

2.2.2. Menurut jenis tegangan

Jenis **tegangan rendah**, adalah penjumlahan golongan tarif S-1, S-2, R-1, R-2, R-3, B-1, B-2, I-1, I-2, P-1 dan P-3.
Jenis **tegangan menengah**, adalah penjumlahan golongan tarif S-3, B-3, I-3, P-2, Traksi (T) dan C (Curah).
Jenis **tegangan tinggi**, adalah golongan tarif I-4.
Jenis **tarif multiguna**, adalah tarif yang diperuntukkan hanya bagi pengguna listrik yang memerlukan pelayanan dengan kualitas khusus yang tidak termasuk dalam golongan tarif S, R, B, I, P, T (Traksi) dan C (Curah).

3. Energi terjual

Energi yang terjual kepada pelanggan, adalah energi (kWh) yang terjual kepada pelanggan TT (tegangan tinggi), TM (tegangan menengah) dan TR (tegangan rendah) sesuai dengan jumlah kWh yang dibuat rekening (TUL III-09).

4. Status data

Tahun 2023, berarti satu tahun kalender dari tanggal 1 Januari 2023 sampai dengan tanggal 31 Desember 2023.

5. Singkatan

PLTA	: Pembangkit Listrik Tenaga Air
PLTU	: Pembangkit Listrik Tenaga Uap
PLTG	: Pembangkit Listrik Tenaga Gas
PLTGU	: Pembangkit Listrik Tenaga Gas & Uap
PLTD	: Pembangkit Listrik Tenaga Diesel
PLTP	: Pembangkit Listrik Tenaga Panas Bumi
PLTMG	: Pembangkit Listrik Tenaga Mesin Gas
PLTS	: Pembangkit Listrik Tenaga Surya
PLTB	: Pembangkit Listrik Tenaga Bayu
PLTM	: Pembangkit Listrik Tenaga Minihidro
PLTMH	: Pembangkit Listrik Tenaga Mikrohidro
PLTBm	: Pembangkit Listrik Tenaga Biomassa
VA	: volt-ampere
MVA	: mega-volt-ampere
kW	: kilowatt
MW	: megawatt
kWh	: kilowatt-hour
MWh	: megawatt-hour
GWh	: gigawatt-hour
kms	: kilometer-sirkuit
MSCF	: 10^3 Standard Cubic Foot ($M=10^3$)
MMSCF	: 10^6 Standard Cubic Foot ($MM=10^6$)
MMBTU	: 10^6 British Thermal Unit ($MM=10^6$)
HSD	: High Speed Diesel Oil
IDO	: Intermediate Diesel Oil
MFO	: Marine Fuel Oil
SAIDI	: System Average Interruption Duration Index
SAIFI	: System Average Interruption Frequency Index
Dist.	: Distribusi
Gdg. Kantor Pemerintah	: Gedung Kantor Pemerintah
PJU	: Penerangan Jalan Umum
PJB	: Pembangkitan Tenaga Listrik Jawa - Bali
SOD	: System Outage Duration
SOF	: System Outage Frequency
n.a	: not available

British Thermal Unit (BTU), adalah jumlah panas yang diperlukan untuk menaikkan 1 pound air 1 derajat Fahrenheit pada temperatur 60 derajat Fahrenheit, pada tekanan absolut 14,7 pound per square inch.

Standard Cubic Foot (SCF), adalah sejumlah gas yang diperlukan untuk mengisi ruangan 1 Cubic Foot, dengan tekanan sebesar 14,7 pounds per square inch absolut dan pada temperatur 60 derajat Fahrenheit, dalam kondisi kering.

1000 BTU Gas, adalah gas mempunyai Gross Heating Value sebesar 1000 BTU per SCF.

Gross Heating Value, adalah jumlah panas yang dinyatakan dalam satuan BTU yang dihasilkan oleh pembakaran sempurna dari satu Standard Cubic Foot Gas, pada temperatur 60 derajat Fahrenheit dan tekanan absolut 14,7 pounds per square inch, dengan udara pada temperatur dan tekanan yang sama dengan gas tersebut, dan setelah pendinginan hasil pembakaran pada tingkat temperatur permulaan gas dan udara, uap air yang terbentuk dalam proses pembakaran itu terkondensasikan ke dalam bentuk cair.

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Note:

1. *UIK SUM, UIK KAL, UIK SUL merupakan pembangkit ex UIK/UIKL yang merupakan Unit Bisnis Holding (PT PLN (Persero)) yang saat ini pencatatan data dilakukan oleh Subholding Indonesia Power dan Nusantara Power sehubungan dengan adanya pembentukan Holding Subholding.*
2. *Pada tahun 2023, terjadi penyesuaian klasifikasi Daya Terpasang untuk PLTA, PLTM dan PLTMH, yaitu:*
   a. Daya Terpasang untuk PLTA >10.000 kW
   b. Daya Terpasang untuk PLTM antara 1.000 kW s.d 10.000 kW
   c. Daya Terpasang untuk PLTMH <1.000 kW



DATA TAHUNAN 2023

01

Tabel 1 : Neraca Daya (MW) 2023

Satuan PLN/Provinsi	Kapasitas Terpasang*)	Daya Mampu*)	Beban Puncak
UID Aceh	179,56	142,70	125,11
UID Sumatera Utara	186,44	185,52	185,88
UID Sumatera Barat	99,42	93,03	71,64
UID Riau dan Kepulauan Riau	633,17	582,96	464,57
- Riau	478,39	453,35	384,06
- Kepulauan Riau	154,78	129,60	80,51
UID Sumatera Selatan, Jambi dan Bengkulu	263,21	233,27	155,29
- Sumatera Selatan	126,54	122,44	78,29
- Jambi	46,48	37,23	19,71
- Bengkulu	90,19	73,59	57,30
UIW Bangka Belitung	346,78	321,53	298,79
UID Lampung	46,48	42,70	17,76
UID Kalimantan Barat	108,02	88,15	45,57
UID Kalimantan Selatan dan Tengah	80,25	56,05	19,72
- Kalimantan Selatan	17,73	12,69	2,94
- Kalimantan Tengah	62,53	43,36	16,77
UID Kalimantan Timur dan Utara	76,80	52,88	30,02
UID Sulawesi Utara, Tengah dan Gorontalo	315,90	288,84	194,09
- Sulawesi Utara	70,77	64,57	26,94
- Sulawesi Tengah	223,94	203,42	149,53
- Gorontalo	21,18	20,85	17,63
UID Sulawesi Selatan, Tenggara dan Barat	158,17	150,14	132,14
- Sulawesi Selatan	117,14	115,23	108,70
- Sulawesi Tenggara	39,01	33,18	23,44
- Sulawesi Barat	2,02	1,73	-
UIW Maluku dan Maluku Utara	586,42	507,13	249,52
- Maluku	421,89	368,42	192,87
- Maluku Utara	164,53	138,70	56,65
UIW Papua dan Papua Barat	691,92	606,71	460,38
- Papua	197,90	165,72	111,54
- Papua Barat	494,02	440,99	348,84
UID Bali	7,10	6,99	1,93
UIW Nusa Tenggara Barat	695,84	626,49	557,67
UIW Nusa Tenggara Timur	510,23	405,13	334,29
PT PLN Batam	843,37	761,93	698,67
UIP3B Sumatera	4.637,44	4.258,54	3.713,56
UIP3B Kalimantan	1.518,00	1.518,00	1.594,15
UIP3B Sulawesi	1.671,00	1.671,00	1.035,65
UIK Kalimantan	649,61	579,83	279,57
UIK Sulawesi	428,86	414,40	218,35
UIK Sumatera	776,22	706,61	341,50
PLN Indonesia Power - Kalimantan	992,47	796,25	649,53
PLN Indonesia Power - Sulawesi	312,81	264,47	261,47
PLN Indonesia Power - Sumatera	2.659,26	2.238,13	1.982,13
PLN Nusantara Power - Kalimantan	846,96	642,07	522,83
PLN Nusantara Power - Sulawesi	1.265,63	1.102,13	909,83
PLN Nusantara Power - Sumatera	3.496,36	2.794,41	2.451,10
PLN Nusantara Power - Maluku Utara	145,00	133,74	56,30
Luar Jawa	25.228,69	22.271,70	18.059,01
UID Jawa Timur	76,16	67,52	60,73
UID Jawa Tengah dan Yogyakarta	40,02	34,74	32,07
- Jawa Tengah	39,24	34,07	31,62
- D.I. Yogyakarta	0,78	0,67	0,45
UID Jawa Barat	150,43	150,43	95,88
UID Banten	16,82	16,82	13,01
UID Jakarta Raya	0,40	0,35	0,14
PLN Indonesia Power - Jawabali	16.019,35	14.605,28	13.036,75
PLN Nusantara Power - Jawabali	12.316,90	11.183,32	9.341,86
Unit Induk Pusat Pengaturan Beban	16.216,13	16.216,13	15.119,45
UIK Tanjung Jati B	2.811,40	2.643,80	2.523,58
Jawa	47.647,61	44.918,40	40.223,47
UIP Nusa Tenggara	100,00	-	-
Proyek Pembangkitan	100,00	-	-
Indonesia	72.976,30	67.190,10	58.282,48

**) Pembangkit milik PLN, Sewa dan IPP*

Tabel 2 : Neraca Energi

Satuan PLN/Provinsi	Dibeli dari Luar PLN	Proyek (GWh)	Terima dari Unit Lain (GWh)	Produksi Sendiri (GWh)	Sewa (GWh)	Pemakaian Sendiri Sentral		Produksi Netto (GWh)	Pemakaian Sendiri GI	
						(GWh)	(%)		(GWh)	(%)
UID Aceh	115,92	-	3.628,17	108,02	42,99	1,67	1,11	3.893,42	-	-
UID Sumatera Utara	1.096,75	-	13.585,07	5,31	-	-	-	14.687,13	-	-
UID Sumatera Barat	301,64	-	4.068,95	23,05	-	0,75	3,25	4.392,89	-	-
UID Riau dan Kepulauan Riau	2.211,02	-	7.019,52	504,81	300,84	15,33	1,90	10.020,86	0,72	0,01
UID Sumatera Selatan, Jambi dan Bengkulu	886,08	-	10.745,25	17,27	134,70	-	-	11.783,30	-	-
UIW Bangka Belitung	293,27	-	606,43	828,98	37,18	73,07	8,44	1.692,79	1,45	0,09
UID Lampung	67,43	-	6.591,54	1,91	-	-	0,07	6.660,88	-	-
UID Kalimantan Barat	43,84	-	3.480,47	92,60	91,39	2,57	1,40	3.705,72	-	-
UID Kalimantan Selatan dan Tengah	65,90	-	5.758,49	56,47	-	0,91	1,62	5.879,95	-	-
UID Kalimantan Timur dan Utara	134,48	-	5.193,32	49,97	0,34	1,08	2,15	5.377,02	-	-
UID Sulawesi Utara, Tengah dan Gorontalo	317,59	-	3.936,52	251,91	393,64	7,63	1,18	4.892,03	-	-
UID Sulawesi Selatan, Tenggara dan Barat	411,63	-	10.712,89	38,25	18,63	1,17	2,05	11.180,23	-	-
UIW Maluku dan Maluku Utara	21,06	-	51,17	869,63	636,15	42,79	2,84	1.535,23	0,65	0,04
UIW Papua dan Papua Barat	700,36	-	-	1.045,15	506,47	51,58	3,32	2.200,40	1,05	0,05
UID Bali	13,49	-	6.632,90	-	-	-	-	6.646,39	-	-
UIW Nusa Tenggara Barat	340,62	-	-	2.288,61	310,34	142,32	5,48	2.797,25	1,81	0,06
UIW Nusa Tenggara Timur	245,84	27,46	-	801,84	451,28	56,36	4,50	1.470,07	1,56	0,11
PT PLN Batam	2.569,37	-	-	1.096,01	322,44	31,90	2,25	3.955,92	1,47	0,04
UIP3B Sumatera	19.349,58	-	27.335,87	-	-	-	-	46.685,45	34,32	0,07
UIP3B Kalimantan	7.807,19	31,99	5.106,65	-	-	-	-	12.945,83	11,04	0,09
UIP3B Sulawesi	7.529,25	-	6.886,10	-	-	-	-	14.415,35	11,50	0,08
UIK Kalimantan	19,95	-	-	349,72	655,19	18,68	1,86	1.006,18	-	-
UIK Sulawesi	-	-	-	1.082,89	312,14	95,54	6,85	1.299,50	-	-
UIK Sumatera	489,23	-	-	-	161,65	-	-	650,88	-	-
PLN Indonesia Power - Kalimantan	-	-	-	3.539,90	-	320,19	9,05	3.219,71	-	-
PLN Indonesia Power - Sulawesi	-	-	-	1.395,86	-	117,40	8,41	1.278,46	-	-
PLN Indonesia Power - Sumatera	-	-	-	11.588,93	-	856,63	7,39	10.732,30	-	-
PLN Nusantara Power - Kalimantan	-	-	-	2.846,75	-	288,73	10,14	2.558,02	-	-
PLN Nusantara Power - Sulawesi	-	-	-	4.921,05	-	293,82	5,97	4.627,23	-	-
PLN Nusantara Power - Sumatera	-	-	-	14.467,05	-	912,51	6,31	13.554,54	-	-
PLN Nusantara Power - Maluku Utara	-	-	-	51,17	-	-	-	51,17	-	-
Luar Jawa	45.031,50	59,45	-	48.323,10	4.375,37	3.332,64	6,32	94.456,78	65,57	0,07
UID Jawa Timur	51,85	-	44.420,35	122,54	-	2,31	1,89	44.592,42	-	-
UID Jawa Tengah dan Yogyakarta	109,53	-	34.029,19	0,42	-	-	-	34.139,14	-	-
UID Jawa Barat	438,96	-	62.028,99	-	-	-	-	62.467,95	-	-
UID Banten	45,97	-	29.950,93	1,03	-	-	-	29.997,93	-	-
UID Jakarta Raya	-	-	40.123,18	0,24	-	-	-	40.123,43	-	-
PLN Indonesia Power - Jawabali	-	-	(3,72)	67.393,08	-	3.240,79	4,81	64.148,57	-	-
PLN Nusantara Power - Jawabali	-	0,08	(3,43)	44.560,05	-	2.172,48	4,88	42.384,22	-	-
Unit Induk Pusat Pengaturan Beban	93.079,85	522,53	124.257,77	-	-	-	-	217.860,15	111,06	0,05
UIK Tanjung Jati B	-	-	20,49	19.205,06	-	1.249,79	6,51	17.975,76	-	-
Jawa	93.726,17	522,61	-	131.282,41	-	6.665,37	5,08	218.865,82	111,06	0,05
Indonesia	138.757,67	582,06	-	179.605,52	4.375,37	9.998,01	5,43	313.322,61	176,63	0,06

Susut Transmisi		Dikirim ke Unit lain	Dikirim Distribusi (GWh)	Pemakaian Sendiri									
				Gardu Distribusi		Susut Distribusi		Susut Energi		Susut Energi & PS		Pemakaian	
(GWh)	(%)			(GWh)	(%)	(GWh)	(%)	(GWh)	(%)	(GWh)	(%)	(GWh)	(%)
-	-	126,37	3.767,05	45,53	1,17	313,53	8,32	313,53	8,05	359,06	9,22	3.407,99	87,53
-	-	1.103,02	13.584,10	106,91	0,73	1.195,10	8,80	1.195,10	8,14	1.302,02	8,86	12.282,09	83,62
-	-	376,48	4.016,41	28,95	0,66	226,01	5,63	226,01	5,14	254,97	5,80	3.761,45	85,63
10,59	0,11	187,63	9.821,92	56,84	0,57	637,16	6,49	647,75	6,46	704,59	7,03	9.127,92	91,09
-	-	859,94	10.923,36	96,18	0,82	1.184,52	10,84	1.184,52	10,05	1.280,70	10,87	9.642,66	81,83
19,71	1,16	0,06	1.671,58	10,01	0,59	105,20	6,29	124,91	7,38	134,91	7,97	1.556,43	91,94
-	-	97,42	6.563,46	54,10	0,81	828,48	12,62	828,48	12,44	882,59	13,25	5.680,87	85,29
-	-	51,25	3.654,47	27,32	0,74	360,46	9,86	360,46	9,73	387,78	10,46	3.266,68	88,15
-	-	26,65	5.853,30	43,27	0,74	409,16	6,99	409,16	6,96	452,43	7,69	5.400,87	91,85
-	-	22,68	5.354,34	36,12	0,67	344,24	6,43	344,24	6,40	380,36	7,07	4.973,98	92,50
-	-	40,97	4.851,06	32,06	0,66	466,96	9,63	466,96	9,55	499,02	10,20	4.352,04	88,96
-	-	187,25	10.992,98	59,42	0,53	661,69	6,02	661,69	5,92	721,11	6,45	10.271,87	91,88
1,52	0,10	-	1.533,06	12,66	0,82	115,48	7,53	117,00	7,62	129,66	8,45	1.404,91	91,51
2,58	0,12	-	2.196,77	18,60	0,85	191,70	8,73	194,28	8,83	212,88	9,67	1.986,48	90,28
-	-	-	6.646,39	32,01	0,48	348,00	5,24	348,00	5,24	380,01	5,72	6.266,38	94,28
27,51	0,98	2,41	2.765,52	34,50	1,23	196,58	7,11	224,08	8,01	258,58	9,24	2.534,44	90,60
27,10	1,84	-	1.441,42	13,07	0,89	118,77	8,24	145,87	9,92	158,94	10,81	1.309,58	89,08
6,24	0,16	627,35	3.320,85	4,31	0,11	106,74	3,21	112,98	2,86	117,30	2,96	3.209,79	81,14
1.378,14	2,95	45.272,98	-	-	-	-	-	1.378,14	2,95	1.378,14	2,95	-	-
265,60	2,05	12.669,19	-	-	-	-	-	265,60	2,05	265,60	2,05	-	-
290,12	2,01	14.113,73	-	-	-	-	-	290,12	2,01	290,12	2,01	-	-
-	-	1.006,18	-	-	-	-	-	-	-	-	-	-	-
-	-	1.299,50	-	-	-	-	-	-	-	-	-	-	-
-	-	650,88	-	-	-	-	-	-	-	-	-	-	-
-	-	3.219,71	-	-	-	-	-	-	-	-	-	-	-
-	-	1.278,46	-	-	-	-	-	-	-	-	-	-	-
-	-	10.732,30	-	-	-	-	-	-	-	-	-	-	-
-	-	2.558,02	-	-	-	-	-	-	-	-	-	-	-
-	-	4.627,23	-	-	-	-	-	-	-	-	-	-	-
-	-	13.554,54	-	-	-	-	-	-	-	-	-	-	-
-	-	51,17	-	-	-	-	-	-	-	-	-	-	-
2.029,11	2,15	-	98.958,03	711,87	0,75	7.809,80	7,89	9.838,91	10,42	10.550,78	11,17	90.436,43	95,74
-	-	-	44.592,42	328,53	0,74	2.904,13	6,51	2.904,13	6,51	3.232,66	7,25	41.359,76	92,75
-	-	0,40	34.138,74	138,41	0,41	2.378,01	6,97	2.378,01	6,97	2.516,42	7,37	31.622,32	92,63
-	-	454,87	62.013,09	338,02	0,54	3.883,06	6,26	3.883,06	6,22	4.221,08	6,76	57.792,01	92,51
-	-	1.859,35	28.138,58	150,62	0,50	1.317,40	4,68	1.317,40	4,39	1.468,02	4,89	26.670,56	88,91
-	-	1.229,11	38.894,31	251,90	0,63	2.276,75	5,85	2.276,75	5,67	2.528,64	6,30	36.365,67	90,63
-	-	64.148,57	-	-	-	-	-	-	-	-	-	-	-
-	-	42.384,22	-	-	-	-	-	-	-	-	-	-	-
4.255,62	1,95	213.493,46	-	-	-	-	-	4.255,62	1,95	4.255,62	1,95	-	-
-	-	17.975,76	-	-	-	-	-	-	-	-	-	-	-
4.255,62	1,94	-	207.777,15	1.207,47	0,55	12.759,35	6,14	17.014,97	7,77	18.222,44	8,33	193.810,32	88,55
6.284,73	2,01	126,06*)	306.735,18	1.919,35	0,61	20.569,14	6,71	26.853,87	8,57	28.773,22	9,18	284.246,75	90,72

*) Transfer Energi ke IPP dan Proyek

Tabel 3 : Faktor Beban, Faktor Kapasitas, Faktor Permintaan **2023**

Satuan PLN/Provinsi	Faktor Beban (%)	Faktor Kapasitas (%)	Faktor Permintaan (%)
UID Aceh	24,36	16,97	7,19
UID Sumatera Utara	67,68	67,48	3,10
UID Sumatera Barat	51,74	37,28	3,67
UID Riau dan Kepulauan Riau	74,13	54,39	11,76
UID Sumatera Selatan, Jambi dan Bengkulu	76,31	45,02	3,03
UIW Bangka Belitung	44,30	38,17	32,70
UID Lampung	44,57	17,03	0,60
UID Kalimantan Barat	57,07	24,08	2,47
UID Kalimantan Selatan dan Tengah	70,85	17,41	0,71
UID Kalimantan Timur dan Utara	70,28	27,47	1,16
UID Sulawesi Utara, Tengah dan Gorontalo	56,65	34,80	7,89
UID Sulawesi Selatan, Tenggara dan Barat	40,48	33,81	2,49
UIW Maluku dan Maluku Utara	69,85	29,72	26,37
UIW Papua dan Papua Barat	55,84	37,15	34,89
UID Bali	79,73	21,69	0,05
UIW Nusa Tenggara Barat	60,17	48,22	32,20
UIW Nusa Tenggara Timur	51,19	33,54	26,26
PT PLN Batam	65,16	53,98	47,68
UIP3B Sumatera	59,48	47,63	-
UIP3B Kalimantan	55,91	58,71	-
UIP3B Sulawesi	82,99	51,44	-
UIK Kalimantan	41,85	18,01	-
UIK Sulawesi	72,93	37,13	-
UIK Sumatera	21,76	9,57	-
PLN Indonesia Power - Kalimantan	62,21	40,72	-
PLN Indonesia Power - Sulawesi	60,94	50,94	-
PLN Indonesia Power - Sumatera	66,74	49,75	-
PLN Nusantara Power - Kalimantan	62,16	38,37	-
PLN Nusantara Power - Sulawesi	61,74	44,39	-
PLN Nusantara Power - Sumatera	67,38	47,23	-
PLN Nusantara Power - Maluku Utara	10,37	4,03	-
Luar Jawa	61,78	44,22	37,64
UID Jawa Timur	32,78	26,14	0,30
UID Jawa Tengah dan Yogyakarta	39,14	31,36	0,20
UID Jawa Barat	52,26	33,31	0,38
UID Banten	41,25	31,89	0,12
UID Jakarta Raya	19,41	6,92	-
PLN Indonesia Power - Jawabali	59,01	48,02	-
PLN Nusantara Power - Jawabali	54,45	41,30	-
Unit Induk Pusat Pengaturan Beban	70,28	65,52	-
UIK Tanjung Jati B	86,88	77,98	-
Jawa	63,86	53,91	45,08
Proyek Pembangkitan	-	66,44	-
Indonesia	63,33	50,58	42,48

Tabel 4 : Jumlah Pelanggan per Jenis Pelanggan 2023

Satuan PLN/Provinsi	Rumah Tangga	Industri	Bisnis	Sosial	Gdg. Kantor Pemerintah	Penerangan Jalan Umum	Jumlah	(%)
UID Aceh	1.483.479	4.235	165.516	55.282	12.904	2.944	1.724.360	1,93
UID Sumatera Utara	4.185.942	5.114	159.835	82.040	11.482	18.308	4.462.721	5,01
UID Sumatera Barat	1.446.887	765	192.468	41.426	6.906	4.727	1.693.179	1,90
UID Riau dan Kepulauan Riau	2.230.728	909	209.833	51.743	9.715	6.851	2.509.779	2,82
- Riau	1.936.633	763	179.138	45.086	7.130	5.096	2.173.846	2,44
- Kepulauan Riau	294.095	146	30.695	6.657	2.585	1.755	335.933	0,38
UID Sumatera Selatan, Jambi dan Bengkulu	4.041.827	3.736	143.143	82.505	15.746	13.957	4.300.914	4,82
- Sumatera Selatan	2.356.358	2.725	65.486	44.448	7.626	7.962	2.484.605	2,79
- Jambi	1.067.285	829	56.581	25.644	4.837	4.864	1.160.040	1,30
- Bengkulu	618.184	182	21.076	12.413	3.283	1.131	656.269	0,74
UIW Bangka Belitung	500.396	817	40.374	9.558	3.526	3.343	558.014	0,63
UID Lampung	2.441.987	8.912	108.882	67.355	4.978	3.121	2.635.235	2,96
UID Kalimantan Barat	1.394.593	703	83.795	30.677	5.780	4.486	1.520.034	1,70
UID Kalimantan Selatan dan Tengah	2.057.435	1.161	146.821	66.276	11.957	6.830	2.290.480	2,57
- Kalimantan Selatan	1.341.112	823	75.597	44.219	6.366	4.905	1.473.022	1,65
- Kalimantan Tengah	716.323	338	71.224	22.057	5.591	1.925	817.458	0,92
UID Kalimantan Timur dan Utara	1.353.823	699	94.423	30.200	7.390	4.034	1.490.569	1,67
UID Sulawesi Utara, Tengah dan Gorontalo	1.955.938	1.157	67.621	58.434	13.587	3.466	2.100.203	2,36
- Sulawesi Utara	759.766	541	28.889	17.359	6.007	1.719	814.281	0,91
- Sulawesi Tengah	867.911	436	28.178	32.930	5.171	1.168	935.794	1,05
- Gorontalo	328.261	180	10.554	8.145	2.409	579	350.128	0,39
UID Sulawesi Selatan, Tenggara dan Barat	3.638.718	5.093	156.629	71.941	18.833	6.607	3.897.821	4,37
- Sulawesi Selatan	2.568.432	4.178	113.574	46.825	10.518	4.531	2.748.058	3,08
- Sulawesi Tenggara	737.591	688	30.363	16.895	6.328	1.780	793.645	0,89
- Sulawesi Barat	332.695	227	12.692	8.221	1.987	296	356.118	0,40
UIW Maluku dan Maluku Utara	740.943	161	25.824	18.004	6.307	1.424	792.663	0,89
- Maluku	306.812	85	11.448	6.713	2.572	364	327.994	0,37
- Maluku Utara	434.131	76	14.376	11.291	3.735	1.060	464.669	0,52
UIW Papua dan Papua Barat	756.557	167	50.353	19.912	8.125	1.788	836.902	0,94
- Papua	497.980	119	33.432	12.747	4.708	985	549.971	0,62
- Papua Barat	258.577	48	16.921	7.165	3.417	803	286.931	0,32
UID Bali	1.398.359	1.345	246.440	44.689	4.397	6.282	1.701.512	1,91
UIW Nusa Tenggara Barat	1.818.269	641	42.078	33.152	4.917	3.252	1.902.309	2,13
UIW Nusa Tenggara Timur	1.120.916	409	36.583	25.229	8.189	1.166	1.192.492	1,34
PT PLN Batam	310.362	397	51.933	4.335	464	1.248	368.739	0,41
Luar Jawa	32.877.159	36.421	2.022.551	792.758	155.203	93.834	35.977.926	40,36
UID Jawa Timur	12.385.526	121.755	746.319	369.734	25.011	72.762	13.721.107	15,39
UID Jawa Tengah dan Yogyakarta	12.183.369	17.883	652.659	345.005	30.735	66.901	13.296.552	14,91
- Jawa Tengah	10.833.630	17.033	579.526	310.234	26.710	53.588	11.820.721	13,26
- D.I. Yogyakarta	1.349.739	850	73.133	34.771	4.025	13.313	1.475.831	1,66
UID Jawa Barat	15.593.849	17.645	841.546	363.088	19.897	101.825	16.937.850	19,00
UID Banten	3.664.711	7.322	236.560	72.864	4.341	8.968	3.994.766	4,48
UID Jakarta Raya	4.846.734	5.744	306.506	49.629	7.087	9.377	5.225.077	5,86
Jawa	48.674.189	170.349	2.783.590	1.200.320	87.071	259.833	53.175.352	59,64
Indonesia	81.551.348	206.770	4.806.141	1.993.078	242.274	353.667	89.153.278	100,00
(%)	91,47	0,23	5,39	2,24	0,27	0,40	100,00	

Tabel 5 : Daya Tersambung per Kelompok Pelanggan (MVA) **2023**

Satuan PLN/Provinsi	Rumah Tangga	Industri	Bisnis	Sosial	Gdg. Kantor Pemerintah	Penerangan Jalan Umum	Jumlah	(%)
UID Aceh	1.248,88	178,43	440,91	175,27	92,63	37,74	2.173,86	1,27
UID Sumatera Utara	4.205,01	1.431,76	1.264,00	361,78	116,82	104,03	7.483,40	4,36
UID Sumatera Barat	1.384,72	295,83	524,07	143,45	66,87	24,13	2.439,06	1,42
UID Riau dan Kepulauan Riau	2.757,43	716,49	1.034,24	250,50	130,27	49,89	4.938,84	2,88
- Riau	2.337,86	694,35	838,73	212,51	92,24	39,92	4.215,61	2,46
- Kepulauan Riau	419,57	22,14	195,52	37,99	38,03	9,98	723,23	0,42
UID Sumatera Selatan, Jambi dan Bengkulu	4.225,88	642,92	1.015,58	297,59	156,38	64,27	6.402,61	3,73
- Sumatera Selatan	2.411,20	474,35	625,81	177,80	90,72	39,22	3.819,10	2,23
- Jambi	1.235,35	114,55	286,82	82,40	40,66	19,43	1.779,22	1,04
- Bengkulu	579,32	54,02	102,95	37,39	25,00	5,62	804,30	0,47
UIW Bangka Belitung	623,93	207,33	207,63	58,65	34,35	10,17	1.142,07	0,67
UID Lampung	2.311,72	614,32	528,90	183,22	58,20	23,66	3.720,02	2,17
UID Kalimantan Barat	1.468,16	154,93	461,90	128,80	68,84	21,36	2.303,99	1,34
UID Kalimantan Selatan dan Tengah	1.997,10	441,13	655,56	206,86	119,98	37,28	3.457,91	2,02
- Kalimantan Selatan	1.236,15	359,32	417,08	134,44	69,53	26,68	2.243,20	1,31
- Kalimantan Tengah	760,94	81,81	238,48	72,42	50,45	10,61	1.214,71	0,71
UID Kalimantan Timur dan Utara	1.784,19	351,27	749,87	179,32	154,99	22,83	3.242,48	1,89
UID Sulawesi Utara, Tengah dan Gorontalo	1.897,41	310,86	533,90	183,82	123,73	25,43	3.075,16	1,79
- Sulawesi Utara	784,16	166,46	301,43	83,14	45,94	10,92	1.392,06	0,81
- Sulawesi Tengah	827,10	83,98	165,36	72,15	47,61	9,87	1.206,07	0,70
- Gorontalo	286,14	60,42	67,11	28,53	30,18	4,64	477,03	0,28
UID Sulawesi Selatan, Tenggara dan Barat	3.900,55	1.058,95	1.063,85	369,33	182,51	60,81	6.636,00	3,87
- Sulawesi Selatan	2.720,53	952,42	838,27	279,04	116,80	47,83	4.954,88	2,89
- Sulawesi Tenggara	822,15	77,87	173,97	63,06	44,37	10,20	1.191,63	0,69
- Sulawesi Barat	357,87	28,67	51,61	27,23	21,34	2,78	489,49	0,29
UIW Maluku dan Maluku Utara	777,99	92,40	183,56	62,94	59,31	6,77	1.182,96	0,69
- Maluku	330,24	5,60	98,03	33,17	32,97	2,39	502,39	0,29
- Maluku Utara	447,75	86,80	85,53	29,77	26,34	4,38	680,57	0,40
UIW Papua dan Papua Barat	1.037,06	21,19	346,42	107,63	129,01	8,21	1.649,53	0,96
- Papua	692,53	9,68	230,63	69,00	81,14	5,96	1.088,95	0,63
- Papua Barat	344,53	11,51	115,78	38,63	47,86	2,25	560,58	0,33
UID Bali	2.209,14	119,21	1.899,89	194,25	79,86	34,39	4.536,74	2,65
UIW Nusa Tenggara Barat	1.534,82	135,01	338,06	96,91	43,17	16,84	2.164,81	1,26
UIW Nusa Tenggara Timur	1.161,77	39,08	229,82	97,13	56,59	6,99	1.591,38	0,93
PT PLN Batam	649,42	428,04	648,34	60,83	34,30	10,85	1.831,77	1,07
Luar Jawa	35.175,18	7.239,17	12.126,50	3.158,27	1.707,80	565,67	59.972,59	34,97
UID Jawa Timur	11.192,27	7.658,86	4.281,16	1.230,92	373,47	256,42	24.993,10	14,57
UID Jawa Tengah dan Yogyakarta	10.425,74	3.927,20	3.528,06	1.213,45	331,91	208,33	19.634,69	11,45
- Jawa Tengah	8.982,08	3.789,72	2.956,50	993,46	265,06	180,33	17.167,15	10,01
- D.I. Yogyakarta	1.443,66	137,48	571,56	219,99	66,85	28,00	2.467,54	1,44
UID Jawa Barat	15.108,87	9.443,21	5.539,39	1.123,65	438,24	154,28	31.807,64	18,55
UID Banten	4.019,17	6.614,14	2.341,27	300,36	139,99	50,78	13.465,69	7,85
UID Jakarta Raya	9.397,64	1.815,54	8.244,62	1.040,02	997,73	139,17	21.634,72	12,61
Jawa	50.143,67	29.458,94	23.934,50	4.908,39	2.281,34	808,99	111.535,83	65,03
Indonesia	85.318,86	36.698,11	36.060,99	8.066,67	3.989,14	1.374,66	171.508,42	100,00
(%)	49,75	21,40	21,03	4,70	2,33	0,80	100,00	

Tabel 6 : Energi Terjual per Kelompok Pelanggan (GWh) 2023

Satuan PLN/Provinsi	Rumah Tangga	Industri	Bisnis	Sosial	Gdg. Kantor Pemerintah	Penerangan Jalan Umum	Jumlah	(%)
UID Aceh	1.986,67	339,79	631,21	251,10	115,55	133,98	3.458,30	1,20
UID Sumatera Utara	6.187,34	3.137,13	1.992,01	576,89	158,68	420,80	12.472,84	4,32
UID Sumatera Barat	1.837,36	839,60	730,29	217,24	86,04	100,31	3.810,84	1,32
UID Riau dan Kepulauan Riau	3.665,58	3.219,97	1.683,34	342,45	162,67	138,15	9.212,16	3,19
- Riau	3.142,80	3.180,60	1.358,50	296,71	119,24	114,71	8.212,56	2,85
- Kepulauan Riau	522,77	39,37	324,84	45,74	43,43	23,45	999,60	0,35
UID Sumatera Selatan, Jambi dan Bengkulu	5.801,19	1.375,90	1.789,46	430,20	210,40	198,49	9.805,65	3,40
- Sumatera Selatan	3.494,16	1.110,18	1.140,58	262,06	123,84	147,68	6.278,50	2,18
- Jambi	1.501,59	182,49	473,90	116,75	54,12	42,33	2.371,18	0,82
- Bengkulu	805,45	83,24	174,98	51,39	32,44	8,48	1.155,97	0,40
UIW Bangka Belitung	820,81	431,14	249,42	61,27	38,18	9,99	1.610,81	0,56
UID Lampung	3.239,05	1.194,64	854,76	267,07	76,91	129,48	5.761,91	2,00
UID Kalimantan Barat	2.054,90	266,91	692,01	159,76	87,34	47,67	3.308,59	1,15
UID Kalimantan Selatan dan Tengah	3.035,63	939,91	1.032,43	267,97	160,03	88,98	5.524,95	1,92
- Kalimantan Selatan	1.950,32	747,47	662,18	176,53	92,01	65,37	3.693,87	1,28
- Kalimantan Tengah	1.085,32	192,44	370,25	91,44	68,02	23,61	1.831,08	0,63
UID Kalimantan Timur dan Utara	2.723,69	616,36	1.233,09	244,96	196,61	52,20	5.066,92	1,76
UID Sulawesi Utara, Tengah dan Gorontalo	2.517,65	631,10	823,05	228,97	157,77	81,98	4.440,52	1,54
- Sulawesi Utara	1.010,27	417,45	468,94	105,61	54,44	38,67	2.095,38	0,73
- Sulawesi Tengah	1.059,72	121,86	242,85	83,53	62,58	32,38	1.602,92	0,56
- Gorontalo	447,65	91,79	111,26	39,83	40,75	10,93	742,22	0,26
UID Sulawesi Selatan, Tenggara dan Barat	4.722,79	3.138,99	1.689,34	462,61	246,20	159,39	10.419,32	3,61
- Sulawesi Selatan	3.524,89	3.008,86	1.352,63	370,64	170,71	130,31	8.558,03	2,97
- Sulawesi Tenggara	861,59	83,06	261,49	63,77	51,47	21,56	1.342,95	0,47
- Sulawesi Barat	336,31	47,08	75,22	28,19	24,02	7,52	518,33	0,18
UIW Maluku dan Maluku Utara	875,04	297,55	291,10	75,00	94,88	18,52	1.652,08	0,57
- Maluku	367,39	12,08	155,26	38,53	52,49	7,82	633,56	0,22
- Maluku Utara	507,65	285,47	135,84	36,47	42,39	10,70	1.018,52	0,35
UIW Papua dan Papua Barat	1.187,92	24,23	503,10	126,67	149,81	18,65	2.010,38	0,70
- Papua	794,03	11,83	339,33	85,50	99,30	12,40	1.342,39	0,47
- Papua Barat	393,89	12,40	163,77	41,16	50,51	6,25	667,98	0,23
UID Bali	2.738,18	207,62	3.033,84	210,03	101,77	63,09	6.354,53	2,20
UIW Nusa Tenggara Barat	1.608,71	238,93	492,64	125,64	51,72	54,96	2.572,60	0,89
UIW Nusa Tenggara Timur	808,83	43,19	316,24	92,72	54,13	18,15	1.333,25	0,46
PT PLN Batam	1.001,20	963,06	1.097,16	90,17	44,81	13,39	3.209,79	1,11
Luar Jawa	46.812,52	17.906,03	19.134,47	4.230,72	2.193,51	1.748,19	92.025,44	31,91
UID Jawa Timur	16.004,06	17.166,79	5.932,68	1.716,78	475,59	590,40	41.886,30	14,52
UID Jawa Tengah dan Yogyakarta	15.548,24	8.677,19	5.064,91	1.746,51	405,14	553,99	31.995,98	11,09
- Jawa Tengah	13.620,27	8.408,15	4.170,67	1.418,82	324,66	489,18	28.431,75	9,86
- D.I. Yogyakarta	1.927,97	269,05	894,24	327,69	80,48	64,81	3.564,23	1,24
UID Jawa Barat	21.854,79	25.026,44	9.013,71	1.679,84	560,75	428,79	58.564,31	20,30
UID Banten	6.475,33	15.814,03	3.964,60	463,42	167,91	86,12	26.971,40	9,35
UID Jakarta Raya	15.644,75	3.997,21	14.001,63	1.658,84	1.482,22	207,71	36.992,35	12,83
Jawa	75.527,17	70.681,65	37.977,53	7.265,39	3.091,60	1.867,00	196.410,34	68,09
Indonesia	122.339,69	88.587,68	57.112,00	11.496,10	5.285,12	3.615,19	288.435,78	100,00
(%)	42,41	30,71	19,80	3,99	1,83	1,25	100,00	

Tabel 7 : Pendapatan per Kelompok Pelanggan (juta Rp) **2023**

Satuan PLN/Provinsi	Rumah Tangga	Industri	Bisnis	Sosial	Gdg. Kantor Pemerintah	Penerangan Jalan Umum	Jumlah	(%)
UID Aceh	1.815.455,58	389.041,47	752.299,88	199.103,42	183.751,88	227.739,06	3.567.391,30	1,07
UID Sumatera Utara	6.846.704,07	3.554.044,49	2.587.899,80	463.660,55	250.947,00	715.186,63	14.418.442,53	4,33
UID Sumatera Barat	2.025.752,47	882.660,35	880.041,23	176.728,88	137.722,72	170.821,19	4.273.726,82	1,28
UID Riau dan Kepulauan Riau	4.802.461,42	1.827.896,38	2.094.372,21	293.236,91	262.000,23	234.865,13	9.514.832,27	2,85
- Riau	4.074.931,75	1.784.157,09	1.685.671,79	254.176,05	192.172,77	195.018,11	8.186.127,56	2,46
- Kepulauan Riau	727.529,67	43.739,30	408.700,42	39.060,85	69.827,46	39.847,02	1.328.704,71	0,40
UID Sumatera Selatan, Jambi dan Bengkulu	6.762.418,55	1.533.974,00	2.297.823,75	344.977,25	333.063,84	342.114,03	11.614.371,41	3,48
- Sumatera Selatan	3.995.638,67	1.232.598,21	1.482.251,00	215.354,36	196.076,98	254.807,59	7.376.726,80	2,21
- Jambi	1.897.551,54	205.564,80	592.098,50	89.654,14	85.152,56	72.846,30	2.942.867,84	0,88
- Bengkulu	869.228,34	95.810,99	223.474,25	39.968,75	51.834,30	14.460,15	1.294.776,77	0,39
UIW Bangka Belitung	1.098.218,26	510.651,42	320.910,32	54.154,43	61.440,98	16.980,95	2.062.356,35	0,62
UID Lampung	3.306.460,60	1.354.754,13	1.063.780,91	206.954,89	122.402,69	224.426,22	6.278.779,44	1,88
UID Kalimantan Barat	2.321.054,95	306.405,95	876.612,63	129.201,54	139.664,08	81.024,94	3.853.964,09	1,16
UID Kalimantan Selatan dan Tengah	3.453.476,83	1.056.772,65	1.293.853,41	211.232,44	255.446,66	151.464,24	6.422.246,23	1,93
- Kalimantan Selatan	2.137.165,18	832.470,40	846.332,60	139.821,64	147.215,27	111.171,15	4.214.176,23	1,26
- Kalimantan Tengah	1.316.311,65	224.302,26	447.520,81	71.410,79	108.231,40	40.293,10	2.208.070,00	0,66
UID Kalimantan Timur dan Utara	3.656.826,85	712.101,78	1.603.845,67	206.710,37	313.073,05	88.755,09	6.581.312,80	1,97
UID Sulawesi Utara, Tengah dan Gorontalo	2.696.036,59	710.936,13	1.076.551,82	182.972,44	250.613,11	139.299,81	5.056.409,89	1,52
- Sulawesi Utara	1.099.008,89	466.191,66	611.908,18	88.353,09	87.003,22	65.719,88	2.418.184,91	0,73
- Sulawesi Tengah	1.155.307,65	142.366,88	314.174,48	63.442,70	99.062,09	55.004,77	1.829.358,57	0,55
- Gorontalo	441.720,05	102.377,59	150.469,16	31.176,65	64.547,80	18.575,17	808.866,40	0,24
UID Sulawesi Selatan, Tenggara dan Barat	5.426.318,57	3.227.155,38	2.191.905,83	390.105,78	390.045,05	270.933,91	11.896.464,51	3,57
- Sulawesi Selatan	4.025.759,38	3.073.440,46	1.757.597,71	313.765,64	271.514,01	221.482,04	9.663.559,24	2,90
- Sulawesi Tenggara	1.009.013,95	100.166,44	338.895,07	53.025,87	80.506,77	36.678,38	1.618.286,48	0,49
- Sulawesi Barat	391.545,24	53.548,48	95.413,05	23.314,27	38.024,27	12.773,48	614.618,80	0,18
UIW Maluku dan Maluku Utara	1.066.935,05	222.656,28	388.733,19	60.133,08	152.523,54	31.474,24	1.922.455,38	0,58
- Maluku	449.705,60	13.570,01	205.629,23	32.222,59	84.541,99	13.289,81	798.959,23	0,24
- Maluku Utara	617.229,45	209.086,27	183.103,96	27.910,49	67.981,55	18.184,43	1.123.496,15	0,34
UIW Papua dan Papua Barat	1.636.745,38	28.231,21	638.883,76	105.075,67	238.910,03	31.732,14	2.679.578,18	0,80
- Papua	1.100.066,44	13.374,56	429.557,17	70.941,57	157.242,68	21.102,45	1.792.284,87	0,54
- Papua Barat	536.678,94	14.856,65	209.326,58	34.134,09	81.667,35	10.629,69	887.293,31	0,27
UID Bali	3.899.228,34	231.698,73	3.886.905,33	181.027,92	165.709,25	106.804,82	8.471.374,39	2,54
UIW Nusa Tenggara Barat	1.427.903,37	272.524,55	653.150,98	99.168,94	81.501,58	93.149,45	2.627.398,86	0,79
UIW Nusa Tenggara Timur	968.640,57	51.545,40	416.096,87	79.954,17	84.857,87	30.842,64	1.631.937,52	0,49
PT PLN Batam	1.435.414,59	1.243.265,12	1.670.368,61	98.934,78	87.406,91	29.346,20	4.564.736,21	1,37
Luar Jawa	54.646.052,04	18.116.315,40	24.694.036,19	3.483.333,45	3.511.080,44	2.986.960,67	107.437.778,18	32,24
UID Jawa Timur	16.607.975,54	18.692.897,70	7.575.815,13	1.387.591,50	752.920,38	1.004.061,78	46.021.262,01	13,81
UID Jawa Tengah dan Yogyakarta	15.035.109,28	9.582.129,32	6.423.625,61	1.441.602,46	634.260,25	942.968,83	34.059.695,73	10,22
- Jawa Tengah	12.808.078,66	9.283.136,89	5.302.731,77	1.158.794,79	507.541,86	831.599,82	29.891.883,77	8,97
- D.I. Yogyakarta	2.227.030,62	298.992,42	1.120.893,85	282.807,67	126.718,39	111.369,01	4.167.811,96	1,25
UID Jawa Barat	24.131.537,60	27.920.378,65	11.254.117,70	1.340.386,38	873.821,46	744.482,04	66.264.723,84	19,88
UID Banten	7.736.323,16	17.024.717,19	5.072.508,04	385.095,80	270.007,53	146.388,15	30.635.039,87	9,19
UID Jakarta Raya	23.285.549,67	4.366.818,41	16.978.039,97	1.526.534,82	2.350.270,04	354.151,04	48.861.363,93	14,66
Jawa	86.796.495,24	77.586.941,27	47.304.106,44	6.081.210,95	4.881.279,65	3.192.051,83	225.842.085,39	67,76
Indonesia	141.442.547,28	95.703.256,67	71.998.142,63	9.564.544,40	8.392.360,09	6.179.012,50	333.279.863,57	100,00
(%)	42,44	28,72	21,60	2,87	2,52	1,85	100,00	

Catatan: Data diambil dari Aplikasi Pengelolaan Pelanggan Terpusat (AP2T)

Tabel 8 : Energi Terjual Rata-rata per Jenis Pelanggan (kWh) 2023

Satuan PLN/Provinsi	Rumah Tangga	Industri	Bisnis	Sosial	Gdg. Kantor Pemerintah	Penerangan Jalan Umum	Jumlah
UID Aceh	1.339,20	80.233,77	3.813,59	4.542,17	8.954,59	45.509,51	2.005,56
UID Sumatera Utara	1.478,12	613.439,58	12.462,91	7.031,81	13.819,89	22.984,49	2.794,90
UID Sumatera Barat	1.269,87	1.097.516,34	3.794,35	5.244,05	12.458,73	21.220,65	2.250,70
UID Riau dan Kepulauan Riau	1.643,22	3.542.321,23	8.022,28	6.618,29	16.744,21	20.164,94	3.670,51
- Riau	1.622,82	4.168.545,22	7.583,54	6.580,98	16.723,70	22.509,81	3.777,89
- Kepulauan Riau	1.777,55	269.657,53	10.582,83	6.870,96	16.800,77	13.361,82	2.975,59
UID Sumatera Selatan, Jambi dan Bengkulu	1.435,29	368.281,58	12.501,21	5.214,23	13.362,12	14.221,54	2.279,90
- Sumatera Selatan	1.482,86	407.405,50	17.417,16	5.895,88	16.239,18	18.548,10	2.526,96
- Jambi	1.406,93	220.132,69	8.375,60	4.552,72	11.188,75	8.702,71	2.044,05
- Bengkulu	1.302,93	457.362,64	8.302,33	4.140,01	9.881,21	7.497,79	1.761,44
UIW Bangka Belitung	1.640,32	527.711,14	6.177,74	6.410,34	10.828,13	2.988,33	2.886,68
UID Lampung	1.326,40	134.048,47	7.850,33	3.965,11	15.449,98	41.486,70	2.186,49
UID Kalimantan Barat	1.473,48	379.672,83	8.258,37	5.207,81	15.110,73	10.626,39	2.176,66
UID Kalimantan Selatan dan Tengah	1.475,44	809.569,34	7.031,90	4.043,24	13.383,79	13.027,82	2.412,14
- Kalimantan Selatan	1.454,26	908.226,00	8.759,34	3.992,18	14.453,35	13.327,22	2.507,69
- Kalimantan Tengah	1.515,13	569.349,11	5.198,39	4.145,62	12.165,98	12.264,94	2.239,97
UID Kalimantan Timur dan Utara	2.011,85	881.773,96	13.059,21	8.111,26	26.604,87	12.940,01	3.399,31
UID Sulawesi Utara, Tengah dan Gorontalo	1.287,18	545.462,40	12.171,51	3.918,44	11.611,83	23.652,63	2.114,33
- Sulawesi Utara	1.329,71	771.626,62	16.232,48	6.083,88	9.062,76	22.495,64	2.573,29
- Sulawesi Tengah	1.221,00	279.495,41	8.618,43	2.536,59	12.102,11	27.722,60	1.712,90
- Gorontalo	1.363,70	509.944,44	10.541,97	4.890,12	16.915,73	18.877,37	2.119,82
UID Sulawesi Selatan, Tenggara dan Barat	1.297,93	616.334,18	10.785,61	6.430,41	13.072,80	24.124,41	2.673,11
- Sulawesi Selatan	1.372,39	720.167,54	11.909,68	7.915,43	16.230,27	28.759,66	3.114,21
- Sulawesi Tenggara	1.168,11	120.726,74	8.612,13	3.774,49	8.133,69	12.112,36	1.692,12
- Sulawesi Barat	1.010,87	207.400,88	5.926,57	3.429,02	12.088,58	25.405,41	1.455,53
UIW Maluku dan Maluku Utara	1.180,98	1.848.136,65	11.272,46	4.165,74	15.043,60	13.005,62	2.084,23
- Maluku	1.197,44	142.117,65	13.562,19	5.739,61	20.408,24	21.483,52	1.931,65
- Maluku Utara	1.169,35	3.756.184,21	9.449,08	3.230,01	11.349,40	10.094,34	2.191,93
UIW Papua dan Papua Barat	1.570,17	145.089,82	9.991,46	6.361,49	18.438,15	10.430,65	2.402,17
- Papua	1.594,50	99.411,76	10.149,86	6.707,46	21.091,76	12.588,83	2.440,84
- Papua Barat	1.523,30	258.333,33	9.678,51	5.744,59	14.781,97	7.783,31	2.328,02
UID Bali	1.958,14	154.364,31	12.310,66	4.699,81	23.145,33	10.042,98	3.734,64
UIW Nusa Tenggara Barat	884,75	372.745,71	11.707,78	3.789,82	10.518,61	16.900,37	1.352,36
UIW Nusa Tenggara Timur	721,58	105.599,02	8.644,45	3.675,14	6.610,09	15.566,04	1.118,05
PT PLN Batam	3.225,91	2.425.843,83	21.126,45	20.800,46	96.573,28	10.729,17	8.704,77
Luar Jawa	1.423,86	491.640,26	9.460,56	5.336,71	14.133,17	18.630,67	2.557,83
UID Jawa Timur	1.292,16	140.994,54	7.949,25	4.643,28	19.015,23	8.114,13	3.052,69
UID Jawa Tengah dan Yogyakarta	1.276,19	485.220,04	7.760,42	5.062,27	13.181,71	8.280,74	2.406,34
- Jawa Tengah	1.257,22	493.638,82	7.196,69	4.573,39	12.155,00	9.128,54	2.405,25
- D.I. Yogyakarta	1.428,40	316.529,41	12.227,59	9.424,23	19.995,03	4.868,17	2.415,07
UID Jawa Barat	1.401,50	1.418.330,41	10.710,89	4.626,54	28.182,64	4.211,05	3.457,60
UID Banten	1.766,94	2.159.796,50	16.759,38	6.360,07	38.680,03	9.603,03	6.751,69
UID Jakarta Raya	3.227,90	695.893,11	45.681,42	33.424,81	209.146,32	22.151,01	7.079,77
Jawa	1.551,69	414.922,60	13.643,36	6.052,88	35.506,66	7.185,38	3.693,63
Indonesia	1.500,15	428.435,85	11.883,13	5.768,01	21.814,64	10.222,02	3.235,28

Tabel 9 : Tarif Listrik Rata-rata per Kelompok Pelanggan (Rp/kWh) 2023

Satuan PLN/Provinsi	Rumah Tangga	Industri	Bisnis	Sosial	Gdg. Kantor Pemerintah	Penerangan Jalan Umum	Jumlah
UID Aceh	913,82	1.144,95	1.191,84	792,92	1.590,24	1.699,80	1.031,54
UID Sumatera Utara	1.106,57	1.132,90	1.299,14	803,72	1.581,47	1.699,59	1.155,99
UID Sumatera Barat	1.102,53	1.051,29	1.205,06	813,52	1.600,68	1.702,93	1.121,47
UID Riau dan Kepulauan Riau	1.310,15	567,67	1.244,18	856,29	1.610,62	1.700,07	1.032,86
- Riau	1.296,59	560,95	1.240,83	856,65	1.611,65	1.700,10	996,78
- Kepulauan Riau	1.391,68	1.110,98	1.258,16	853,98	1.607,82	1.699,23	1.329,24
UID Sumatera Selatan, Jambi dan Bengkulu	1.165,70	1.114,89	1.284,09	801,90	1.583,00	1.723,58	1.184,46
- Sumatera Selatan	1.143,52	1.110,27	1.299,56	821,78	1.583,31	1.725,40	1.174,92
- Jambi	1.263,69	1.126,44	1.249,42	767,92	1.573,40	1.720,91	1.241,10
- Bengkulu	1.079,18	1.151,02	1.277,14	777,75	1.597,85	1.705,21	1.120,07
UIW Bangka Belitung	1.337,97	1.184,42	1.286,63	883,87	1.609,25	1.699,79	1.280,32
UID Lampung	1.020,81	1.134,03	1.244,54	774,91	1.591,51	1.733,29	1.089,70
UID Kalimantan Barat	1.129,52	1.147,97	1.266,76	808,72	1.599,08	1.699,71	1.164,84
UID Kalimantan Selatan dan Tengah	1.137,65	1.124,33	1.253,21	788,27	1.596,24	1.702,23	1.162,41
- Kalimantan Selatan	1.095,80	1.113,72	1.278,10	792,06	1.599,99	1.700,64	1.140,85
- Kalimantan Tengah	1.212,83	1.165,57	1.208,70	780,96	1.591,17	1.706,61	1.205,88
UID Kalimantan Timur dan Utara	1.342,60	1.155,33	1.300,67	843,85	1.592,36	1.700,29	1.298,88
UID Sulawesi Utara, Tengah dan Gorontalo	1.070,85	1.126,50	1.308,00	799,11	1.588,47	1.699,19	1.138,70
- Sulawesi Utara	1.087,84	1.116,76	1.304,88	836,60	1.598,15	1.699,51	1.154,06
- Sulawesi Tengah	1.090,20	1.168,28	1.293,70	759,52	1.582,97	1.698,73	1.141,27
- Gorontalo	986,75	1.115,35	1.352,41	782,74	1.584,00	1.699,47	1.089,81
UID Sulawesi Selatan, Tenggara dan Barat	1.148,96	1.028,09	1.297,49	843,27	1.584,26	1.699,82	1.141,77
- Sulawesi Selatan	1.142,10	1.021,46	1.299,39	846,55	1.590,50	1.699,65	1.129,18
- Sulawesi Tenggara	1.171,11	1.205,95	1.296,02	831,52	1.564,15	1.701,22	1.205,03
- Sulawesi Barat	1.164,24	1.137,39	1.268,45	827,04	1.583,03	1.698,60	1.185,74
UIW Maluku dan Maluku Utara	1.219,30	748,30	1.335,39	801,77	1.607,54	1.699,47	1.163,65
- Maluku	1.224,06	1.123,35	1.324,42	836,30	1.610,63	1.699,46	1.261,04
- Maluku Utara	1.215,86	732,43	1.347,94	765,30	1.603,72	1.699,48	1.103,07
UIW Papua dan Papua Barat	1.377,82	1.165,13	1.269,89	829,52	1.594,75	1.701,46	1.332,87
- Papua	1.385,42	1.130,56	1.265,90	829,73	1.583,51	1.701,81	1.335,14
- Papua Barat	1.362,51	1.198,12	1.278,17	829,30	1.616,86	1.700,75	1.328,32
UID Bali	1.424,02	1.115,98	1.281,18	861,91	1.628,27	1.692,90	1.333,12
UIW Nusa Tenggara Barat	887,61	1.140,60	1.325,82	789,31	1.575,82	1.694,86	1.021,30
UIW Nusa Tenggara Timur	1.197,58	1.193,46	1.315,76	862,32	1.567,67	1.699,32	1.224,02
PT PLN Batam	1.433,69	1.290,95	1.522,45	1.097,20	1.950,61	2.191,65	1.422,13
Luar Jawa	1.167,34	1.011,74	1.290,55	823,34	1.600,67	1.708,60	1.167,48
UID Jawa Timur	1.037,74	1.088,90	1.276,96	808,25	1.583,13	1.700,65	1.098,72
UID Jawa Tengah dan Yogyakarta	967,00	1.104,29	1.268,26	825,42	1.565,53	1.702,14	1.064,50
- Jawa Tengah	940,37	1.104,06	1.271,43	816,73	1.563,30	1.699,99	1.051,36
- D.I. Yogyakarta	1.155,12	1.111,29	1.253,46	863,03	1.574,53	1.718,39	1.169,34
UID Jawa Barat	1.104,18	1.115,64	1.248,56	797,93	1.558,31	1.736,24	1.131,49
UID Banten	1.194,74	1.076,56	1.279,45	830,99	1.608,05	1.699,82	1.135,83
UID Jakarta Raya	1.488,39	1.092,47	1.212,58	920,24	1.585,64	1.705,03	1.320,85
J a w a	1.149,21	1.097,70	1.245,58	837,01	1.578,88	1.709,72	1.149,85
I n d o n e s i a	1.156,15	1.080,32	1.260,65	831,98	1.587,92	1.709,18	1.155,47

Catatan: Data diambil dari Aplikasi Pelayanan Pelanggan Terpusat (AP2T)

Tabel 10 : Jumlah Pelanggan per Jenis Tegangan 2023

Satuan PLN/Provinsi	Tegangan			Jumlah	(%)
	Rendah	Menengah	Tinggi		
UID Aceh	1.723.806	554	-	1.724.360	1,93
UID Sumatera Utara	4.453.660	9.059	2	4.462.721	5,01
UID Sumatera Barat	1.691.494	1.683	2	1.693.179	1,90
UID Riau dan Kepulauan Riau	2.506.508	3.269	2	2.509.779	2,82
- Riau	2.170.781	3.063	2	2.173.846	2,44
- Kepulauan Riau	335.727	206	-	335.933	0,38
UID Sumatera Selatan, Jambi dan Bengkulu	4.299.301	1.612	1	4.300.914	4,82
- Sumatera Selatan	2.483.463	1.141	1	2.484.605	2,79
- Jambi	1.159.769	271	-	1.160.040	1,30
- Bengkulu	656.069	200	-	656.269	0,74
UIW Bangka Belitung	555.015	2.999	-	558.014	0,63
UID Lampung	2.634.412	823	-	2.635.235	2,96
UID Kalimantan Barat	1.519.438	596	-	1.520.034	1,70
UID Kalimantan Selatan dan Tengah	2.289.848	630	2	2.290.480	2,57
- Kalimantan Selatan	1.472.566	454	2	1.473.022	1,65
- Kalimantan Tengah	817.282	176	-	817.458	0,92
UID Kalimantan Timur dan Utara	1.489.593	974	2	1.490.569	1,67
UID Sulawesi Utara, Tengah dan Gorontalo	2.099.300	901	2	2.100.203	2,36
- Sulawesi Utara	813.866	414	1	814.281	0,91
- Sulawesi Tengah	935.420	374	-	935.794	1,05
- Gorontalo	350.014	113	1	350.128	0,39
UID Sulawesi Selatan, Tenggara dan Barat	3.894.266	3.548	7	3.897.821	4,37
- Sulawesi Selatan	2.745.079	2.972	7	2.748.058	3,08
- Sulawesi Tenggara	793.316	329	-	793.645	0,89
- Sulawesi Barat	355.871	247	-	356.118	0,40
UIW Maluku dan Maluku Utara	791.082	1.580	1	792.663	0,89
- Maluku	327.106	888	-	327.994	0,37
- Maluku Utara	463.976	692	1	464.669	0,52
UIW Papua dan Papua Barat	836.044	858	-	836.902	0,94
- Papua	549.497	474	-	549.971	0,62
- Papua Barat	286.547	384	-	286.931	0,32
UID Bali	1.657.690	43.822	-	1.701.512	1,91
UIW Nusa Tenggara Barat	1.901.670	639	-	1.902.309	2,13
UIW Nusa Tenggara Timur	1.191.677	815	-	1.192.492	1,34
PT PLN Batam	365.509	3.230	-	368.739	0,41
Luar Jawa	35.900.313	77.592	21	35.977.926	40,36
UID Jawa Timur	13.712.184	8.893	30	13.721.107	15,39
UID Jawa Tengah dan Yogyakarta	13.291.028	5.515	9	13.296.552	14,91
- Jawa Tengah	11.815.770	4.942	9	11.820.721	13,26
- D.I. Yogyakarta	1.475.258	573	-	1.475.831	1,66
UID Jawa Barat	16.927.138	10.681	31	16.937.850	19,00
UID Banten	3.984.208	10.528	30	3.994.766	4,48
UID Jakarta Raya	5.209.360	15.711	6	5.225.077	5,86
Jawa	53.123.918	51.328	106	53.175.352	59,64
Indonesia	89.024.231	128.920	127	89.153.278	100,00
(%)	99,86	0,14	0,00	100	

Tabel 11 : Daya Tersambung per Jenis Tegangan (MVA) **2023**

Satuan PLN/Provinsi	Tegangan			Jumlah	(%)
	Rendah	Menengah	Tinggi		
UID Aceh	1.993,24	180,63	-	2.173,86	1,27
UID Sumatera Utara	5.778,64	1.624,66	80,10	7.483,40	4,36
UID Sumatera Barat	2.089,51	209,54	140,00	2.439,06	1,42
UID Riau dan Kepulauan Riau	3.992,35	586,49	360,00	4.938,84	2,88
- Riau	3.352,02	503,59	360,00	4.215,61	2,46
- Kepulauan Riau	640,33	82,90	-	723,23	0,42
UID Sumatera Selatan, Jambi dan Bengkulu	5.511,79	845,82	45,00	6.402,61	3,73
- Sumatera Selatan	3.133,68	640,43	45,00	3.819,10	2,23
- Jambi	1.636,69	142,53	-	1.779,22	1,04
- Bengkulu	741,43	62,87	-	804,30	0,47
UIW Bangka Belitung	927,29	214,78	-	1.142,07	0,67
UID Lampung	3.072,02	648,00	-	3.720,02	2,17
UID Kalimantan Barat	2.069,76	234,24	-	2.303,99	1,34
UID Kalimantan Selatan dan Tengah	2.864,39	463,52	130,00	3.457,91	2,02
- Kalimantan Selatan	1.769,23	343,98	130,00	2.243,20	1,31
- Kalimantan Tengah	1.095,17	119,55	-	1.214,71	0,71
UID Kalimantan Timur dan Utara	2.594,14	498,34	150,00	3.242,48	1,89
UID Sulawesi Utara, Tengah dan Gorontalo	2.610,83	391,82	72,50	3.075,16	1,79
- Sulawesi Utara	1.118,81	233,25	40,00	1.392,06	0,81
- Sulawesi Tengah	1.094,43	111,63	-	1.206,07	0,70
- Gorontalo	397,59	46,94	32,50	477,03	0,28
UID Sulawesi Selatan, Tenggara dan Barat	5.426,81	696,95	512,25	6.636,00	3,87
- Sulawesi Selatan	3.869,13	573,50	512,25	4.954,88	2,89
- Sulawesi Tenggara	1.096,45	95,18	-	1.191,63	0,69
- Sulawesi Barat	461,23	28,27	-	489,49	0,29
UIW Maluku dan Maluku Utara	1.027,24	75,72	80,00	1.182,96	0,69
- Maluku	455,00	47,39	-	502,39	0,29
- Maluku Utara	572,24	28,33	80,00	680,57	0,40
UIW Papua dan Papua Barat	1.498,36	151,17	-	1.649,53	0,96
- Papua	990,35	98,60	-	1.088,95	0,63
- Papua Barat	508,01	52,57	-	560,58	0,33
UID Bali	3.774,99	761,75	-	4.536,74	2,65
UIW Nusa Tenggara Barat	1.962,76	202,04	-	2.164,81	1,26
UIW Nusa Tenggara Timur	1.497,97	93,41	-	1.591,38	0,93
PT PLN Batam	1.080,21	751,56	-	1.831,77	1,07
Luar Jawa	49.772,29	8.630,45	1.569,85	59.972,59	34,97
UID Jawa Timur	17.448,38	6.220,56	1.324,16	24.993,10	14,57
UID Jawa Tengah dan Yogyakarta	15.251,39	3.995,80	387,50	19.634,69	11,45
- Jawa Tengah	13.185,59	3.594,06	387,50	17.167,15	10,01
- D.I. Yogyakarta	2.065,80	401,74	-	2.467,54	1,44
UID Jawa Barat	20.848,55	9.257,72	1.701,37	31.807,64	18,55
UID Banten	6.180,62	5.219,29	2.065,78	13.465,69	7,85
UID Jakarta Raya	13.611,66	7.644,92	378,14	21.634,72	12,61
Jawa	73.340,60	32.338,29	5.856,95	111.535,83	65,03
Indonesia	123.112,89	40.968,74	7.426,80	171.508,42	100,00
(%)	71,78	23,89	4,33	100,00	

Tabel 12 : Energi Terjual per Jenis Tegangan (GWh) 2023

Satuan PLN/Provinsi	Tegangan			Jumlah	(%)
	Rendah	Menengah	Tinggi		
UID Aceh	3.060,92	397,38	-	3.458,30	1,20
UID Sumatera Utara	8.756,99	3.455,66	260,19	12.472,84	4,32
UID Sumatera Barat	2.851,31	407,27	552,26	3.810,84	1,32
UID Riau dan Kepulauan Riau	5.511,26	1.294,29	2.406,60	9.212,16	3,19
- Riau	4.682,97	1.122,99	2.406,60	8.212,56	2,85
- Kepulauan Riau	828,30	171,30	-	999,60	0,35
UID Sumatera Selatan, Jambi dan Bengkulu	7.839,53	1.794,59	171,53	9.805,65	3,40
- Sumatera Selatan	4.677,82	1.429,15	171,53	6.278,50	2,18
- Jambi	2.115,54	255,64	-	2.371,18	0,82
- Bengkulu	1.046,17	109,81	-	1.155,97	0,40
UIW Bangka Belitung	1.180,58	430,24	-	1.610,81	0,56
UID Lampung	4.455,19	1.306,72	-	5.761,91	2,00
UID Kalimantan Barat	2.904,82	403,77	-	3.308,59	1,15
UID Kalimantan Selatan dan Tengah	4.326,01	907,97	290,97	5.524,95	1,92
- Kalimantan Selatan	2.744,93	657,96	290,97	3.693,87	1,28
- Kalimantan Tengah	1.581,08	250,00	-	1.831,08	0,63
UID Kalimantan Timur dan Utara	3.907,34	1.071,88	87,70	5.066,92	1,76
UID Sulawesi Utara, Tengah dan Gorontalo	3.539,99	674,34	226,19	4.440,52	1,54
- Sulawesi Utara	1.485,92	433,07	176,38	2.095,38	0,73
- Sulawesi Tengah	1.435,71	167,21	-	1.602,92	0,56
- Gorontalo	618,35	74,05	49,81	742,22	0,26
UID Sulawesi Selatan, Tenggara dan Barat	6.956,46	1.156,25	2.306,61	10.419,32	3,61
- Sulawesi Selatan	5.245,73	1.005,70	2.306,61	8.558,03	2,97
- Sulawesi Tenggara	1.233,73	109,22	-	1.342,95	0,47
- Sulawesi Barat	477,00	41,33	-	518,33	0,18
UIW Maluku dan Maluku Utara	1.261,52	113,86	276,70	1.652,08	0,57
- Maluku	566,35	67,22	-	633,56	0,22
- Maluku Utara	695,17	46,64	276,70	1.018,52	0,35
UIW Papua dan Papua Barat	1.808,10	202,28	-	2.010,38	0,70
- Papua	1.204,80	137,59	-	1.342,39	0,47
- Papua Barat	603,30	64,69	-	667,98	0,23
UID Bali	4.823,37	1.531,16	-	6.354,53	2,20
UIW Nusa Tenggara Barat	2.220,24	352,36	-	2.572,60	0,89
UIW Nusa Tenggara Timur	1.179,70	153,55	-	1.333,25	0,46
PT PLN Batam	1.616,57	1.593,22	-	3.209,79	1,11
Luar Jawa	68.199,90	17.246,78	6.578,76	92.025,44	31,91
UID Jawa Timur	24.079,37	14.133,90	3.673,02	41.886,30	14,52
UID Jawa Tengah dan Yogyakarta	22.303,90	8.547,25	1.144,83	31.995,98	11,09
- Jawa Tengah	19.492,56	7.794,35	1.144,83	28.431,75	9,86
- D.I. Yogyakarta	2.811,34	752,89	-	3.564,23	1,24
UID Jawa Barat	30.032,63	23.059,47	5.472,20	58.564,31	20,30
UID Banten	9.593,56	12.532,93	4.844,91	26.971,40	9,35
UID Jakarta Raya	21.374,27	14.612,02	1.006,07	36.992,35	12,83
Jawa	107.383,73	72.885,57	16.141,04	196.410,34	68,09
Indonesia	175.583,63	90.132,35	22.719,80	288.435,78	100,00
(%)	60,87	31,25	7,88	100,00	

Tabel 13 : Pendapatan per Jenis Tegangan (juta Rp) **2023**

Satuan PLN/Provinsi	Tegangan				Jumlah	(%)
	Rendah	Menengah	Tinggi	Layanan Khusus		
UID Aceh	3.086.811,26	403.940,86	-	76.639,18	3.567.391,29	1,07
UID Sumatera Utara	10.105.013,05	3.829.181,30	279.095,88	205.152,29	14.418.442,53	4,33
UID Sumatera Barat	3.225.617,83	425.414,80	550.463,90	72.230,29	4.273.726,82	1,28
UID Riau dan Kepulauan Riau	7.086.724,77	1.445.074,44	900.464,78	82.568,28	9.514.832,27	2,85
- Riau	5.964.607,29	1.243.932,61	900.464,78	77.122,88	8.186.127,56	2,46
- Kepulauan Riau	1.122.117,48	201.141,83	-	5.445,40	1.328.704,71	0,40
UID Sumatera Selatan, Jambi dan Bengkulu	9.351.423,76	1.931.470,09	170.971,33	160.506,24	11.614.371,41	3,48
- Sumatera Selatan	5.536.523,74	1.540.922,92	170.971,33	128.308,81	7.376.726,80	2,21
- Jambi	2.650.764,63	272.758,53	-	19.344,68	2.942.867,84	0,88
- Bengkulu	1.164.135,39	117.788,64	-	12.852,74	1.294.776,77	0,39
UIW Bangka Belitung	1.549.463,78	499.256,93	-	13.635,64	2.062.356,35	0,62
UID Lampung	4.781.182,59	1.460.041,80	-	37.555,05	6.278.779,44	1,88
UID Kalimantan Barat	3.376.825,10	452.777,46	-	24.361,53	3.853.964,09	1,16
UID Kalimantan Selatan dan Tengah	5.047.458,77	1.015.511,72	296.506,52	62.769,22	6.422.246,23	1,93
- Kalimantan Selatan	3.135.960,25	735.554,29	296.506,52	46.155,17	4.214.176,23	1,26
- Kalimantan Tengah	1.911.498,52	279.957,43	-	16.614,05	2.208.070,00	0,66
UID Kalimantan Timur dan Utara	5.171.759,07	1.251.090,76	87.411,82	71.051,15	6.581.312,80	1,97
UID Sulawesi Utara, Tengah dan Gorontalo	4.011.423,59	752.424,70	239.471,12	53.090,48	5.056.409,89	1,52
- Sulawesi Utara	1.718.283,82	489.387,88	185.509,27	25.003,95	2.418.184,91	0,73
- Sulawesi Tengah	1.631.610,26	184.695,01	-	13.053,30	1.829.358,57	0,55
- Gorontalo	661.529,50	78.341,81	53.961,85	15.033,23	808.866,40	0,24
UID Sulawesi Selatan, Tenggara dan Barat	8.242.930,07	1.234.319,56	2.285.756,23	133.458,66	11.896.464,51	3,57
- Sulawesi Selatan	6.199.654,70	1.064.632,20	2.285.756,23	113.516,11	9.663.559,24	2,90
- Sulawesi Tenggara	1.478.892,73	124.747,19	-	14.646,56	1.618.286,48	0,49
- Sulawesi Barat	564.382,64	44.940,17	-	5.295,99	614.618,80	0,18
UIW Maluku dan Maluku Utara	1.574.318,81	87.689,01	198.083,41	62.364,15	1.922.455,38	0,58
- Maluku	713.522,50	61.072,95	-	24.363,79	798.959,23	0,24
- Maluku Utara	860.796,32	26.616,06	198.083,41	38.000,36	1.123.496,15	0,34
UIW Papua dan Papua Barat	2.428.958,21	237.009,60	-	13.610,37	2.679.578,18	0,80
- Papua	1.623.993,49	158.967,69	-	9.323,69	1.792.284,87	0,54
- Papua Barat	804.964,72	78.041,91	-	4.286,68	887.293,31	0,27
UID Bali	6.673.262,24	1.635.780,39	-	162.331,76	8.471.374,39	2,54
UIW Nusa Tenggara Barat	2.213.917,80	360.687,35	-	52.793,71	2.627.398,86	0,79
UIW Nusa Tenggara Timur	1.446.449,40	139.732,77	-	45.755,35	1.631.937,52	0,49
PT PLN Batam	2.401.082,59	2.127.926,00	-	35.727,63	4.564.736,21	1,37
Luar Jawa	81.774.622,69	19.289.329,53	5.008.225,00	1.365.600,96	107.437.778,18	32,24
UID Jawa Timur	26.301.864,45	15.577.720,60	3.679.668,59	462.008,38	46.021.262,01	13,81
UID Jawa Tengah dan Yogyakarta	23.291.723,77	9.425.089,63	1.158.643,64	184.238,69	34.059.695,73	10,22
- Jawa Tengah	19.953.548,38	8.601.750,77	1.158.643,64	177.940,98	29.891.883,77	8,97
- D.I. Yogyakarta	3.338.175,39	823.338,85	-	6.297,71	4.167.811,96	1,25
UID Jawa Barat	33.973.510,45	26.040.807,34	5.524.192,11	726.213,93	66.264.723,84	19,88
UID Banten	11.533.176,90	13.669.234,51	4.845.000,05	587.628,41	30.635.039,87	9,19
UID Jakarta Raya	30.835.375,67	16.350.083,03	1.009.565,75	666.339,49	48.861.363,93	14,66
Jawa	125.935.651,24	81.062.935,10	16.217.070,14	2.626.428,90	225.842.085,39	67,76
Indonesia	207.710.273,94	100.352.264,63	21.225.295,14	3.992.029,86	333.279.863,57	100,00
(%)	62,32	30,11	6,37	1,20	100,00	

Tabel 14 : Jumlah Pelanggan, Daya Tersambung dan Energi yang Dikonsumsi per Golongan Tarif (Rp/kWh) 2023

Golongan Tarif	Pelanggan	Tersambung (MVA)	Terjual (MWh)	Pendapatan *) (ribu Rp)
S-1	23	0,01	0,24	24.607,95
S-2	1.990.389	5.759,20	7.425,79	5.800.190.016,98
S-3	2.689	2.307,47	4.070,31	3.764.354.383,00
R-1	79.044.851	71.353,17	105.603,73	113.073.656.995,16
R-2	2.126.965	9.096,81	10.856,06	18.416.244.185,99
R-3	379.509	4.868,87	5.879,66	9.952.621.484,50
B-1	3.911.853	7.226,72	9.525,85	9.136.263.259,99
B-2	785.947	15.953,22	22.395,98	32.472.703.463,84
B-3 **)	9.147	11.558,67	22.461,29	25.872.932.947,07
I-1	142.481	597,81	420,02	449.938.048,55
I-2	48.334	4.687,38	6.879,85	7.441.997.365,63
I-3	15.828	23.986,12	58.568,02	66.586.026.116,09
I-4	127	7.426,80	22.719,80	21.225.295.140,14
P-1	240.212	2.195,04	2.981,26	4.787.622.012,80
P-2	2.062	1.794,10	2.303,85	3.604.738.080,47
P-3	353.667	1.374,66	3.615,19	6.179.012.494,32
Traksi T-1	87	424,89	383,53	295.164.946,91
Curah C-1	29	73,02	207,23	229.048.156,37
Layanan Khusus	99.078	824,46	2.138,12	3.992.029.861,98
Total	89.153.278	171.508,42	288.435,78	333.279.863.567,74

**) Data diambil dari Aplikasi Pengelolaan Pelanggan Terpusat (AP2T)*

***) Termasuk pelanggan B-4*

Tabel 15 : Daftar Tunggu

Satuan PLN / Provinsi	Daftar Tunggu Bulan Lalu		Permohonan Bulan Ini		Bayar BP Bulan Ini		Menyala	
	Jumlah	Daya (kVA)	Jumlah	Daya (kVA)	Jumlah	Daya (kVA)	Jumlah	Daya (kVA)
UID Aceh	12.807	230.912.100	64.155	208.331.300,00	58.661	83.007.150,00	60.486	107.256.300,00
UID Sumatera Utara	33.661	154.180.100	193.798	408.655.250,00	164.791	278.544.050,00	166.621	283.056.900,00
UID Sumatera Barat	7.040	39.599.500	71.659	111.949.550,00	65.723	94.452.250,00	65.554	92.973.850,00
UID Riau dan Kepulauan Riau	16.566	250.186.300	139.123	353.013.350,00	116.519	199.738.150,00	113.991	206.877.350,00
- Riau	-	-	-	-	-	-	-	-
- Kepulauan Riau	-	-	-	-	-	-	-	-
UID Sumatera Selatan, Jambi dan Bengkulu	65.892	314.944.750	219.413	395.389.150,00	186.410	283.972.250,00	189.359	276.076.350,00
- Sumatera Selatan	-	-	-	-	-	-	-	-
- Jambi	-	-	-	-	-	-	-	-
- Bengkulu	-	-	-	-	-	-	-	-
UIW Bangka Belitung	5.525	152.201.000	26.068	94.160.050,00	21.879	71.146.000,00	21.639	76.413.300,00
UID Lampung	41.699	223.065.150	104.672	165.030.050,00	96.279	131.973.000,00	98.448	168.284.600,00
UID Kalimantan Barat	52.453	191.119.300	101.566	171.198.900,00	85.836	130.394.650,00	90.002	137.910.300,00
UID Kalimantan Selatan dan Tengah	45.840	1.585.726.450	129.465	576.356.450,00	107.035	310.267.600,00	105.065	270.926.000,00
- Kalimantan Selatan	-	-	-	-	-	-	-	-
- Kalimantan Tengah	-	-	-	-	-	-	-	-
UID Kalimantan Timur dan Utara	22.582	3.525.376.150	98.513	260.199.600,00	84.114	169.904.900,00	82.476	330.269.400,00
UID Sulawesi Utara, Tengah dan Gorontalo	74.476	2.820.177.600	151.619	337.488.950,00	118.180	223.045.400,00	118.426	211.485.000,00
- Sulawesi Utara	-	-	-	-	-	-	-	-
- Sulawesi Tengah	-	-	-	-	-	-	-	-
- Gorontalo	-	-	-	-	-	-	-	-
UID Sulawesi Selatan, Tenggara dan Barat	230.612	6.509.878.600	215.228	868.756.100,00	180.761	521.608.200,00	195.922	412.852.900,00
- Sulawesi Selatan	-	-	-	-	-	-	-	-
- Sulawesi Tenggara	-	-	-	-	-	-	-	-
- Sulawesi Barat	-	-	-	-	-	-	-	-
UIW Maluku dan Maluku Utara	3.620	95.847.750	51.469	70.319.600,00	48.731	62.635.700,00	48.544	142.222.400,00
- Maluku	-	-	-	-	-	-	-	-
- Maluku Utara	-	-	-	-	-	-	-	-
UIW Papua dan Papua Barat	16.632	53.610.750	68.999	124.706.450,00	44.583	81.789.300,00	44.724	78.258.550,00
- Papua	-	-	-	-	-	-	-	-
- Papua Barat	-	-	-	-	-	-	-	-
UID Bali	14.459	108.724.200	80.619	282.625.250,00	74.252	221.617.900,00	72.507	211.656.800,00
UIW Nusa Tenggara Barat	11.833	230.269.150	129.696	139.640.900,00	120.241	114.418.750,00	119.706	114.398.450,00
UIW Nusa Tenggara Timur	44.626	101.549.950	97.284	114.608.650,00	87.833	98.608.450,00	88.331	97.484.000,00
PT PLN Batam	327.710	1.145.155	16.312	29.373,70	13.141	79.937,80	12.559	77.572,30
Luar Jawa	1.028.033	16.588.513.955	1.959.658	4.682.458.923,70	1.674.969	3.077.203.637,80	1.694.360	3.218.480.022,30
UID Jawa Timur	57.343	1.921.861.350	557.094	1.150.541.550,00	462.998	794.122.900,00	454.574	944.316.800,00
UID Jawa Tengah dan Yogyakarta	31.080	116.169.100	516.915	1.236.281.200,00	448.095	818.154.550,00	450.690	826.467.200,00
- Jawa Tengah	-	-	-	-	-	-	-	-
- D.I. Yogyakarta	-	-	-	-	-	-	-	-
UID Jawa Barat	130.316	1.944.839.650	765.009	2.622.833.200,00	618.756	1.411.693.650,00	636.641	1.433.798.600,00
UID Banten	11.513	3.391.450.450	217.994	871.179.250,00	174.500	430.098.250,00	175.052	556.263.700,00
UID Jakarta Raya	14.239	1.148.795.750	197.471	814.070.850,00	172.195	480.897.250,00	171.088	606.323.100,00
J a w a	244.491	8.523.116.300	2.254.483	6.694.906.050,00	1.876.544	3.934.966.600,00	1.888.045	4.367.169.400,00
I n d o n e s i a	1.272.524	25.111.630.255	4.214.141	11.377.364.973,70	3.551.513	7.012.170.237,80	3.582.405	7.585.649.422,30

2023

Digugurkan/Batal		Terima dari BP Titipan		Koreksi Permohonan PB/PD		Pindah dari Unit Lain		Pindah ke Unit Lain		Daftar Tunggu Akhir	
Jumlah	Daya (kVA)	Jumlah	Daya (kVA)	Jumlah	Daya (kVA)	Jumlah	Daya (kVA)	Jumlah	Daya (kVA)	Jumlah	Daya (kVA)
273	12.875.100	112	156.650	2	241.300	214	381.850	214	381.850	10.823	194.185.800
409	1.115.200	65	270.500	51	26.500	2.000	4.676.100	1.999	4.658.500	31.539	148.866.650
474	865.750	120	136.900	4	26.100	177	269.150	175	261.250	6.861	40.383.050
536	3.211.300	-	-	5	108.600	1.217	3.361.550	1.219	3.380.450	18.561	239.925.500
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
3.664	8.410.200	1.206	2.298.350	4	3.600	1.020	2.675.550	995	2.658.750	60.514	316.749.200
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
617	3.941.350	169	334.900	5	4.500	23	51.300	23	51.300	5.322	143.331.750
570	1.525.900	219	103.500	2	83.400	728	1.678.800	754	1.702.200	39.155	185.391.150
1.711	5.517.250	645	2.076.950	12	7.150	351	1.452.350	351	1.452.350	47.233	180.170.500
4.891	11.885.400	2.363	2.465.100	2	245.500	615	1.140.500	615	1.140.500	45.284	1.615.893.250
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
554	3.899.050	248	452.750	1	900	363	6.118.600	363	6.118.600	23.915	3.361.566.250
1.178	3.993.300	460	612.200	2	1.800	110	493.300	110	493.300	73.514	2.828.358.700
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
2.299	108.963.000	97	182.600	61	919.000	1.177	1.950.350	1.177	1.950.350	213.310	6.510.772.500
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
45	190.000	-	-	-	-	6	37.500	6	37.500	3.762	16.071.050
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
94	684.850	5	7.400	1	197.000	12	22.000	12	22.000	16.403	56.661.050
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
1.028	5.591.650	-	-	-	-	394	1.173.650	394	1.173.650	15.176	113.093.650
1.311	1.568.950	135	144.600	18	18.200	378	412.100	378	412.100	11.210	228.883.300
1.425	2.023.950	23	21.400	4	3.600	94	271.950	94	271.950	42.730	100.675.450
36	1.217	-	-	-	-	-	-	-	-	328.256	1.146.304
21.115	176.263.417	5.867	9.263.800	174	1.887.150	8.879	26.166.600	8.879	26.166.600	993.568	16.282.125.104
14.449	28.134.350	5.240	9.052.300	197	1.899.150	6.239	10.529.450	6.243	10.552.350	56.751	1.754.461.650
7.179	12.861.250	2.969	5.170.850	46	172.800	4.915	7.232.850	4.912	7.210.400	24.324	100.361.300
-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-
8.371	25.825.350	6.810	17.469.050	1	105.000	8.897	336.516.300	10.092	338.615.450	109.676	1.912.384.250
1.148	123.094.800	73	212.450	6	120.013.000	1.329	31.153.600	1.208	30.943.550	10.013	3.262.625.700
2.321	6.467.400	731	1.689.100	1	5.500	8.376	30.840.700	7.301	28.951.150	14.832	1.020.486.650
33.468	196.383.150	15.823	33.593.750	251	122.195.450	29.756	416.272.900	29.756	416.272.900	215.596	8.050.319.550
54.583	372.646.567	21.690	42.857.550	425	124.082.600	38.635	442.439.500	38.635	442.439.500	1.209.164	24.332.444.654

Tabel 16 : SAIDI dan SAIFI **2023**

Satuan PLN/Provinsi	SAIDI Jam/Pelanggan	SAIFI Kali/Pelanggan
UID Aceh	7,19	5,51
UID Sumatera Utara	7,05	5,22
UID Sumatera Barat	3,62	2,03
UID Riau dan Kepulauan Riau	7,51	5,14
UID Sumatera Selatan, Jambi dan Bengkulu	9,03	5,21
UIW Bangka Belitung	1,66	2,48
UID Lampung	12,01	6,33
UID Kalimantan Barat	14,87	13,47
UID Kalimantan Selatan dan Tengah	9,53	6,88
UID Kalimantan Timur dan Utara	11,30	9,18
UID Sulawesi Utara,Tengah dan Gorontalo	11,73	10,61
UID Sulawesi Selatan, Tenggara dan Barat	11,75	7,64
UIW Maluku dan Maluku Utara	1,29	3,14
UIW Papua dan Papua Barat	7,50	6,78
UID Bali	0,91	0,86
UIW Nusa Tenggara Barat	3,61	3,13
UIW Nusa Tenggara Timur	2,51	4,11
PT PLN Batam	8,51	3,60
Luar Jawa	8,17	5,93
UID Jawa Timur	2,91	2,49
UID Jawa Tengah dan Yogyakarta	4,73	3,62
UID Jawa Barat	5,64	4,49
UID Jakarta Raya	0,50	0,71
UID Banten	1,88	1,33
Jawa	3,92	3,15
Indonesia	5,64	4,27

Tabel 17 : Jumlah dan Lama Gangguan Transmisi per 100 kms 2023

Satuan PLN/Provinsi	Lama Gangguan (Jam)	Jumlah Gangguan (Kali)	Panjang Jaringan Transmisi (kms)	Lama Keluar Sistem (SOD) (Jam/100 kms)	Jumlah Keluar Sistem (SOF) (Kali/100 kms)
UID Aceh	-	-	-	-	-
UID Sumatera Utara	-	-	-	-	-
UID Sumatera Barat	-	-	-	-	-
UID Riau dan Kepulauan Riau	-	-	-	-	-
- Riau	-	-	-	-	-
- Kepulauan Riau	-	-	-	-	-
UID Sumatera Selatan, Jambi dan Bengkulu	-	-	-	-	-
- Sumatera Selatan	-	-	-	-	-
- Jambi	-	-	-	-	-
- Bengkulu	-	-	-	-	-
UIW Bangka Belitung	0,94	8	777,51	0,12	1,03
UID Lampung	-	-	-	-	-
UID Kalimantan Barat	-	-	-	-	-
UID Kalimantan Selatan dan Tengah	-	-	-	-	-
- Kalimantan Selatan	-	-	-	-	-
- Kalimantan Tengah	-	-	-	-	-
UID Kalimantan Timur dan Utara	-	-	-	-	-
UID Sulawesi Utara, Tengah dan Gorontalo	-	-	-	-	-
- Sulawesi Utara	-	-	-	-	-
- Sulawesi Tengah	-	-	-	-	-
- Gorontalo	-	-	-	-	-
UIW Sulawesi Selatan, Tenggara dan Barat	-	-	-	-	-
- Sulawesi Selatan	-	-	-	-	-
- Sulawesi Tenggara	-	-	-	-	-
- Sulawesi Barat	-	-	-	-	-
UIW Maluku dan Maluku Utara	-	-	93,72	-	-
- Maluku	-	-	78,22	-	-
- Maluku Utara	-	-	15,50	-	-
UIW Papua dan Papua Barat	1,30	1	298,88	0,43	0,33
- Papua	1,30	1	217,96	0,60	0,46
- Papua Barat	-	-	80,92	-	-
UID Bali	-	-	-	-	-
UIW Nusa Tenggara Barat	3,05	4	1.295,00	0,24	0,31
UIW Nusa Tenggara Timur	-	1	1.415,18	-	0,07
PT PLN Batam	5,43	3	200,91	2,70	1,49
PT PLN Nusa Daya*)	-	-	-	-	-
UIP3B Sumatera	27,20	56	19.928,68	0,14	0,28
UIP3B Kalimantan	25,20	55	7.507,46	0,34	0,73
UIP3B Sulawesi	1,65	4	7.893,38	0,02	0,05
Luar Jawa	64,77	132	39.410,72	0,16	0,33
UID Jawa Timur	-	-	-	-	-
UID Jawa Tengah dan Yogyakarta	-	-	-	-	-
- Jawa Tengah	-	-	-	-	-
- D.I. Yogyakarta	-	-	-	-	-
UID Jawa Barat	-	-	-	-	-
UID Banten	-	-	-	-	-
UID Jakarta Raya	-	-	-	-	-
PLN Indonesia Power	-	-	-	-	-
PLN Nusantara Power	-	-	-	-	-
Unit Induk Pusat Pengaturan Beban	-	-	-	-	-
J a w a	-	-	-	-	-
I n d o n e s i a	64,77	132	39.410,72	0,16	0,33

SOD = Lama gangguan di jaringan transmisi
SOF = Jumlah gangguan di jaringan transmisi
**) Sebelumnya adalah PT PLN Tarakan*

Tabel 18 : Jumlah Gangguan Distribusi per 100 kms **2023**

Satuan PLN/Provinsi	Jumlah Gangguan (Kali)	Panjang Jaringan JTM (kms)	Jumlah Gangguan (Kali/100 kms)
UID Aceh	2.749	14.437,00	19,04
UID Sumatera Utara	79	30.251,95	0,26
UID Sumatera Barat	2.401	11.388,55	21,08
UID Riau dan Kepulauan Riau	89	18.082,80	0,49
- Riau	84	15.504,07	0,54
- Kepulauan Riau	5	2.578,73	0,19
UID Sumatera Selatan, Jambi dan Bengkulu	1.597	30.637,06	5,21
- Sumatera Selatan	1.053	16.101,84	6,54
- Jambi	402	9.657,91	4,16
- Bengkulu	142	4.877,31	2,91
UIW Bangka Belitung	1.078	6.005,49	17,95
UID Lampung	2.347	14.858,00	15,80
UID Kalimantan Barat	854	14.889,04	5,74
UID Kalimantan Selatan dan Tengah	265	18.482,00	1,43
- Kalimantan Selatan	154	9.794,00	1,57
- Kalimantan Tengah	111	8.688,00	1,28
UID Kalimantan Timur dan Utara	3.309	11.342,85	29,17
UID Sulawesi Utara, Tengah dan Gorontalo	179	16.942,36	1,06
- Sulawesi Utara	106	5.953,31	1,78
- Sulawesi Tengah	59	8.411,56	0,70
- Gorontalo	14	2.577,49	0,54
UID Sulawesi Selatan, Tenggara dan Barat	5.102	28.099,85	18,16
- Sulawesi Selatan	3.764	16.995,27	22,15
- Sulawesi Tenggara	1.092	7.174,59	15,22
- Sulawesi Barat	246	3.929,99	6,26
UIW Maluku dan Maluku Utara	977	8.398,31	11,63
- Maluku	777	4.670,23	16,64
- Maluku Utara	200	3.728,07	5,36
UIW Papua dan Papua Barat	39	7.805,42	0,50
- Papua	27	5.013,68	0,54
- Papua Barat	12	2.791,74	0,43
UID Bali	126	8.830,06	1,43
UIW Nusa Tenggara Barat	752	7.134,87	10,54
UIW Nusa Tenggara Timur	84	12.073,01	0,70
PT PLN Batam	64	2.205,45	2,90
PT PLN Nusa Daya*)	-	-	-
UIP3B Sumatera	-	-	-
UIP3B Kalimantan	-	-	-
UIP3B Sulawesi	-	-	-
Luar Jawa	22.091	261.864,07	8,44
UID Jawa Timur	101	41.807,71	0,24
UID Jawa Tengah dan Yogyakarta	501	55.204,21	0,91
- Jawa Tengah	449	49.306,38	0,91
- D.I. Yogyakarta	52	5.897,83	0,88
UID Jawa Barat	156	50.137,68	0,31
UID Banten	274	16.676,51	1,64
UID Jakarta Raya	1.121	17.908,00	6,26
PLN Indonesia Power	-	-	-
PLN Nusantara Power	-	-	-
Unit Induk Pusat Pengaturan Beban	-	-	-
J a w a	2.153	181.734,10	1,18
I n d o n e s i a	24.244	443.598,17	5,47

**) Sebelumnya adalah PT PLN Tarakan*

Tabel 19 : Rasio Elektrifikasi dan Energi yang Dikonsumsi per Kapita 2023

Satuan PLN/Provinsi	Rumah Tangga (x1.000)	Pelanggan Rumah Tangga *)	Rasio Elektrifikasi **) (%)
UID Aceh	1.484,11	1.483.479	99,96
UID Sumatera Utara	4.184,98	4.176.868	99,81
UID Sumatera Barat	1.461,48	1.444.577	98,84
UID Riau dan Kepulauan Riau	2.656,16	2.550.171	96,01
- Riau	2.048,51	1.945.714	94,98
- Kepulauan Riau	607,65	604.457	99,47
UID Sumatera Selatan, Jambi dan Bengkulu	4.143,40	4.041.623	97,54
- Sumatera Selatan	2.415,13	2.367.188	98,02
- Jambi	1.103,98	1.056.251	95,68
- Bengkulu	624,29	618.184	99,02
UIW Bangka Belitung	500,44	500.396	99,99
UID Lampung	2.449,75	2.444.494	99,79
UID Kalimantan Barat	1.477,04	1.394.596	94,42
UID Kalimantan Selatan dan Tengah	2.100,59	2.057.432	97,95
- Kalimantan Selatan	1.343,35	1.339.183	99,69
- Kalimantan Tengah	757,23	718.249	94,85
UID Kalimantan Timur dan Utara	1.418,20	1.353.823	95,46
UID Sulawesi Utara, Tengah dan Gorontalo	1.972,39	1.955.938	99,17
- Sulawesi Utara	764,70	759.769	99,36
- Sulawesi Tengah	877,99	868.021	98,86
- Gorontalo	329,70	328.148	99,53
UID Sulawesi Selatan, Tenggara dan Barat	3.814,17	3.638.718	99,40
- Sulawesi Selatan	2.650,61	2.568.422	96,90
- Sulawesi Tenggara	794,59	737.600	92,83
- Sulawesi Barat	368,98	332.696	90,17
UIW Maluku dan Maluku Utara	805,45	740.943	91,99
- Maluku	443,94	422.107	95,08
- Maluku Utara	361,51	318.836	88,20
UIW Papua dan Papua Barat	1.179,00	761.411	64,58
- Papua	286,91	257.607	89,79
- Papua Barat	146,56	130.615	89,12
- Papua Tengah	242,77	119.751	49,33
- Papua Selatan	121,48	91.734	75,51
- Papua Pegunungan	235,60	33.129	14,06
- Papua Barat Daya	145,69	128.575	88,25
UID Bali	1.398,36	1.398.359	100,00
UIW Nusa Tenggara Barat	1.822,75	1.818.269	99,75
UIW Nusa Tenggara Timur	1.281,30	1.120.916	87,48
Luar Jawa	34.149,56	32.882.013	96,29
UID Jawa Timur	12.448,40	12.387.141	99,51
UID Jawa Tengah dan Yogyakarta	12.187,90	12.181.754	99,95
- Jawa Tengah	10.833,18	10.832.100	99,99
- D.I. Yogyakarta	1.354,72	1.349.654	99,63
UID Jawa Barat	16.283,47	16.236.989	99,71
UID Banten	4.475,95	4.474.572	99,97
UID Jakarta Raya	3.393,73	3.393.733	100,00
J a w a	48.789,46	48.674.189	99,76
I n d o n e s i a	82.939,02	81.556.202	98,33

**) Termasuk pelanggan Alat Penyalur Daya Listrik (APDAL)*
***) Tidak termasuk pelanggan non-PLN*

Tabel 20 : Jumlah Unit Pembangkit *) 2023

Satuan PLN/Provinsi	PLTA	PLTM	PLTMH	PLTU	PLTG	PLTGU	PLTP	PLTD	PLTMG	PLT Surya	PLT Bayu	PLT Biomass	Jumlah	IPP	Sewa	Total
UID Aceh	-	-	4	-	-	-	-	199	-	-	-	-	203	8	3	214
UID Sumatera Utara	-	-	-	-	-	-	-	28	-	-	-	-	28	26	-	54
UID Sumatera Barat	-	-	3	-	-	-	-	96	-	4	-	-	103	14	-	117
UID Riau dan Kepulauan Riau	-	-	-	-	-	-	-	540	2	10	-	-	552	15	15	582
- Riau	-	-	-	-	-	-	-	248	-	1	-	-	249	14	7	270
- Kepulauan Riau	-	-	-	-	-	-	-	292	2	9	-	-	303	1	8	312
UID Sumatera Selatan, Jambi dan Bengkulu	-	1	1	-	-	-	-	158	-	-	-	-	160	27	4	191
- Sumatera Selatan	-	-	-	-	-	-	-	43	-	-	-	-	43	15	-	58
- Jambi	-	-	-	-	-	-	-	49	-	-	-	-	49	4	1	54
- Bengkulu	-	1	1	-	-	-	-	66	-	-	-	-	68	8	3	79
UIW Bangka Belitung	-	-	-	4	-	-	-	98	-	4	-	1	107	7	3	117
UID Lampung	-	-	-	-	-	-	-	45	-	-	-	-	45	5	-	50
UID Kalimantan Barat	-	-	6	-	-	-	-	212	-	2	-	-	220	6	4	230
UID Kalimantan Selatan dan Tengah	-	-	-	-	-	-	-	382	-	-	-	-	382	8	-	390
- Kalimantan Selatan	-	-	-	-	-	-	-	96	-	-	-	-	96	1	-	97
- Kalimantan Tengah	-	-	-	-	-	-	-	286	-	-	-	-	286	7	-	293
UID Kalimantan Timur dan Utara	-	-	-	-	-	-	-	197	-	1	-	-	198	9	6	213
UID Sulawesi Utara, Tengah dan Gorontalo	-	8	9	-	-	-	-	482	-	8	1	1	509	15	21	545
- Sulawesi Utara	-	3	3	-	-	-	-	176	-	7	1	-	190	1	6	197
- Sulawesi Tengah	-	5	4	-	-	-	-	302	-	-	-	-	311	10	15	336
- Gorontalo	-	-	2	-	-	-	-	4	-	1	-	1	8	4	-	12
UID Sulawesi Selatan, Tenggara dan Barat	-	-	-	-	-	-	-	202	-	10	-	-	212	16	4	232
- Sulawesi Selatan	-	-	-	-	-	-	-	85	-	7	-	-	92	15	3	110
- Sulawesi Tenggara	-	-	-	-	-	-	-	112	-	3	-	-	115	1	1	117
- Sulawesi Barat	-	-	-	-	-	-	-	5	-	-	-	-	5	-	-	5
UIW Maluku dan Maluku Utara	-	-	-	2	-	-	-	775	12	13	-	-	802	1	27	830
- Maluku	-	-	-	2	-	-	-	337	12	8	-	-	359	-	13	372
- Maluku Utara	-	-	-	-	-	-	-	438	-	5	-	-	443	1	14	458
UIW Papua dan Papua Barat	2	4	13	2	-	-	-	594	18	137	-	-	770	10	24	804
- Papua	-	-	12	-	-	-	-	307	3	84	-	-	406	2	15	423
- Papua Barat	2	4	1	2	-	-	-	287	15	53	-	-	364	8	9	381
UID Bali	-	-	-	-	-	-	-	1	-	-	3	-	4	7	-	11
UIW Nusa Tenggara Barat	-	1	3	5	-	-	-	151	20	8	-	-	188	15	8	211
UIW Nusa Tenggara Timur	-	2	12	4	-	-	5	472	12	44	1	-	552	11	19	582
PT PLN Batam	-	-	-	-	-	3	-	22	3	1	-	-	29	15	4	48
UIP3B Sumatera	-	-	-	-	-	-	-	-	-	-	-	-	-	31	-	31
UIP3B Kalimantan	-	-	-	-	-	-	-	-	-	-	-	-	-	12	-	12
UIP3B Sulawesi	-	-	-	-	-	-	-	-	-	-	-	-	-	16	-	16
UIK Kalimantan	-	-	-	2	-	-	-	104	22	1	-	-	129	2	48	179
UIK Sulawesi	-	-	-	2	3	-	-	45	10	-	-	-	60	-	3	63
UIK Sumatera	-	-	-	4	2	-	-	15	-	-	-	-	21	4	10	35
PLN Indonesia Power - Kalimantan	-	3	-	13	5	3	-	112	2	-	-	-	138	-	-	138
PLN Indonesia Power - Sulawesi	-	-	-	2	2	-	4	18	-	-	-	-	26	-	-	26
PLN Indonesia Power - Sumatera	11	8	2	12	10	4	2	9	11	-	-	-	69	-	-	69
PLN Nusantara Power - Kalimantan	-	-	-	6	1	-	-	159	18	-	-	-	184	-	-	184
PLN Nusantara Power - Sulawesi	3	14	12	10	3	6	-	137	-	-	-	-	185	-	-	185
PLN Nusantara Power - Sumatera	11	-	13	16	10	6	-	50	44	-	-	-	150	-	-	150
PLN Nusantara Power - Maluku Utara	-	-	-	-	6	-	-	-	-	-	-	-	6	-	-	6
Luar Jawa	27	41	78	84	42	22	11	5.303	174	243	5	2	6.032	280	203	6.515
UID Jawa Timur	-	3	1	-	-	-	-	87	-	14	-	-	105	8	-	113
UID Jawa Tengah dan Yogyakarta	-	-	4	-	-	-	-	6	-	5	-	-	15	24	-	39
- Jawa Tengah	-	-	3	-	-	-	-	6	-	5	-	-	14	23	-	37
- D.I. Yogyakarta	-	-	1	-	-	-	-	-	-	-	-	-	1	1	-	2
UID Jawa Barat	-	-	-	-	-	-	-	-	-	-	-	-	-	30	-	30
UID Banten	-	-	-	-	-	-	-	7	-	-	-	-	7	4	-	11
UID Jakarta Raya	-	-	-	-	-	-	-	-	-	1	-	-	1	-	-	1
PLN Indonesia Power - Jawabali	10	50	3	20	13	35	7	25	12	-	-	-	175	-	-	175
PLN Nusantara Power - Jawabali	17	12	5	18	8	32	-	-	3	-	-	-	95	-	-	95
Unit Induk Pusat Pengaturan Beban	-	-	-	-	-	-	-	-	-	-	-	-	-	41	-	41
UIK Tanjung Jati B	-	-	-	4	-	-	-	-	-	-	-	-	4	-	-	4
Jawa	27	65	13	42	21	67	7	125	15	20	-	-	402	107	-	509
PLN Nusantara Power - Jawabali	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	1
UIP Jawa Bagian Barat	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	1
UIP Jawa Bagian Timur	2	-	-	-	-	-	-	-	-	-	-	-	2	-	-	2
UIP Kalimantan Bagian Timur	-	-	-	2	-	-	-	-	-	-	-	-	2	-	-	2
UIP Nusa Tenggara	-	-	-	4	-	-	-	-	-	-	-	-	4	-	-	4
UIP Sulawesi	-	-	-	2	-	-	-	-	-	-	-	-	2	-	-	2
Proyek Pembangkitan	2	-	-	9	-	1	-	-	-	-	-	-	12	-	-	12
Indonesia	56	106	91	135	63	90	18	5.428	189	263	5	2	6.446	387	203	7.036

**) Pembangkit milik PLN, Sewa dan IPP*

Tabel 21 : Kapasitas Terpasang (MW) 2023

Satuan PLN/Provinsi	PLTA	PLTM	PLTMH	PLTU	PLTG	PLTGU	PLTP	PLTD	PLTMG	PLT Surya	PLT Bayu	PLT Biomas	Jumlah	Sewa	IPP	Total	(%)
UID Aceh	-	-	2,42	-	-	-	-	139,15	-	-	-	-	141,57	9,00	29,00	179,56	0,25
UID Sumatera Utara	-	-	-	-	-	-	-	3,99	-	-	-	-	3,99	-	182,45	186,44	0,26
UID Sumatera Barat	-	-	0,66	-	-	-	-	29,93	-	0,26	-	-	30,84	-	68,58	99,42	0,14
UID Riau dan Kepulauan Riau	-	-	-	-	-	-	-	245,22	0,20	1,51	-	-	246,93	76,34	309,90	633,17	0,87
- Riau	-	-	-	-	-	-	-	117,34	-	0,15	-	-	117,49	51,90	309,00	478,39	0,66
- Kepulauan Riau	-	-	-	-	-	-	-	127,88	0,20	1,36	-	-	129,44	24,44	0,90	154,78	0,21
UID Sumatera Selatan, Jambi dan Bengkulu	-	1,00	0,60	-	-	-	-	60,73	-	-	-	-	62,33	19,00	181,88	263,21	0,36
- Sumatera Selatan	-	-	-	-	-	-	-	7,48	-	-	-	-	7,48	-	119,06	126,54	0,17
- Jambi	-	-	-	-	-	-	-	17,27	-	-	-	-	17,27	8,00	21,20	46,48	0,06
- Bengkulu	-	1,00	0,60	-	-	-	-	35,97	-	-	-	-	37,57	11,00	41,62	90,19	0,12
UIW Bangka Belitung	-	-	-	93,00	-	-	-	129,44	-	0,33	-	0,02	222,78	12,00	112,00	346,78	0,48
UID Lampung	-	-	-	-	-	-	-	5,28	-	-	-	-	5,28	-	41,20	46,48	0,06
UID Kalimantan Barat	-	-	2,02	-	-	-	-	71,85	-	0,41	-	-	74,28	13,50	20,24	108,02	0,15
UID Kalimantan Selatan dan Tengah	-	-	-	-	-	-	-	60,40	-	-	-	-	60,40	-	19,85	80,25	0,11
- Kalimantan Selatan	-	-	-	-	-	-	-	15,33	-	-	-	-	15,33	-	2,40	17,73	0,02
- Kalimantan Tengah	-	-	-	-	-	-	-	45,08	-	-	-	-	45,08	-	17,45	62,53	0,09
UID Kalimantan Timur dan Utara	-	-	-	-	-	-	-	40,95	-	0,09	-	-	41,03	0,30	35,46	76,80	0,11
UID Sulawesi Utara, Tengah dan Gorontalo	-	9,55	5,85	-	-	-	-	173,28	-	2,15	0,08	0,50	191,41	59,54	64,95	315,90	0,43
- Sulawesi Utara	-	3,40	1,85	-	-	-	-	51,81	-	2,10	0,08	-	59,24	8,54	3,00	70,77	0,10
- Sulawesi Tengah	-	6,15	2,80	-	-	-	-	119,04	-	-	-	-	127,99	51,00	44,95	223,94	0,31
- Gorontalo	-	-	1,20	-	-	-	-	2,44	-	0,04	-	0,50	4,18	-	17,00	21,18	0,03
UID Sulawesi Selatan, Tenggara dan Barat	-	-	-	-	-	-	-	36,55	-	2,50	-	-	39,05	31,12	88,00	158,17	0,22
- Sulawesi Selatan	-	-	-	-	-	-	-	11,05	-	2,09	-	-	13,14	30,00	74,00	117,14	0,16
- Sulawesi Tenggara	-	-	-	-	-	-	-	23,48	-	0,41	-	-	23,89	1,12	14,00	39,01	0,05
- Sulawesi Barat	-	-	-	-	-	-	-	2,02	-	-	-	-	2,02	-	-	2,02	-
UIW Maluku dan Maluku Utara	-	-	-	14,00	-	-	-	257,99	136,02	2,41	-	-	410,42	171,00	5,00	586,42	0,80
- Maluku	-	-	-	14,00	-	-	-	139,77	136,02	1,10	-	-	290,89	131,00	-	421,89	0,58
- Maluku Utara	-	-	-	-	-	-	-	118,22	-	1,31	-	-	119,53	40,00	5,00	164,53	0,23
UIW Papua dan Papua Barat	20,05	5,13	4,83	24,00	-	-	-	231,68	174,03	8,64	-	-	468,36	92,10	131,46	691,92	0,95
- Papua	-	-	4,67	-	-	-	-	92,34	23,40	4,82	-	-	125,24	53,10	19,56	197,90	0,27
- Papua Barat	20,05	5,13	0,16	24,00	-	-	-	139,34	150,63	3,82	-	-	343,12	39,00	111,90	494,02	0,68
UID Bali	-	-	-	-	-	-	-	0,20	-	-	0,30	-	0,50	-	6,60	7,10	0,01
UIW Nusa Tenggara Barat	-	1,00	1,02	107,00	-	-	-	145,31	244,62	1,14	-	-	500,09	60,00	135,75	695,84	0,95
UIW Nusa Tenggara Timur	-	2,00	3,24	47,00	-	-	12,50	173,40	119,44	9,52	0,09	-	367,19	94,00	49,03	510,23	0,70
PT PLN Batam	-	-	-	-	-	135,29	-	108,91	26,25	1,00	-	-	271,45	125,00	446,92	843,37	1,16
UIP3B Sumatera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.637,44	4.637,44	6,35
UIP3B Kalimantan	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.518,00	1.518,00	2,08
UIP3B Sulawesi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.671,00	1.671,00	2,29
UIK Kalimantan	-	-	-	7,00	-	-	-	121,87	212,30	0,34	-	-	341,51	208,09	100	649,61	0,89
UIK Sulawesi	-	-	-	110,00	55,92	-	-	80,14	97,80	-	-	-	343,86	85,00	-	428,86	0,59
UIK Sumatera	-	-	-	155,00	41,45	-	-	54,89	-	-	-	-	251,34	267,38	257,50	776,22	1,06
PLN Indonesia Power - Kalimantan	-	30,00	-	414,00	221,55	60,00	-	252,98	13,94	-	-	-	992,47	-	-	992,47	1,36
PLN Indonesia Power - Sulawesi	-	-	-	100,00	66,80	-	80,00	66,01	-	-	-	-	312,81	-	-	312,81	0,43
PLN Indonesia Power - Sumatera	456,00	32,50	1,32	1.508,00	240,02	160,00	110,00	46,70	104,72	-	-	-	2.659,26	-	-	2.659,26	3,64
PLN Nusantara Power - Kalimantan	-	-	-	360,00	34,00	-	-	285,28	167,68	-	-	-	846,96	-	-	846,96	1,16
PLN Nusantara Power - Sulawesi	139,69	65,16	7,12	355,50	75,00	331,60	-	291,57	-	-	-	-	1.265,63	-	-	1.265,63	1,73
PLN Nusantara Power - Sumatera	364,60	-	7,50	1.244,00	303,86	817,88	-	187,06	571,46	-	-	-	3.496,36	-	-	3.496,36	4,79
PLN Nusantara Power - Maluku Utara	-	-	-	-	145,00	-	-	-	-	-	-	-	145,00	-	-	145,00	0,20
Luar Jawa	980,33	146,34	36,59	4.538,50	1.183,59	1.504,77	202,50	3.300,76	1.868,46	30,30	0,47	0,52	13.793,12	1.323,37	10.112,21	25.228,69	34,57
UID Jawa Timur	-	11,20	0,65	-	-	-	-	37,56	-	1,35	-	-	50,76	-	25,40	76,16	0,10
UID Jawa Tengah dan Yogyakarta	-	-	1,16	-	-	-	-	0,61	-	0,28	-	-	2,05	-	37,98	40,02	0,05
- Jawa Tengah	-	-	0,97	-	-	-	-	0,61	-	0,28	-	-	1,87	-	37,38	39,24	0,05
- D.I. Yogyakarta	-	-	0,18	-	-	-	-	-	-	-	-	-	0,18	-	0,60	0,78	-
UID Jawa Barat	-	-	-	-	-	-	-	-	-	-	-	-	-	-	150,43	150,43	0,21
UID Banten	-	-	-	-	-	-	-	1,22	-	-	-	-	1,22	-	15,60	16,82	0,02
UID Jakarta Raya	-	-	-	-	-	-	-	-	-	0,40	-	-	0,40	-	-	0,40	-
PLN Indonesia Power - Jawabali	930,52	198,69	1,95	7.580,00	682,18	5.868,53	376,76	181,07	199,66	-	-	-	16.019,35	-	-	16.019,35	21,95
PLN Nusantara Power - Jawabali	1.232,00	53,20	4,50	5.410,00	898,20	4.715,80	-	-	3,19	-	-	-	12.316,90	-	-	12.316,90	16,88
Unit Induk Pusat Pengaturan Beban	-	-	-	-	-	-	-	-	-	-	-	-	-	-	16.216,13	16.216,13	22,22
UIK Tanjung Jati B	-	-	-	2.811,40	-	-	-	-	-	-	-	-	2.811,40	-	-	2.811,40	3,85
Jawa	2.162,52	263,09	8,26	15.801,40	1.580,38	10.584,33	376,76	220,46	202,85	2,03	-	-	31.202,08	-	16.445,53	47.647,61	65,29
UIP Nusa Tenggara	-	-	-	100,00	-	-	-	-	-	-	-	-	100,00	-	-	100,00	0,14
Proyek Pembangkitan*)	-	-	-	100,00	-	-	-	-	-	-	-	-	100,00	-	-	100,00	0,14
Indonesia	3.142,85	409,43	44,84	20.439,90	2.763,97	12.089,10	579,26	3.521,21	2.071,31	32,33	0,47	0,52	45.095,19	1.323,37	26.557,74	72.976,30	100,00
%	4,31	0,56	0,06	28,01	3,79	16,57	0,79	4,83	2,84	0,04	-	-	61,79	1,81	36,39	100,00	100,00

**) Termasuk proyek yang sudah dalam tahap commissioning*

Tabel 22 : Daya Mampu (MW)

Satuan PLN/Provinsi	PLTA	PLTM	PLTMH	PLTU	PLTG	PLTGU	PLTP
UID Aceh	-	-	1,95	-	-	-	-
UID Sumatera Utara	-	-	-	-	-	-	-
UID Sumatera Barat	-	-	0,53	-	-	-	-
UID Riau dan Kepulauan Riau	-	-	-	-	-	-	-
- Riau	-	-	-	-	-	-	-
- Kepulauan Riau	-	-	-	-	-	-	-
UID Sumatera Selatan, Jambi dan Bengkulu	-	0,50	0,40	-	-	-	-
- Sumatera Selatan	-	-	-	-	-	-	-
- Jambi	-	-	-	-	-	-	-
- Bengkulu	-	0,50	0,40	-	-	-	-
UIW Bangka Belitung	-	-	-	78,00	-	-	-
UID Lampung	-	-	-	-	-	-	-
UID Kalimantan Barat	-	-	1,68	-	-	-	-
UID Kalimantan Selatan dan Tengah	-	-	-	-	-	-	-
- Kalimantan Selatan	-	-	-	-	-	-	-
- Kalimantan Tengah	-	-	-	-	-	-	-
UID Kalimantan Timur dan Utara	-	-	-	-	-	-	-
UID Sulawesi Utara, Tengah dan Gorontalo	-	9,39	5,83	-	-	-	-
- Sulawesi Utara	-	3,40	1,82	-	-	-	-
- Sulawesi Tengah	-	5,99	2,80	-	-	-	-
- Gorontalo	-	-	1,20	-	-	-	-
UID Sulawesi Selatan, Tenggara dan Barat	-	-	-	-	-	-	-
- Sulawesi Selatan	-	-	-	-	-	-	-
- Sulawesi Tenggara	-	-	-	-	-	-	-
- Sulawesi Barat	-	-	-	-	-	-	-
UIW Maluku dan Maluku Utara	-	-	-	12,60	-	-	-
- Maluku	-	-	-	12,60	-	-	-
- Maluku Utara	-	-	-	-	-	-	-
UIW Papua dan Papua Barat	19,00	4,30	4,03	16,30	-	-	-
- Papua	-	-	3,87	-	-	-	-
- Papua Barat	19,00	4,30	0,16	16,30	-	-	-
UID Bali	-	-	-	-	-	-	-
UIW Nusa Tenggara Barat	-	1,00	0,98	83,00	-	-	-
UIW Nusa Tenggara Timur	-	2,00	2,90	44,00	-	-	9,76
PT PLN Batam	-	-	-	-	-	125,54	-
UIP3B Sumatera	-	-	-	-	-	-	-
UIP3B Kalimantan	-	-	-	-	-	-	-
UIP3B Sulawesi	-	-	-	-	-	-	-
UIK Kalimantan	-	-	-	6,00	-	-	-
UIK Sulawesi	-	-	-	110	50,32	-	-
UIK Sumatera	-	-	-	96,50	36,00	-	-
PLN Indonesia Power - Kalimantan	-	28,50	-	340,60	190	45,60	-
PLN Indonesia Power - Sulawesi	-	-	-	90,77	54,00	-	74,90
PLN Indonesia Power - Sumatera	451,54	31,82	1,08	1.226,50	187,00	113,00	103,84
PLN Nusantara Power - Kalimantan	-	-	-	286,00	30	-	-
PLN Nusantara Power - Sulawesi	139,69	62,73	6,21	314,50	70,50	313,96	-
PLN Nusantara Power - Sumatera	354,44	-	6,79	946,50	228,86	619,00	-
PLN Nusantara Power - Maluku Utara	-	-	-	-	133,74	-	-
Luar Jawa	964,66	140,24	32,36	3.651,27	980,42	1.217,10	188,50
UID Jawa Timur	-	11,20	0,65	-	-	-	-
UID Jawa Tengah dan Yogyakarta	-	-	1,04	-	-	-	-
- Jawa Tengah	-	-	0,88	-	-	-	-
- D.I. Yogyakarta	-	-	0,16	-	-	-	-
UID Jawa Barat	-	-	-	-	-	-	-
UID Banten	-	-	-	-	-	-	-
UID Jakarta Raya	-	-	-	-	-	-	-
PLN Indonesia Power - Jawabali	926,49	189,60	1,91	6.935,60	637,95	5.205,41	356,60
PLN Nusantara Power - Jawabali	1.204,79	50,10	4,43	4.808,00	871,00	4.242,00	-
Unit Induk Pusat Pengaturan Beban	-	-	-	-	-	-	-
UIK Tanjung Jati B	-	-	-	2.643,80	-	-	-
Jawa	2.131,28	250,90	8,03	14.387,40	1.508,95	9.447,41	356,60
Proyek Pembangkitan	-	-	-	-	-	-	-
Indonesia	3.095,95	391,13	40,39	18.038,67	2.489,37	10.664,51	545,10
%	4,61	0,58	0,06	26,85	3,70	15,87	0,81

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PLTD	PLTMG	PLT Surya	PLT Bayu	PLT Biomas	Jumlah	Sewa	IPP	Total	(%)
102,76	-	-	-	-	104,71	9,00	29,00	142,70	0,21
3,07	-	-	-	-	3,07	-	182,45	185,52	0,28
23,71	-	0,21	-	-	24,45	-	68,58	93,03	0,14
196,71	0,20	1,30	-	-	198,21	74,85	309,90	582,96	0,87
92,81	-	0,04	-	-	92,85	51,50	309,00	453,35	0,67
103,90	0,20	1,26	-	-	105,35	23,35	0,90	129,60	0,19
34,19	-	-	-	-	35,09	19,00	179,18	233,27	0,35
4,58	-	-	-	-	4,58	-	117,86	122,44	0,18
8,83	-	-	-	-	8,83	8,00	20,40	37,23	0,06
20,77	-	-	-	-	21,67	11,00	40,92	73,59	0,11
119,19	-	0,33	-	0,02	197,53	12,00	112,00	321,53	0,48
1,50	-	-	-	-	1,50	-	41,20	42,70	0,06
52,37	-	0,37	-	-	54,41	13,50	20,24	88,15	0,13
41,55	-	-	-	-	41,55	-	14,50	56,05	0,08
11,49	-	-	-	-	11,49	-	1,20	12,69	0,02
30,06	-	-	-	-	30,06	-	13,30	43,36	0,06
24,02	-	0,05	-	-	24,07	-	28,81	52,88	0,08
146,67	-	1,94	0,07	0,45	164,35	59,54	64,95	288,84	0,43
45,84	-	1,90	0,07	-	53,03	8,54	3,00	64,57	0,10
98,68	-	-	-	-	107,47	51,00	44,95	203,42	0,30
2,15	-	0,04	-	0,45	3,85	-	17,00	20,85	0,03
29,18	-	2,15	-	-	31,34	30,80	88,00	150,14	0,22
9,40	-	1,82	-	-	11,23	30	74,00	115,23	0,17
18,05	-	0,33	-	-	18,38	0,80	14,00	33,18	0,05
1,73	-	-	-	-	1,73	-	-	1,73	-
197,87	118,89	1,77	-	-	331,13	171,00	5,00	507,13	0,75
105,20	118,89	0,73	-	-	237,42	131,00	-	368,42	0,55
92,67	-	1,03	-	-	93,70	40	5,00	138,70	0,21
178,76	169,50	6,50	-	-	398,40	82,50	125,81	606,71	0,90
71,31	23,40	4,07	-	-	102,65	44,40	18,67	165,72	0,25
107,45	146,10	2,44	-	-	295,75	38,10	107,14	440,99	0,66
0,18	-	-	0,27	-	0,45	-	6,54	6,99	0,01
103,86	240,76	1,14	-	-	430,74	6-	135,75	626,49	0,93
84,52	110,90	8,02	-	-	262,10	94,00	49,03	405,13	0,60
73,89	24,30	1,00	-	-	224,73	125,00	412,20	761,93	1,13
-	-	-	-	-	-	-	4.258,54	4.258,54	6,34
-	-	-	-	-	-	-	1.518,00	1.518,00	2,26
-	-	-	-	-	-	-	1.671,00	1.671,00	2,49
97,69	193,44	0,15	-	-	297,28	182,55	10-	579,83	0,86
72,24	96,84	-	-	-	329,40	85,00	-	414,40	0,62
49,23	-	-	-	-	181,73	267,38	257,50	706,61	1,05
180,54	11,00	-	-	-	796,25	-	-	796,25	1,19
44,80	-	-	-	-	264,47	-	-	264,47	0,39
29,85	93,50	-	-	-	2.238,13	-	-	2.238,13	3,33
180,47	145,60	-	-	-	642,07	-	-	642,07	0,96
194,55	-	-	-	-	1.102,13	-	-	1.102,13	1,64
109,29	529,53	-	-	-	2.794,41	-	-	2.794,41	4,16
-	-	-	-	-	133,74	-	-	133,74	0,20
2.372,67	1.734,45	24,92	0,34	0,47	11.307,41	1.286,11	9.678,18	22.271,70	33,15
28,92	-	1,35	-	-	42,12	-	25,40	67,52	0,10
0,52	-	0,24	-	-	1,80	-	32,94	34,74	0,05
0,52	-	0,24	-	-	1,64	-	32,43	34,07	0,05
-	-	-	-	-	0,16	-	0,51	0,67	-
-	-	-	-	-	-	-	150,43	150,43	0,22
1,22	-	-	-	-	1,22	-	15,60	16,82	0,03
-	-	0,35	-	-	0,35	-	-	0,35	-
169,33	182,40	-	-	-	14.605,28	-	-	14.605,28	21,74
-	3,00	-	-	-	11.183,32	-	-	11.183,32	16,64
-	-	-	-	-	-	-	16.216,13	16.216,13	24,13
-	-	-	-	-	2.643,80	-	-	2.643,80	3,93
200	185,40	1,94	-	-	28.477,90	-	16.440,49	44.918,39	66,85
-	-	-	-	-	-	-	-	-	-
2.572,66	1.919,85	26,87	0,34	0,47	39.785,31	1.286,11	26.118,67	67.190,10	100,00
3,83	2,86	0,04	0,00	0,00	59,21	1,91	38,87	100,00	100,00

Tabel 23 : Energi yang Diproduksi Per Jenis Pembangkit (GWh)

Satuan PLN/Provinsi	Produksi Sendiri									
	PLTA	PLTM	PLTMH	PLTU	PLTG	PLTGU	PLTP	PLTD	PLTMG	PLT Surya
UID Aceh	-	-	1,84	-	-	-	-	106,18	-	-
UID Sumatera Utara	-	-	-	-	-	-	-	5,31	-	-
UID Sumatera Barat	-	-	-	-	-	-	-	23,05	-	0,01
UID Riau dan Kepulauan Riau	-	-	-	-	-	-	-	504,51	0,25	0,05
- Riau	-	-	-	-	-	-	-	196,83	-	-
- Kepulauan Riau	-	-	-	-	-	-	-	307,69	0,25	0,04
UID Sumatera Selatan, Jambi dan Bengkulu	-	-	0,54	-	-	-	-	16,73	-	-
- Sumatera Selatan	-	-	-	-	-	-	-	-	-	-
- Jambi	-	-	-	-	-	-	-	-	-	-
- Bengkulu	-	-	0,54	-	-	-	-	16,73	-	-
UIW Bangka Belitung	-	-	-	586,03	-	-	-	242,92	-	0,02
UID Lampung	-	-	-	-	-	-	-	1,91	-	-
UID Kalimantan Barat	-	-	4,39	-	-	-	-	88,17	-	0,04
UID Kalimantan Selatan dan Tengah	-	-	-	-	-	-	-	56,47	-	-
- Kalimantan Selatan	-	-	-	-	-	-	-	12,99	-	-
- Kalimantan Tengah	-	-	-	-	-	-	-	43,47	-	-
UID Kalimantan Timur dan Utara	-	-	-	-	-	-	-	49,84	-	0,13
UID Sulawesi Utara, Tengah dan Gorontalo	-	25,11	19,73	-	-	-	-	205,74	-	1,33
- Sulawesi Utara	-	11,52	6,45	-	-	-	-	57,42	-	1,28
- Sulawesi Tengah	-	13,59	9,88	-	-	-	-	148,33	-	-
- Gorontalo	-	-	3,39	-	-	-	-	-	-	0,05
UID Sulawesi Selatan, Tenggara dan Barat	-	-	-	-	-	-	-	36,38	-	1,87
- Sulawesi Selatan	-	-	-	-	-	-	-	9,73	-	1,75
- Sulawesi Tenggara	-	-	-	-	-	-	-	26,66	-	0,11
- Sulawesi Barat	-	-	-	-	-	-	-	-	-	-
UIW Maluku dan Maluku Utara	-	-	-	99,39	-	-	-	235,22	535,02	-
- Maluku	-	-	-	99,39	-	-	-	111,18	535,02	-
- Maluku Utara	-	-	-	-	-	-	-	124,05	-	-
UIW Papua dan Papua Barat	56,38	11,62	18,43	55,04	-	-	-	148,42	753,11	2,15
- Papua	1,61	-	18,19	-	-	-	-	82,12	78,74	1,39
- Papua Barat	54,77	11,62	0,24	55,04	-	-	-	66,30	674,37	0,77
UID Bali	-	-	-	-	-	-	-	-	-	-
UIW Nusa Tenggara Barat	-	3,40	3,78	659,61	-	-	-	195,42	1.425,52	0,87
UIW Nusa Tenggara Timur	0,73	7,66	5,27	336,40	-	-	58,14	62,97	326,96	3,72
PT PLN Batam	-	-	-	-	50,45	893,80	-	16,85	133,57	1,35
UIP3B Sumatera	-	-	-	-	-	-	-	-	-	-
UIP3B Kalimantan	-	-	-	-	-	-	-	-	-	-
UIP3B Sulawesi	-	-	-	-	-	-	-	-	-	-
UIK Kalimantan	-	-	-	28,61	-	-	-	19,98	301,02	0,10
UIK Sulawesi	-	-	-	681,57	1,81	16,70	-	-	382,82	-
UIK Sumatera	-	-	-	-	-	-	-	-	-	-
PLN Indonesia Power - Kalimantan	14,94	99,28	-	2.802,18	375,13	23,26	-	224,75	0,36	-
PLN Indonesia Power - Sulawesi	-	-	-	672,40	68,80	-	544,60	110,05	-	-
PLN Indonesia Power - Sumatera	1.966,10	140,88	0,27	7.034,18	413,18	813,78	768,35	13,42	438,76	-
PLN Nusantara Power - Kalimantan	-	-	-	1.973,48	0,40	-	-	334,83	538,03	-
PLN Nusantara Power - Sulawesi	1.004,80	197,02	21,30	2.024,63	185,45	1.120,90	-	366,94	-	-
PLN Nusantara Power - Sumatera	1.499,10	-	45,94	6.401,18	66,60	4.229,98	-	48,36	2.175,90	-
PLN Nusantara Power - Maluku Utara	-	-	-	-	51,17	-	-	-	-	-
Luar Jawa	4.542,04	484,98	121,49	23.354,70	1.212,99	7.098,41	1.371,09	3.114,43	7.011,32	11,64
UID Jawa Timur	5,86	33,46	2,66	-	-	-	-	79,72	-	0,83
UID Jawa Tengah dan Yogyakarta	-	-	-	-	-	-	-	0,29	-	0,14
- Jawa Tengah	-	-	-	-	-	-	-	0,29	-	0,14
- D.I. Yogyakarta	-	-	-	-	-	-	-	-	-	-
UID Jawa Barat	-	-	-	-	-	-	-	-	-	-
UID Banten	-	-	-	-	-	-	-	1,03	-	-
UID Jakarta Raya	-	-	-	-	-	-	-	-	-	0,24
PLN Indonesia Power - Jawabali	2.489,87	580,40	7,41	43.978,25	376,41	15.598,92	2.939,41	211,83	1.210,58	-
PLN Nusantara Power - Jawabali	2.172,24	201,06	13,60	28.060,53	62,65	14.028,90	-	-	21,05	-
Unit Induk Pusat Pengaturan Beban	-	-	-	-	-	-	-	-	-	-
UIK Tanjung Jati B	-	-	-	19.205,06	-	-	-	-	-	-
Jawa	4.667,97	814,92	23,68	91.243,85	439,06	29.627,82	2.939,41	292,86	1.231,64	1,21
Proyek Pembangkitan	-	-	-	-	-	-	-	-	-	-
Indonesia	9.210,01	1.299,90	145,16	114.598,55	1.652,05	36.726,23	4.310,50	3.407,29	8.242,96	12,84
%	2,85	0,40	0,04	35,44	0,51	11,36	1,33	1,05	2,55	0,00

PLT Bayu	PLT Biomas	Sewa Genset							Sub Jumlah	Pembelian dan Proyek	Jumlah	%
		PLTD	PLTMG	PLTG	PLTGU	PLTU	PLTA	PLT Surya				
-	-	42,99	-	-	-	-	-	-	151,01	115,92	266,93	0,08
-	-	-	-	-	-	-	-	-	5,31	1.096,75	1.102,06	0,34
-	-	-	-	-	-	-	-	-	23,05	301,64	324,70	0,10
-	-	147,80	153,04	-	-	-	-	-	805,65	2.211,02	3.016,67	0,93
-	-	89,09	153,04	-	-	-	-	-	438,96	2.203,96	2.642,92	0,82
-	-	58,71	-	-	-	-	-	-	366,69	7,05	373,74	0,12
-	-	90,71	44,00	-	-	-	-	-	151,97	886,08	1.038,05	0,32
-	-	-	-	-	-	-	-	-	0,00	595,37	595,37	0,18
-	-	-	44,00	-	-	-	-	-	44,00	73,81	117,81	0,04
-	-	90,71	-	-	-	-	-	-	107,97	216,90	324,88	0,10
-	0,01	37,18	-	-	-	-	-	-	866,16	293,27	1.159,43	0,36
-	-	-	-	-	-	-	-	-	1,91	67,43	69,34	0,02
-	-	91,39	-	-	-	-	-	-	183,99	43,84	227,83	0,07
-	-	-	-	-	-	-	-	-	56,47	65,90	122,37	0,04
-	-	-	-	-	-	-	-	-	12,99	10,93	23,92	0,01
-	-	-	-	-	-	-	-	-	43,47	54,98	98,45	0,03
-	-	0,34	-	-	-	-	-	-	50,30	134,48	184,79	0,06
-	-	393,64	-	-	-	-	-	-	645,55	317,59	963,14	0,30
-	-	43,21	-	-	-	-	-	-	119,89	18,28	138,17	0,04
-	-	350,43	-	-	-	-	-	-	522,23	256,25	778,47	0,24
-	-	-	-	-	-	-	-	-	3,44	43,06	46,50	0,01
-	-	18,63	-	-	-	-	-	-	56,88	411,63	468,51	0,14
-	-	18,04	-	-	-	-	-	-	29,52	320,98	350,50	0,11
-	-	0,59	-	-	-	-	-	-	27,36	90,65	118,01	0,04
-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	636,15	-	-	-	-	-	-	1.505,79	21,06	1.526,85	0,47
-	-	402,85	-	-	-	-	-	-	1.148,44	0,00	1.148,44	0,36
-	-	233,30	-	-	-	-	-	-	357,35	21,06	378,41	0,12
-	-	506,47	-	-	-	-	-	-	1.551,62	700,36	2.251,98	0,70
-	-	269,85	-	-	-	-	-	-	451,89	108,71	560,60	0,17
-	-	236,62	-	-	-	-	-	-	1.099,73	591,66	1.691,39	0,52
-	-	-	-	-	-	-	-	-	-	13,49	13,49	-
-	-	310,34	-	-	-	-	-	-	2.598,94	340,62	2.939,57	0,91
-	-	451,28	-	-	-	-	-	-	1.253,12	245,85	1.498,97	0,46
-	-	1,84	320,60	-	-	-	-	-	1.418,45	2.569,37	3.987,82	1,23
-	-	-	-	-	-	-	-	-	-	19.349,58	19.349,58	5,98
-	-	-	-	-	-	-	-	-	-	7.807,19	7.807,19	2,41
-	-	-	-	-	-	-	-	-	-	7.529,25	7.529,25	2,33
-	-	322,72	232,68	-	-	99,79	-	-	1.004,91	19,95	1.024,86	0,32
-	-	4,91	-	-	-	307,24	-	-	1.395,03	-	1.395,03	0,43
-	-	18,23	143,42	-	-	-	-	-	161,65	489,23	650,88	0,20
-	-	-	-	-	-	-	-	-	3.539,90	-	3.539,90	1,09
-	-	-	-	-	-	-	-	-	1.395,86	-	1.395,86	0,43
-	-	-	-	-	-	-	-	-	11.588,93	-	11.588,93	3,58
-	-	-	-	-	-	-	-	-	2.846,75	-	2.846,75	0,88
-	-	-	-	-	-	-	-	-	4.921,05	-	4.921,05	1,52
-	-	-	-	-	-	-	-	-	14.467,05	-	14.467,05	4,47
-	-	-	-	-	-	-	-	-	51,17	-	51,17	0,02
-	0,01	3.074,60	893,74	-	-	407,03	-	-	52.698,47	45.031,50	97.729,97	30,23
-	-	-	-	-	-	-	-	-	122,54	51,85	174,39	0,05
-	-	-	-	-	-	-	-	-	0,42	109,53	109,96	0,03
-	-	-	-	-	-	-	-	-	0,42	106,05	106,48	0,03
-	-	-	-	-	-	-	-	-	-	3,48	3,48	-
-	-	-	-	-	-	-	-	-	-	438,96	438,96	0,14
-	-	-	-	-	-	-	-	-	1,03	45,97	47,00	0,01
-	-	-	-	-	-	-	-	-	0,24	-	0,24	-
-	-	-	-	-	-	-	-	-	67.393,08	-	67.393,08	20,84
-	-	-	-	-	-	-	-	-	44.560,05	0,08	44.560,13	13,78
-	-	-	-	-	-	-	-	-	-	93.079,85	93.079,85	28,79
-	-	-	-	-	-	-	-	-	19.205,06	-	19.205,06	5,94
-	-	-	-	-	-	-	-	-	131.282,41	93.726,25	225.008,67	69,59
-	-	-	-	-	-	-	-	-	-	581,98	581,98	0,18
-	0,01	3.074,60	893,74	-	-	407,03	-	-	183.980,89	139.339,73	323.320,62	100,00
0,00	0,00	0,95	0,28	0,00	0,00	0,13	0,00	0,00	56,90	43,10	100,00	

Tabel 24 : Pemakaian Bahan Bakar 2023

Satuan PLN/Provinsi	Bahan Bakar Minyak (kilo liter)										Batu Bara (ton)	Gas Alam (MMSCF)	Biomass (ton)
	HSD	IDO	MFO	Bio Diesel	Olein	Bio HSD	HFO	Bio Fame	CPO	Jumlah			
UID Aceh	-	-	-	-	-	28.741,01	-	15.129,68	-	43.870,69	-	-	-
UID Sumatera Utara	-	-	-	-	-	1.453,13	-	622,77	-	2.075,91	-	-	-
UID Sumatera Barat	-	-	-	-	-	4.977,21	-	2.586,52	-	7.563,72	-	-	-
UID Riau dan Kepulauan Riau	-	-	-	-	-	126.167,08	-	61.748,97	-	187.916,05	-	1.512,94	-
- Riau	-	-	-	-	-	54.937,22	-	25.161,87	-	80.099,09	-	1.512,94	-
- Kepulauan Riau	-	-	-	-	-	71.229,85	-	36.587,11	-	107.816,96	-	-	-
UID Sumatera Selatan, Jambi dan Bengkulu	-	-	-	-	-	19.449,40	-	9.917,75	-	29.367,15	-	489,09	-
- Sumatera Selatan	-	-	-	-	-	-	-	-	-	-	-	-	-
- Jambi	-	-	-	-	-	-	-	-	-	-	-	489,09	-
- Bengkulu	-	-	-	-	-	19.449,40	-	9.917,75	-	29.367,15	-	-	-
UIW Bangka Belitung	77.096,98	-	-	-	-	52.574,42	-	27.118,29	-	156.789,69	575.306,29	-	17.680,56
UID Lampung	-	-	-	-	-	501,93	-	202,51	-	704,44	-	-	-
UID Kalimantan Barat	-	-	-	-	-	35.424,31	-	17.440,09	-	52.864,39	-	-	-
UID Kalimantan Selatan dan Tengah	-	-	-	-	-	13.105,19	-	5.657,88	-	18.763,07	-	-	-
- Kalimantan Selatan	-	-	-	-	-	3.402,81	-	924,84	-	4.327,66	-	-	-
- Kalimantan Tengah	-	-	-	-	-	9.702,38	-	4.733,03	-	14.435,41	-	-	-
UID Kalimantan Timur dan Utara	-	-	-	-	-	10.325,58	-	5.462,09	-	15.787,68	-	-	-
UID Sulawesi Utara, Tengah dan Gorontalo	-	-	-	-	-	121.570,77	-	52.101,76	-	173.672,53	-	-	-
- Sulawesi Utara	-	-	-	-	-	21.211,64	-	9.090,70	-	30.302,35	-	-	-
- Sulawesi Tengah	-	-	-	-	-	100.359,13	-	43.011,06	-	143.370,19	-	-	-
- Gorontalo	-	-	-	-	-	-	-	-	-	-	-	-	-
UID Sulawesi Selatan, Tenggara dan Barat	-	-	-	-	-	11.202,77	-	4.728,58	-	15.931,35	-	-	-
- Sulawesi Selatan	-	-	-	-	-	5.612,78	-	2.332,87	-	7.945,65	-	-	-
- Sulawesi Tenggara	-	-	-	-	-	5.589,99	-	2.395,71	-	7.985,69	-	-	-
- Sulawesi Barat	-	-	-	-	-	-	-	-	-	-	-	-	-
UIW Maluku dan Maluku Utara	1.537,00	-	-	-	-	257.539,85	-	122.009,06	-	381.085,91	112.416,89	-	27,16
- Maluku	1.537,00	-	-	-	-	187.265,01	-	89.468,30	-	278.270,31	112.416,89	-	27,16
- Maluku Utara	-	-	-	-	-	70.274,84	-	32.540,76	-	102.815,60	-	-	-
UIW Papua dan Papua Barat	375,33	-	-	-	-	316.643,73	-	143.632,39	-	460.651,45	69.949,94	2.340,85	1.273,20
- Papua	-	-	-	-	-	100.793,18	-	45.349,85	-	146.143,03	-	-	-
- Papua Barat	375,33	-	-	-	-	215.850,55	-	98.282,55	-	314.508,42	69.949,94	2.340,85	1.273,20
UID Bali	-	-	-	-	-	-	-	-	-	-	-	-	-
UIW Nusa Tenggara Barat	39.942,71	-	90.203,31	-	-	248.352,27	-	123.657,11	-	502.155,39	648.977,30	-	11.015,36
UIW Nusa Tenggara Timur	-	-	34.344,56	-	-	131.445,97	-	53.364,04	-	219.154,57	533.265,49	-	1.985,03
PT PLN Batam	-	-	3.663,62	-	-	964,14	-	470,15	-	5.097,91	547.320,42	28.092,18	-
UIP3B Sumatera	-	-	-	-	-	-	-	-	-	-	-	9.006,54	-
UIP3B Kalimantan	-	-	-	-	-	-	-	-	-	-	-	-	-
UIP3B Sulawesi	-	-	-	-	-	-	-	-	-	-	-	-	-
UIK Kalimantan	6.517,05	-	-	-	-	79.970,12	-	39.190,74	-	125.677,91	92.755,82	4.300,71	0,07
UIK Sulawesi	1.149,31	-	-	-	-	66.878,89	-	33.975,62	-	102.003,81	801.398,34	109,73	-
UIK Sumatera	6.886,61	-	-	-	-	3.626,17	-	1.768,20	-	12.280,98	-	6.957,18	-
PLN Indonesia Power - Kalimantan	543,77	-	340,62	-	-	41.525,01	-	20.118,03	-	62.527,44	2.350.423,99	5.582,44	20.508,56
PLN Indonesia Power - Sulawesi	29.486,42	-	-	-	-	20.566,97	-	10.478,61	-	60.532,00	557.289,24	-	3.716,00
PLN Indonesia Power - Sumatera	5.664,74	799,33	-	-	-	11.540,87	-	4.919,70	-	22.924,65	4.896.734,12	15.493,94	23.927,42
PLN Nusantara Power - Kalimantan	163,69	-	2.663,71	-	-	60.613,97	-	29.697,61	-	93.138,99	1.613.215,21	4.821,19	14.873,63
PLN Nusantara Power - Sulawesi	924,71	-	28.570,80	-	-	45.355,46	-	22.922,08	-	97.773,05	1.633.007,16	12.844,95	13.730,68
PLN Nusantara Power - Sumatera	42.641,66	-	-	-	-	42.221,72	-	20.974,00	-	105.837,38	4.611.347,28	56.450,12	59.769,98
PLN Nusantara Power - Maluku Utara	24.913,54	-	-	-	-	-	-	-	-	24.913,54	-	-	-
Luar Jawa	237.843,52	799,33	159.786,62	-	-	1.752.737,93	-	829.894,24	-	2.981.061,64	19.043.407,48	148.001,87	168.507,65
UID Jawa Timur	-	-	-	-	-	14.682,12	-	7.108,10	-	21.790,22	-	-	-
UID Jawa Tengah dan Yogyakarta	-	-	-	-	-	93,96	-	-	-	93,96	-	-	-
- Jawa Tengah	-	-	-	-	-	93,96	-	-	-	93,96	-	-	-
- D.I. Yogyakarta	-	-	-	-	-	-	-	-	-	-	-	-	-
UID Jawa Barat	-	-	-	-	-	-	-	-	-	-	-	-	-
UID Banten	-	-	-	-	-	201,11	-	97,05	-	298,15	-	-	-
UID Jakarta Raya	-	-	-	-	-	-	-	-	-	-	-	-	-
PLN Indonesia Power - Jawabali	117.642,27	-	41.628,21	-	-	15.632,39	-	6.964,62	-	181.867,49	25.933.845,54	135.866,02	444.974,59
PLN Nusantara Power - Jawabali	6.205,33	-	19.656,61	-	-	3.701,04	-	1.586,16	-	31.149,14	15.850.092,34	133.171,59	377.295,15
Unit Induk Pusat Pengaturan Beban	-	-	-	-	-	-	-	-	-	-	-	-	-
UIK Tanjung Jati B	-	-	-	-	-	2.075,76	-	889,61	-	2.965,36	8.046.237,45	-	-
Jawa	123.847,60	-	61.284,81	-	-	36.386,37	-	16.645,54	-	238.164,32	49.830.175,33	269.037,61	822.269,74
Proyek Pembangkit	-	-	-	-	-	4.779,69	-	947,06	-	5.726,75	349.353,18	-	-
Indonesia	361.691,12	799,33	221.071,43	-	-	1.793.903,99	-	847.486,84	-	3.224.952,72	69.222.935,99	417.039,48	990.777,39

Catatan: Pemakaian Bahan Bakar dari Pembangkit Milik PLN, Sewa, IPP dan Proyek

Tabel 25 : Harga Satuan Bahan Bakar 2023

Satuan PLN/Provinsi	Bahan Bakar Minyak (Rp/Liter) *)				Batu Bara (Rp/kg)	Gas Alam (Rp/ MMSCF)	Panas Bumi (Rp/kWh)
	HSD*)	IDO	MFO	Rata-rata			
UID Aceh	11.429,15	-	-	11.429,15	-	-	-
UID Sumatera Utara	12.787,85	-	-	12.787,79	-	-	-
UID Sumatera Barat	12.579,35	-	-	12.579,37	-	-	-
UID Riau dan Kepulauan Riau	12.233,92	-	-	12.233,92	-	70.629,84	-
UID Sumatera Selatan, Jambi dan Bengkulu	12.028,68	-	-	12.028,68	-	101.993,97	-
UIW Bangka Belitung	12.695,63	-	-	12.695,63	814,51	-	-
UID Lampung	14.624,70	-	-	14.624,70	-	-	-
UID Kalimantan Barat	12.616,46	-	-	12.616,47	-	-	-
UID Kalimantan Selatan dan Tengah	12.881,63	-	-	12.881,63	-	-	-
UID Kalimantan Timur dan Utara	15.095,76	-	-	15.095,75	-	-	-
UID Sulawesi Utara, Tengah dan Gorontalo	12.065,79	-	-	12.065,79	-	-	-
UID Sulawesi Selatan, Tenggara dan Barat	8.543,28	-	-	8.543,28	-	-	-
UIW Maluku dan Maluku Utara	13.100,77	-	-	13.100,77	916,02	-	-
UIW Papua dan Papua Barat	12.422,81	-	-	12.422,81	1.635,45	-	-
UID Bali	-	-	-	-	-	-	-
UIW Nusa Tenggara Barat	11.861,77	-	8.372,34	11.234,95	930,05	-	-
UIW Nusa Tenggara Timur	11.764,33	-	-	11.764,33	1.014,46	-	64,64
PT PLN Batam	14.186,63	-	7.327,63	9.257,40	1.052,97	70.800,54	-
Luar Jawa	12.653,22		7.849,99	12.197,79	1.060,58	81.141,45	64,64
UID Jawa Timur	13.008,97	-	-	13.008,97	-	-	-
UID Jawa Tengah dan Yogyakarta	-	-	-	-	-	-	-
UID Jawa Barat	-	-	-	-	-	-	-
UID Banten	12.717,49	-	-	12.717,92	-	-	-
UID Jakarta Raya	-	-	-	-	-	-	-
PLN Indonesia Power	14.366,16	13,137.86	8.531,55	15.658,97	999,76	121.872,48	980,01
PLN Nusantara Power	12.926,96	-	7.967,02	14.269,86	889,82	140.670,52	-
UIK Tanjung Jati B	28.263,50	-	-	28.263,59	1.093,19	-	-
UIK Jawa Bagian Barat	-	-	-	-	-	-	-
UIK Jawa Bagian Tengah	-	-	-	-	-	-	-
UIK Jawa Bagian Timur, Bali dan Nusa Tenggara	-	-	-	-	-	-	-
J a w a	16.256,62	13.137,86	8.249,29	16.783,86	994,26	131.271,50	980,01
I n d o n e s i a **)	14.390,62	13.137,86	8.277,16	14.490,83	1.027,42	106.206,48	522,32

**) Harga satuan BBM (HSD, IDO, MFO) termasuk ongkos angkut dan harga bahan bakar campur, (biodiesel dll).*
***) Termasuk bahan bakar proyek.*

Tabel 26 : Energi yang Diproduksi per Jenis Bahan Bakar (GWh) 2023

Satuan PLN/Provinsi	Bahan Bakar Minyak										Batu Bara	Gas Alam	Bio-mass	Jumlah
	HSD	IDO	MFO	Bio-diesel	Olein	Bio HSD	HFO	Bio Fame	CPO	Jumlah				
UID Aceh	-	-	-	-	-	102,22	-	46,95	-	149,17	-	-	-	149,17
UID Sumatera Utara	-	-	-	-	-	3,71	-	1,59	-	5,31	-	-	29,89	35,20
UID Sumatera Barat	-	-	-	-	-	15,83	-	7,22	-	23,05	-	-	0,97	24,02
UID Riau dan Kepulauan Riau	-	-	-	-	-	457,28	-	195,74	-	653,02	-	2.345,62	17,99	3.016,62
- Riau	-	-	-	-	-	204,74	-	81,89	-	286,62	-	2.345,36	10,93	2.642,92
- Kepulauan Riau	-	-	-	-	-	252,54	-	113,86	-	366,39	-	0,25	7,05	373,70
UID Sumatera Selatan, Jambi dan Bengkulu	-	-	-	-	-	74,45	-	32,98	-	107,43	189,69	409,76	17,84	724,73
- Sumatera Selatan	-	-	-	-	-	-	-	-	-	-	150,96	331,71	7,09	489,77
- Jambi	-	-	-	-	-	-	-	-	-	-	38,73	78,04	0,41	117,18
- Bengkulu	-	-	-	-	-	74,45	-	32,98	-	107,43	-	-	10,34	117,77
UIW Bangka Belitung	233,41	-	-	-	-	184,78	-	95,32	-	513,51	570,22	-	75,68	1.159,41
UID Lampung	-	-	-	-	-	1,39	-	0,52	-	1,91	10,56	-	11,54	24,01
UID Kalimantan Barat	-	-	-	-	-	121,78	-	57,78	-	179,56	-	-	21,36	200,92
UID Kalimantan Selatan dan Tengah	-	-	-	-	-	38,68	-	17,79	-	56,47	14,06	-	51,85	122,37
- Kalimantan Selatan	-	-	-	-	-	9,10	-	3,89	-	12,99	-	-	10,93	23,92
- Kalimantan Tengah	-	-	-	-	-	29,57	-	13,90	-	43,47	14,06	-	40,92	98,45
UID Kalimantan Timur dan Utara	-	-	-	-	-	34,37	-	15,80	-	50,17	117,24	-	17,24	184,66
UID Sulawesi Utara, Tengah dan Gorontalo	-	-	-	-	-	429,89	-	169,50	-	599,39	54,09	-	-	653,48
- Sulawesi Utara	-	-	-	-	-	72,17	-	28,46	-	100,63	-	-	-	100,63
- Sulawesi Tengah	-	-	-	-	-	357,72	-	141,04	-	498,76	54,09	-	-	552,85
- Gorontalo	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UID Sulawesi Selatan, Tenggara dan Barat	-	-	-	-	-	40,09	-	14,92	-	55,01	90,65	-	-	145,66
- Sulawesi Selatan	-	-	-	-	-	20,23	-	7,53	-	27,77	-	-	-	27,77
- Sulawesi Tenggara	-	-	-	-	-	19,85	-	7,39	-	27,24	90,65	-	-	117,89
- Sulawesi Barat	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UIW Maluku dan Maluku Utara	6,03	-	-	-	-	977,92	-	422,45	-	1.406,40	120,42	-	0,03	1.526,85
- Maluku	6,03	-	-	-	-	723,10	-	319,92	-	1.049,05	99,37	-	0,03	1.148,44
- Maluku Utara	-	-	-	-	-	254,82	-	102,53	-	357,35	21,06	-	-	378,41
UIW Papua dan Papua Barat	1,39	-	-	-	-	1.192,78	-	576,21	-	1.770,38	53,11	322,55	16,31	2.162,35
- Papua	-	-	-	-	-	360,48	-	178,93	-	539,41	-	-	-	539,41
- Papua Barat	1,39	-	-	-	-	832,30	-	397,28	-	1.230,97	53,11	322,55	16,31	1.622,94
UID Bali	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UIW Nusa Tenggara Barat	115,93	-	366,93	-	-	1.082,23	-	482,11	-	2.047,20	777,68	-	8,28	2.833,16
UIW Nusa Tenggara Timur	-	-	143,07	-	-	508,17	-	189,97	-	841,21	519,90	-	2,00	1.363,11
PT PLN Batam	-	-	13,89	-	-	3,23	-	1,57	-	18,69	730,28	3.237,50	-	3.986,47
UIP3B Sumatera	-	-	-	-	-	-	-	-	-	-	8.867,59	2.577,95	-	11.445,54
UIP3B Kalimantan	-	-	-	-	-	-	-	-	-	-	6.332,25	496,59	107,93	6.936,76
UIP3B Sulawesi	-	-	-	-	-	-	-	-	-	-	4.559,36	-	-	4.559,36
UIK Kalimantan	20,39	-	-	-	-	292,43	-	142,90	-	455,72	128,38	440,63	0,02	1.024,76
UIK Sulawesi	1,81	-	-	-	-	257,33	-	130,39	-	389,53	988,80	16,70	-	1.395,03
UIK Sumatera	18,80	-	-	-	-	12,42	-	5,81	-	37,03	-	613,85	-	650,88
PLN Indonesia Power - Kalimantan	1,17	-	1,23	-	-	157,20	-	66,33	-	225,92	2.782,83	397,58	19,35	3.425,68
PLN Indonesia Power - Sulawesi	68,80	-	-	-	-	72,91	-	37,14	-	178,85	668,19	-	4,21	851,26
PLN Indonesia Power - Sumatera	10,88	3,46	-	-	-	6,97	-	2,99	-	24,30	7.009,57	1.654,84	24,61	8.713,32
PLN Nusantara Power - Kalimantan	0,40	-	9,72	-	-	217,69	-	107,42	-	335,24	1.957,07	538,03	16,41	2.846,75
PLN Nusantara Power - Sulawesi	2,95	-	126,43	-	-	159,72	-	80,79	-	369,89	2.012,60	1.303,41	12,03	3.697,92
PLN Nusantara Power - Sumatera	122,11	-	-	-	-	145,51	-	74,39	-	342,02	6.334,09	6.178,81	67,09	12.922,01
PLN Nusantara Power - Maluku Utara	51,17	-	-	-	-	-	-	-	-	51,17	-	-	-	51,17
Luar Jawa	655,25	3,46	661,27	-	-	6.590,98	-	2.976,59	-	10.887,55	44.888,63	20.533,83	522,62	76.832,63
UID Jawa Timur	-	-	-	-	-	53,71	-	26,01	-	79,72	-	-	33,61	113,33
UID Jawa Tengah dan Yogyakarta	-	-	-	-	-	0,29	-	-	-	0,29	-	-	-	0,29
- Jawa Tengah	-	-	-	-	-	0,29	-	-	-	0,29	-	-	-	0,29
- D.I. Yogyakarta	-	-	-	-	-	-	-	-	-	-	-	-	-	-
UID Jawa Barat	-	-	-	-	-	-	-	-	-	-	-	-	27,73	27,73
UID Banten	-	-	-	-	-	0,69	-	0,34	-	1,03	-	-	-	1,03
UID Jakarta Raya	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PLN Indonesia Power - Jawabali	307,27	-	187,63	-	-	15,94	-	6,80	-	517,64	43.523,36	16.880,10	454,89	61.376,00
PLN Nusantara Power - Jawabali	24,51	-	75,08	-	-	-	-	-	-	99,59	25.716,80	15.941,18	415,66	42.173,22
Unit Induk Pusat Pengaturan Beban	-	-	-	-	-	-	-	-	-	-	82.861,03	2.623,89	-	85.484,93
UIK Tanjung Jati B	-	-	-	-	-	-	-	-	-	-	19.205,06	-	-	19.205,06
Jawa	331,78	-	262,70	-	-	70,63	-	33,15	-	698,26	171.306,25	35.445,17	931,90	208.381,58
Proyek Pembangkitan	-	-	-	-	-	-	-	-	-	-	581,98	-	-	581,98
Indonesia	987,03	3,46	923,97	-	-	6.661,60	-	3.009,74	-	11.585,81	216.776,86	55.979,00	1.454,52	285.796,19

Catatan: Energi yang Diproduksi dari Pembangkit Milik PLN, Sewa, IPP dan Proyek

Tabel 27 : Captive Power

2023

Satuan PLN/Provinsi	Banyaknya Captive Power (CP)			Daya Terpasang (kVA)			kVA PLN pada CP Cadangan
	CP Murni	CP Cadangan	Jumlah	CP Murni	CP Cadangan	Jumlah	
UID Aceh	15	-	15	34.200,00	-	34.200,00	-
UID Sumatera Utara	-	256	256	-	-	-	168.231,60
UID Sumatera Barat	19	-	19	38.192,00	-	38.192,00	-
UID Riau dan Kepulauan Riau	133	3	136	518.470,50	29.411,76	547.882,26	19.565,00
- Riau	113	-	113	512.107,60	-	512.107,60	-
- Kepulauan Riau	20	3	23	6.362,90	29.411,76	35.774,66	19.565,00
UID Sumatera Selatan, Jambi dan Bengkulu	-	-	-	-	-	-	-
- Sumatera Selatan	-	-	-	-	-	-	-
- Jambi	-	-	-	-	-	-	-
- Bengkulu	-	-	-	-	-	-	-
UIW Bangka Belitung	3	-	3	1.140,00	-	1.140,00	-
UID Lampung	25	-	25	25.307,00	-	25.307,00	-
UID Kalimantan Barat	2	205	207	3.115,00	187.079,00	190.194,00	187.079,00
UID Kalimantan Selatan dan Tengah	-	1	1	-	345,00	345,00	345,00
- Kalimantan Selatan	-	1	1	-	345,00	345,00	345,00
- Kalimantan Tengah	-	-	-	-	-	-	-
UID Kalimantan Timur dan Utara	14	-	14	86,48,00	-	86,48	-
UID Sulawesi Utara, Tengah dan Gorontalo	16	-	16	22.670,00	-	22.670	-
- Sulawesi Utara	3	-	3	15.195,00	-	15.195,00	-
- Sulawesi Tengah	10	-	10	6.020,00	-	6.020,00	-
- Gorontalo	3	-	3	1.455,00	-	1.455,00	-
UID Sulawesi Selatan, Tenggara dan Barat	-	-	-	-	-	-	-
- Sulawesi Selatan	-	-	-	-	-	-	-
- Sulawesi Tenggara	-	-	-	-	-	-	-
- Sulawesi Barat	-	-	-	-	-	-	-
UIW Maluku dan Maluku Utara	5	-	5	53.860.000,00	-	53.860.000,00	-
- Maluku	2	-	2	2.055.000,00	-	2.055.000,00	-
- Maluku Utara	3	-	3	51.805.000,00	-	51.805.000,00	-
UIW Papua dan Papua Barat	-	-	-	-	-	-	-
- Papua	-	-	-	-	-	-	-
- Papua Barat	-	-	-	-	-	-	-
UID Bali	-	513	513	-	434.958,00	434.958,00	520.643,00
UIW Nusa Tenggara Barat	-	-	-	-	-	-	-
UIW Nusa Tenggara Timur	-	-	-	-	-	-	-
PT PLN Batam	1	14	15	18.000,00	139.517,00	157.517,00	63.145,90
PT PLN Nusa Daya*)	-	-	-	-	-	-	-
UIP3B Sumatera	-	-	-	-	-	-	-
UIP3B Kalimantan	-	-	-	-	-	-	-
UIP3B Sulawesi	-	-	-	-	-	-	-
Luar Jawa	233	992	1.225	54.521.180,98	791.310,76	55.312.491,75	959.009,50
UID Jawa Timur	-	-	-	-	-	-	-
UID Jawa Tengah dan Yogyakarta	-	-	-	-	-	-	-
- Jawa Tengah	-	-	-	-	-	-	-
- D.I. Yogyakarta	-	-	-	-	-	-	-
UID Jawa Barat	-	-	-	-	747.655,00	747.655,00	1.493.861,00
UID Banten	9	13	22	886,00	332.235,00	333.121,00	573,69
UID Jakarta Raya	-	6	6	-	63.977,00	63.977,00	64.300,00
PLN Indonesia Power	-	-	-	-	-	-	-
PLN Nusantara Power	-	-	-	-	-	-	-
Unit Induk Pusat Pengaturan Beban	-	-	-	-	-	-	-
J a w a	9	19	28	886,00	1.143.867,00	1.144.753,00	1.558.734,69
I n d o n e s i a	242	1.011	1.253	54.522.066,98	1.935.177,76	56.457.244,75	2.517.744,19

Catatan: CP Murni = Perusahaan/Instansi/Perorangan yang mempergunakan pembangkit tenaga listrik sendiri sebagai sumber tenaga utama dalam proses produksi.
CP Cadangan = CP yang berlangganan listrik kepada PLN
**) Sebelumnya adalah PT PLN Tarakan*

Tabel 28 : Panjang Jaringan Transmisi (kms) 2023

Satuan PLN/Provinsi	Tegangan					Jumlah
	25 - 30 kV	70 kV	150 kV	275 kV	500 kV	
UID Aceh	-	-	-	-	-	-
UID Sumatera Utara	-	-	-	-	-	-
UID Sumatera Barat	-	-	-	-	-	-
UID Riau dan Kepulauan Riau	-	-	179,08	-	-	179,08
- Riau	-	-	-	-	-	-
- Kepulauan Riau	-	-	179,08	-	-	179,08
UID Sumatera Selatan, Jambi dan Bengkulu	-	-	-	-	-	-
- Sumatera Selatan	-	-	-	-	-	-
- Jambi	-	-	-	-	-	-
- Bengkulu	-	-	-	-	-	-
UIW Bangka Belitung	-	140,06	751,57	-	-	891,64
UID Lampung	-	-	-	-	-	-
UID Kalimantan Barat	-	-	1.916,96	162,74	-	2.079,71
UID Kalimantan Selatan dan Tengah	-	123,08	4.410,47	-	-	4.533,55
- Kalimantan Selatan	-	123,08	1.993,73	-	-	2.116,81
- Kalimantan Tengah	-	-	2.416,74	-	-	2.416,74
UID Kalimantan Timur dan Utara	-	-	2.158,81	-	-	2.158,81
UID Sulawesi Utara, Tengah dan Gorontalo	0,76	450,62	2.421,61	-	-	2.872,99
- Sulawesi Utara	0,76	306,82	1.206,14	-	-	1.513,72
- Sulawesi Tengah	-	143,80	629,93	-	-	773,73
- Gorontalo	-	-	585,53	-	-	585,53
UID Sulawesi Selatan, Tenggara dan Barat	3,40	145,30	5.828,08	3,41	-	5.980,19
- Sulawesi Selatan	3,40	119,90	3.264,96	3,41	-	3.391,67
- Sulawesi Tenggara	-	25,40	1.611,35	-	-	1.636,75
- Sulawesi Barat	-	-	951,77	-	-	951,77
UIW Maluku dan Maluku Utara	-	196,30	175,05	-	-	371,34
- Maluku	-	196,30	92,61	-	-	288,90
- Maluku Utara	-	-	82,44	-	-	82,44
UIW Papua dan Papua Barat	-	204,18	84,90	-	-	289,08
- Papua	-	204,18	53,90	-	-	258,08
- Papua Barat	-	-	31,00	-	-	31,00
UID Bali	-	-	-	-	-	-
UIW Nusa Tenggara Barat	-	344,42	889,61	-	-	1.234,03
UIW Nusa Tenggara Timur	-	968,17	657,72	-	-	1.625,89
PT PLN Batam	-	-	200,91	-	-	200,91
PT PLN Nusa Daya	-	-	-	-	-	-
UIP3B Sumatera	-	531,21	16.425,63	4.240,08	400,42	21.597,34
UIP3B Sulawesi	0,38	553,12	7.723,81	3,67	-	8.280,98
UIP3B Kalimantan	-	94,23	8.220,28	162,75	-	8.477,26
Luar Jawa	4,54	3.750,70	52.044,47	4.572,66	400,42	60.772,79
UID Jawa Timur	-	-	-	-	-	-
UID Jawa Tengah dan Yogyakarta	-	-	-	-	-	-
- Jawa Tengah	-	-	-	-	-	-
- D.I. Yogyakarta	-	-	-	-	-	-
UID Jawa Barat	-	-	-	-	-	-
UID Banten	-	-	-	-	-	-
UID Jakarta Raya	-	-	-	-	-	-
PLN Indonesia Power	-	-	-	-	-	-
PLN Nusantara Power	-	-	-	-	-	-
UIT Jawa Bagian Barat	-	237,39	2.612,60	-	1.217,02	4.067,01
UIT Jawa Bagian Tengah	40,64	1.491,04	8.463,88	-	4.233,23	14.228,79
UIT Jawa Bagian Timur dan Bali	56,15	1.268,01	5.954,97	-	1.343,76	8.622,90
Jawa	96,79	2.996,44	17.031,45	-	6.794,01	26.918,69
Indonesia	101,33	6.747,14	69.075,92	4.572,67	7.194,43	87.691,48

Catatan: Tegangan 25-30 kV tidak masuk ke distribusi karena masih dipelihara oleh transmisi dan pembangkit pengelola

Tabel 29 : Panjang Jaringan Tegangan Menengah dan Tegangan Rendah (kms) 2023

Satuan PLN/Provinsi	Tegangan Menengah			Tegangan Rendah
	6 - 7 kV	10 - 12 kV	15-20 kV	
UID Aceh	-	-	14.449,82	16.471,01
UID Sumatera Utara	-	-	30.371,05	32.452,04
UID Sumatera Barat	-	-	11.387,51	18.458,94
UID Riau dan Kepulauan Riau	-	-	18.206,45	28.599,20
- Riau	-	-	15.504,33	26.256,23
- Kepulauan Riau	-	-	2.702,12	2.342,97
UID Sumatera Selatan, Jambi dan Bengkulu	-	-	30.477,06	24.906,23
- Sumatera Selatan	-	-	15.941,84	11.152,98
- Jambi	-	-	9.657,91	7.442,96
- Bengkulu	-	-	4.877,31	6.310,29
UIW Bangka Belitung	-	-	6.106,20	5.779,01
UID Lampung	-	-	14.805,96	18.442,62
UID Kalimantan Barat	-	-	14.889,06	15.537,23
UID Kalimantan Selatan dan Tengah	-	-	18.364,80	16.230,30
- Kalimantan Selatan	-	-	9.792,97	10.859,45
- Kalimantan Tengah	-	-	8.571,83	5.370,85
UID Kalimantan Timur dan Utara	-	-	11.303,67	9.054,19
UID Sulawesi Utara, Tengah dan Gorontalo	-	-	16.207,76	14.987,54
- Sulawesi Utara	-	-	5.679,87	6.255,14
- Sulawesi Tengah	-	-	7.950,40	6.689,32
- Gorontalo	-	-	2.577,49	2.043,08
UID Sulawesi Selatan, Tenggara dan Barat	-	-	28.253,21	28.237,23
- Sulawesi Selatan	-	-	17.148,63	19.208,98
- Sulawesi Tenggara	-	-	7.174,59	6.222,98
- Sulawesi Barat	-	-	3.929,99	2.805,27
UIW Maluku dan Maluku Utara	-	-	8.318,06	4.816,79
- Maluku	-	-	4.626,81	2.496,18
- Maluku Utara	-	-	3.691,25	2.320,61
UIW Papua dan Papua Barat	-	-	7.548,84	10.510,01
- Papua	-	-	5.095,60	8.330,65
- Papua Barat	-	-	2.453,24	2.179,36
UID Bali	-	-	8.830,06	14.939,12
UIW Nusa Tenggara Barat	-	-	7.128,75	7.948,80
UIW Nusa Tenggara Timur	-	-	9.797,85	9.688,20
PT PLN Batam	-	-	-	-
PT PLN Nusa Daya*)	-	-	-	-
UIP3B Sumatera	-	-	-	-
UIP3B Sulawesi	-	-	-	-
UIP3B Kalimantan	-	-	-	-
Luar Jawa	-	-	256.446,12	277.058,46
UID Jawa Timur	-	-	41.807,71	80.431,98
UID Jawa Tengah dan Yogyakarta	-	-	55.204,21	56.833,13
- Jawa Tengah	-	-	49.306,38	50.571,76
- D.I. Yogyakarta	-	-	5.897,83	6.261,38
UID Jawa Barat	-	-	50.225,70	130.191,47
UID Banten	-	-	16.676,51	25.855,28
UID Jakarta Raya	-	-	18.539,92	38.912,67
PLN Indonesia Power	-	-	-	-
PLN Nusantara Power	-	-	-	-
UIT Jawa Bagian Barat	-	-	-	-
UIT Jawa Bagian Tengah	-	-	-	-
UIT Jawa Bagian Timur dan Bali	-	-	-	-
J a w a	-	-	182.454,05	332.224,53
I n d o n e s i a	-	-	438.900,17	609.282,99

**) Sebelumnya adalah PT PLN Tarakan*

Tabel 30 : Jumlah dan Daya Terpasang Trafo Gardu Induk 2023

Satuan PLN/Provinsi	500 kV		275 kV		150 kV		70 kV		<30 kV		Jumlah	
	Unit	MVA	Unit	MVA	Unit	MVA	Unit	MVA	Unit	MVA	Unit	MVA
UID Aceh	-	-	-	-	-	-	-	-	-	-	-	-
UID Sumatera Utara	-	-	-	-	-	-	-	-	-	-	-	-
UID Sumatera Barat	-	-	-	-	-	-	-	-	-	-	-	-
UID Riau dan Kepulauan Riau	-	-	-	-	10	350,00	-	-	-	-	10	350,00
- Riau	-	-	-	-	-	-	-	-	-	-	-	-
- Kepulauan Riau	-	-	-	-	10	350,00	-	-	-	-	10	350,00
UID Sumatera Selatan, Jambi dan Bengkulu	-	-	-	-	-	-	-	-	-	-	-	-
- Sumatera Selatan	-	-	-	-	-	-	-	-	-	-	-	-
- Jambi	-	-	-	-	-	-	-	-	-	-	-	-
- Bengkulu	-	-	-	-	-	-	-	-	-	-	-	-
UIW Bangka Belitung	-	-	-	-	11	570,00	6	180,00	-	-	17	750,00
UID Lampung	-	-	-	-	-	-	-	-	-	-	-	-
UID Kalimantan Barat	-	-	2	498,00	36	1.455,00	-	-	-	-	38	1.953,00
UID Kalimantan Selatan dan Tengah	-	-	-	-	77	3.032,00	14	148,00	-	-	91	3.180,00
- Kalimantan Selatan	-	-	-	-	43	1.782,00	14	148,00	-	-	57	1.930,00
- Kalimantan Tengah	-	-	-	-	34	1.250,00	-	-	-	-	34	1.250,00
UID Kalimantan Timur dan Utara	-	-	-	-	54	2.180,00	-	-	-	-	54	2.180,00
UID Sulawesi Utara, Tengah dan Gorontalo	-	-	-	-	55	2.260,00	29	614,00	-	-	84	2.874,00
- Sulawesi Utara	-	-	-	-	29	1.170,00	23	464,00	-	-	52	1.634,00
- Sulawesi Tengah	-	-	-	-	17	710,00	6	150,00	-	-	23	860,00
- Gorontalo	-	-	-	-	9	380,00	-	-	-	-	9	380,00
UID Sulawesi Selatan, Tenggara dan Barat	-	-	2	340,00	109	3.718,30	18	295,00	2	30	131	4.383,30
- Sulawesi Selatan	-	-	2	340,00	85	2.892,30	13	200,00	2	30	102	3.462,30
- Sulawesi Tenggara	-	-	-	-	13	510,00	5	95,00	-	-	18	605,00
- Sulawesi Barat	-	-	-	-	11	316,00	-	-	-	-	11	316,00
UIW Maluku dan Maluku Utara	-	-	-	-	17	770,00	6	130,00	-	-	23	900,00
- Maluku	-	-	-	-	9	420,00	6	80,00	-	-	15	500,00
- Maluku Utara	-	-	-	-	8	350,00	-	-	-	-	8	350,00
UIW Papua dan Papua Barat	-	-	-	-	13	570,00	15	226,03	-	-	28	796,03
- Papua	-	-	-	-	7	390,00	15	226,03	-	-	22	616,03
- Papua Barat	-	-	-	-	6	180,00	-	-	-	-	6	180,00
UID Bali	-	-	-	-	-	-	-	-	-	-	-	-
UIW Nusa Tenggara Barat	-	-	-	-	28	1.295,00	8	190,00	-	-	36	1.485,00
UIW Nusa Tenggara Timur	-	-	-	-	7	330,00	18	425,00	-	-	25	755,00
PT PLN Batam	-	-	-	-	21	870,00	-	-	-	-	21	870,00
PT PLN Nusa Daya*)	-	-	-	-	-	-	-	-	-	-	-	-
UIP3B Sumatera	5	2.500,00	41	11.410,21	362	17.719,00	26	730,00	-	-	434	32.359,21
UIP3B Sulawesi	-	-	2	340,00	149	5.725,80	33	740,00	-	-	184	6.805,80
UIP3B Kalimantan	-	-	2	500,00	154	6.036,00	5	96,00	-	-	161	6.632,00
Luar Jawa	5	2.500,00	49	13.088,21	1.103	46.881,10	178	3.774,03	2	30	1.337	66.273,34
UID Jawa Timur	-	-	-	-	-	-	-	-	-	-	-	-
UID Jawa Tengah dan Yogyakarta	-	-	-	-	-	-	-	-	-	-	-	-
- Jawa Tengah	-	-	-	-	-	-	-	-	-	-	-	-
- D.I. Yogyakarta	-	-	-	-	-	-	-	-	-	-	-	-
UID Jawa Barat	-	-	-	-	-	-	-	-	-	-	-	-
UID Banten	-	-	-	-	-	-	-	-	-	-	-	-
UID Jakarta Raya	-	-	-	-	-	-	-	-	-	-	-	-
PLN Indonesia Power	-	-	-	-	-	-	-	-	-	-	-	-
PLN Nusantara Power	-	-	-	-	-	-	-	-	-	-	-	-
UIT Jawa Bagian Barat	35	16.334,21	-	-	391	23.306,00	8	220,00	-	-	434	39.860,21
UIT Jawa Bagian Tengah	31	15.500,00	-	-	459	27.601,00	66	1.603,00	-	-	556	44.704,00
UIT Jawa Bagian Timur dan Bali	19	9.515,10	-	-	311	18.374,00	55	1.438,00	-	-	385	29.327,10
J a w a	85	41.349,31	-	-	1.161	69.281,00	129	3.261,00	-	-	1.375	113.891,31
I n d o n e s i a	90	43.849,31	49	13.088,21	2.264	116.162,10	307	7.035,03	2	30	2.712	180.164,65

**) Sebelumnya adalah PT PLN Tarakan*

Tabel 31 : Jumlah dan Daya Terpasang Trafo Gardu Distribusi 2023

Satuan PLN/Provinsi	20 kV		12-15 kV		6-7 kV		Jumlah	
	Unit	MVA	Unit	MVA	Unit	MVA	Unit	MVA
UID Aceh	14.837	1.216,47	-	-	-	-	14.837	1.216,47
UID Sumatera Barat	11.229	1.215,83	-	-	-	-	11.229	1.215,83
UID Riau dan Kepulauan Riau	16.400	2.103,97	-	-	-	-	16.400	2.103,97
- Riau	13.763	1.757,55	-	-	-	-	13.763	1.757,55
- Kepulauan Riau	2.637	346,42	-	-	-	-	2.637	346,42
UID Sumatera Selatan, Jambi dan Bengkulu	30.565	2.819,55	-	-	-	-	30.565	2.819,55
- Sumatera Selatan	16.685	1.629,64	-	-	-	-	16.685	1.629,64
- Jambi	9.670	810,96	-	-	-	-	9.670	810,96
- Bengkulu	4.210	378,94	-	-	-	-	4.210	378,94
UIW Bangka Belitung	4.664	511,58	-	-	-	-	4.664	511,58
UID Lampung	15.564	2.006,91	-	-	-	-	15.564	2.006,91
UID Kalimantan Barat	11.077	1.204,30	-	-	-	-	11.077	1.204,30
UID Kalimantan Selatan dan Tengah	18.095	1.677,13	-	-	-	-	18.095	1.677,13
- Kalimantan Selatan	11.458	1.131,15	-	-	-	-	11.458	1.131,15
- Kalimantan Tengah	6.637	545,97	-	-	-	-	6.637	545,97
UID Kalimantan Timur dan Utara	11.317	1.566,84	-	-	-	-	11.317	1.566,84
UID Sulawesi Utara, Tengah dan Gorontalo	15.626	1.361,46	-	-	-	-	15.626	1.361,46
- Sulawesi Utara	5.819	566,68	-	-	-	-	5.819	566,68
- Gorontalo	2.857	260,17	-	-	-	-	2.857	260,17
- Sulawesi Tengah	6.950	534,61	-	-	-	-	6.950	534,61
UID Sulawesi Selatan, Tenggara dan Barat	29.813	2.875,73	-	-	-	-	29.813	2.875,73
- Sulawesi Selatan	20.889	2.192,77	-	-	-	-	20.889	2.192,77
- Sulawesi Tenggara	5.452	437,50	-	-	-	-	5.452	437,50
- Sulawesi Barat	3.472	245,46	-	-	-	-	3.472	245,46
UIW Maluku dan Maluku Utara	5.471	560,09	-	-	-	-	5.471	560,09
- Maluku	3.147	312,13	-	-	-	-	3.147	312,13
- Maluku Utara	2.324	247,96	-	-	-	-	2.324	247,96
UIW Papua dan Papua Barat	6.196	772,07	-	-	-	-	6.196	772,07
- Papua	3.990	466,85	-	-	-	-	3.990	466,85
- Papua Barat	2.206	305,22	-	-	-	-	2.206	305,22
UID Bali	13.140	2.112,17	-	-	-	-	13.140	2.112,17
UIW Nusa Tenggara Barat	6.346	851,03	-	-	-	-	6.346	851,03
UIW Nusa Tenggara Timur	6.239	460,88	-	-	-	-	6.239	460,88
PT PLN Batam	-	-	-	-	-	-	-	-
PT PLN Nusa Daya*)	-	-	-	-	-	-	-	-
UIP3B Sumatera	-	-	-	-	-	-	-	-
UIP3B Sulawesi	-	-	-	-	-	-	-	-
UIP3B Kalimantan	-	-	-	-	-	-	-	-
Luar Jawa	253.701	27.241,22	-	-	-	-	253.701	27.241,22
UID Jawa Timur	67.445	8.810,16	-	-	-	-	67.445	8.810,16
UID Jawa Tengah dan Yogyakarta	146.220	8.525,86	-	-	-	-	146.220	8.525,86
- Jawa Tengah	128.279	7.482,56	-	-	-	-	128.279	7.482,56
- D.I. Yogyakarta	17.941	1.043,30	-	-	-	-	17.941	1.043,30
UID Jawa Barat	60.149	10.225,65	-	-	-	-	60.149	10.225,65
UID Banten	17.381	4.090,27	-	-	-	-	17.381	4.090,27
UID Jakarta Raya	14.098	7.823,07	-	-	-	-	14.098	7.823,07
PLN Indonesia Power	-	-	-	-	-	-	-	-
PLN Nusantara Power	-	-	-	-	-	-	-	-
UIT Jawa Bagian Barat	-	-	-	-	-	-	-	-
UIT Jawa Bagian Tengah	-	-	-	-	-	-	-	-
UIT Jawa Bagian Timur dan Bali	-	-	-	-	-	-	-	-
J a w a	305.293	39.475,01	-	-	-	-	305.293	39.475,01
I n d o n e s i a	558.994	66.716,23	-	-	-	-	558.994	66.716,23

**) Sebelumnya adalah PT PLN Tarakan*

Tabel 32 : N e r a c a (juta Rp) **2023**

K e t e r a n g a n		K e t e r a n g a n	Desember 2023
ASET TETAP		**MODAL**	1.015.631.399
- Jumlah A T	1.423.711.513		
- Akumulasi Penyusutan	(106.761.876)		-
- Akumulasi Rugi Penurunan Nilai	(3.759.262)		
Jumlah A T (Bersih)	1.313.190.376	Jumlah Modal	1.015.631.399
		LIABILITAS JANGKA PANJANG	511.812.872
P D P dan ATTB	135.780.245	- Liabilitas Pajak Tangguhan	58.228.739
Aset Hak Guna	30.574.504	- Pinjaman Jangka Panjang	363.181.243
Aset tidak Lancar Lainnya	32.643.618	- Liabilitas Jangka Panjang Lainnya	27.571.852
Piutang dari Pemerintah	-	- Liabilitas Manfaat Pekerja	62.831.038
Investasi pada Asosiasi dan Ventura Bersama	26.526.781		
Aset Pajak Tangguhan	540.694		
AKTIVA LANCAR		**LIABILITAS JANGKA PENDEK**	143.195.433
- Kas & Bank	55.920.541	- Utang Usaha	57.147.527
- Piutang dari Pemerintah	22.446.998	- Pinjaman Jangka Pendek	33.037.450
- Investasi Sementara	913.670	- Liabilitas Jangka Pendek Lainnya	45.128.076
- Piutang Usaha	26.840.955	- Liabilitas Manfaat Pekerja	7.882.380
- Persediaan	17.862.312		
- Aktiva Lancar lainnya	7.399.010		
Jumlah Aktiva Lancar	131.383.486	Jumlah Liabilitas Jangka Panjang & Jangka Pendek	655.008.305
JUMLAH AKTIVA	**1.670.639.704**	**JUMLAH EKUITAS & LIABILITAS**	**1.670.639.704**

Tabel 33 : L a b a R u g i (juta Rp) 2023

K e t e r a n g a n	Desember 2023
PENDAPATAN OPERASI	
- Penjualan Tenaga Listrik	333.191.062
- Biaya Penyambungan	1.288.284
- Subsidi Pemerintah	68.636.731
- Pendapatan Kompensasi	73.991.897
- Lain - lain	10.276.090
Jumlah Pendapatan Operasi	**487.384.064**
BIAYA OPERASI	
- Bahan Bakar dan Pelumas	164.731.578
- Pembelian Tenaga Listrik	154.831.184
- Sewa	1.874.862
- Pemeliharaan	29.518.324
- Kepegawaian	32.355.934
- Penyusutan Aset Tetap	43.967.082
- Penyusutan Hak Guna	3.347.165
- Lain-lain	9.557.861
Jumlah Biaya Operasi	**440.183.990**
LABA (RUGI) OPERASI	**47.200.074**
Penghasilan/(Beban) Lain-lain - Bersih	1.513.051
Keuntungan/(Kerugian) Kurs Mata Uang Asing - Bersih	3.723.639
Penghasilan Keuangan	953.515
Beban Keuangan	(21.010.355)
LABA (RUGI) SEBELUM PAJAK	**32.379.924**
BEBAN PAJAK PENGHASILAN	**(10.308.466)**
LABA TAHUN BERJALAN	**22.071.458**

Tabel 34 : Aset Tetap dan Penyusutan (juta Rp) 2023

F u n g s i	S a l d o 2023	Akumulasi Penyusutan	Nilai Buku 2023
- P L T A	96.917.740,43	(4.662.510,59)	92.133.552,09
- P L T U	319.196.105,18	(28.928.610,49)	289.881.210,59
- P L T D	25.107.241,06	(3.182.433,83)	21.326.981,34
- P L T G	62.576.149,91	(4.966.973,22)	57.463.858,53
- P L T P	16.061.149,96	(1.176.673,27)	14.884.033,49
- P L T G U	193.971.975,64	(12.524.404,11)	181.348.961,71
- P L T S	1.680.466,90	(157.705,73)	1.381.063,50
- Sistem Transmisi	368.472.968,11	(18.018.638,33)	348.536.093,24
- Sistem Tele Informasi Data	15.276.181,14	(5.339.562,54)	9.883.839,39
- Sistem Distribusi dan UPD	278.586.913,06	(22.807.843,69)	255.559.002,36
- T U L	4.613.332,75	(596.198,58)	4.004.425,09
- Umum	41.251.289,20	(4.400.321,11)	36.787.354,70
JUMLAH	**1.423.711.513,40**	**(106.761.875,56)**	**1.313.190.376,09**

Tabel 35 : Piutang Langganan (juta Rp) **2023**

Satuan PLN	Umum	TNI & Polri	Non TNI & Polri	PEMDA	BUMN	Jumlah
UID Aceh	184.862,02	21.902,03	3.940,17	65.099,67	9.569,09	285.372,97
UID Sumatera Utara	928.702,20	20.076,74	16.979,01	67.846,86	21.611,51	1.055.216,32
UID Sumatera Barat	214.354,19	6.810,44	7.307,60	23.937,11	50.405,82	302.815,17
UID Riau dan Kepulauan Riau	612.204,87	16.392,17	6.533,23	42.291,50	140.064,96	817.486,72
UID Sumatera Selatan, Jambi dan Bengkulu	711.989,17	15.297,59	13.198,91	93.715,05	29.724,47	863.925,18
UIW Bangka Belitung	56.017,76	3.422,50	1.357,10	4.098,51	2.854,42	67.750,30
UID Lampung	430.621,28	3.225,73	5.761,74	28.278,29	4.136,08	472.023,13
UID Kalimantan Barat	187.007,54	10.878,35	4.645,50	14.330,21	3.514,06	220.375,67
UID Kalimantan Selatan dan Tengah	379.539,33	12.119,21	8.254,31	30.176,05	14.878,76	444.967,66
UID Kalimantan Timur dan Utara	403.882,31	14.967,48	8.682,27	32.911,64	23.918,57	484.362,27
UID Sulawesi Utara, Tengah dan Gorontalo	404.682,41	23.053,48	10.405,64	37.424,12	7.586,72	483.152,37
UID Sulawesi Selatan, Tenggara dan Barat	992.959,65	23.206,31	18.458,06	41.731,63	31.804,45	1.108.160,10
UIW Maluku dan Maluku Utara	77.018,27	19.495,05	7.122,91	6.268,29	40.171,27	150.075,79
UIW Papua dan Papua Barat	86.053,66	37.791,28	7.563,49	13.620,98	7.824,58	152.853,98
UID Bali	534.122,41	7.208,85	8.151,63	15.853,79	6.859,61	572.196,27
UIW Nusa Tenggara Barat	131.598,72	1.823,58	3.032,22	14.618,01	3.689,23	154.761,76
UIW Nusa Tenggara Timur	25.031,74	5.488,71	4.578,10	5.949,41	5.603,25	46.651,22
PT PLN Batam	408.443,01	5.352,95	2.204,13	3.842,63	577,47	420.420,20
Luar Jawa	6.769.090,53	248.512,45	138.176,03	541.993,76	404.794,31	8.102.567,08
UID Jawa Timur	3.283.199,72	55.532,95	43.043,81	110.075,94	123.201,81	3.615.054,23
UID Jawa Tengah dan Yogyakarta	2.178.613,80	34.740,99	47.848,28	105.861,75	44.908,21	2.411.973,02
UID Jawa Barat	4.881.363,83	61.077,29	49.500,18	141.770,41	60.274,18	5.193.985,89
UID Banten	3.487.207,43	212.262,02	137.903,94	105.314,74	27.672,43	3.970.360,56
UID Jakarta Raya	2.687.766,24	10.730,55	11.057,37	26.712,77	40.238,95	2.776.505,86
Jawa	16.518.151,02	374.343,80	289.353,57	489.735,61	296.295,57	17.967.879,57
Indonesia	23.287.241,55	622.856,25	427.529,61	1.031.729,37	701.089,88	26.070.446,65

Catatan: Data diambil dari Aplikasi Pengelolaan Pelanggan Terpusat (AP2T)

Tabel 36 : Kecepatan Rata-rata Penagihan 2023

Satuan PLN	Penjualan (juta Rp)	Piutang (juta Rp)	Rata-rata (hari)
UID Aceh	3.567.391,30	285.372,97	29,20
UID Sumatera Utara	14.418.442,53	1.055.216,32	26,71
UID Sumatera Barat	4.273.726,82	302.815,17	25,86
UID Riau dan Kepulauan Riau	9.514.832,27	817.486,72	31,36
UID Sumatera Selatan, Jambi dan Bengkulu	11.614.371,41	863.925,18	27,15
UIW Bangka Belitung	2.062.356,35	67.750,30	11,99
UID Lampung	6.278.779,44	472.023,13	27,44
UID Kalimantan Barat	3.853.964,09	220.375,67	20,87
UID Kalimantan Selatan dan Tengah	6.422.246,23	444.967,66	25,29
UID Kalimantan Timur dan Utara	6.581.312,80	484.362,27	26,86
UID Sulawesi Utara, Tengah dan Gorontalo	5.056.409,89	483.152,37	34,88
UID Sulawesi Selatan, Tenggara dan Barat	11.896.464,51	1.108.160,10	34,00
UIW Maluku dan Maluku Utara	1.922.455,38	150.075,79	28,49
UIW Papua dan Papua Barat	2.679.578,18	152.853,98	20,82
UID Bali	8.471.374,39	572.196,27	24,65
UIW Nusa Tenggara Barat	2.627.398,86	154.761,76	21,50
UIW Nusa Tenggara Timur	1.631.937,52	46.651,22	10,43
PT PLN Batam	4.564.736,21	420.420,20	33,62
Luar Jawa	107.437.778,18	8.102.567,08	27,53
UID Jawa Timur	46.021.262,01	3.615.054,23	28,67
UID Jawa Tengah dan Yogyakarta	34.059.695,73	2.411.973,02	25,85
UID Jawa Barat	66.264.723,84	5.193.985,89	28,61
UID Banten	30.635.039,87	2.776.505,86	33,08
UID Jakarta Raya	48.861.363,93	3.970.360,56	29,66
Jawa	225.842.085,39	17.967.879,57	29,04
Indonesia	333.279.863,57	26.070.446,65	28,55

Tabel 37 : Beban Usaha Pembangkit Per Jenis Pembangkit 2023

Jenis Pembangkit	Beban Usaha (juta Rp)					
	Bahan Bakar*)	Pemeliharaan	Penyusutan Aset	Lain-lain	Pegawai	Jumlah
P L T A	388.816,92	622.081,17	2.186.439,61	46.263,95	269.529,97	3.513.131,61
P L T U	72.747.173,41	9.321.084,81	12.932.762,07	439.553,00	1.774.118,04	97.214.691,33
P L T D**)	31.105.925,63	2.263.972,14	1.340.409,17	55.737,11	601.545,55	35.367.589,60
P L T G	13.103.172,35	1.423.237,11	2.179.539,06	101.527,56	274.007,05	17.081.483,13
P L T P	4.190.279,41	134.864,65	512.477,09	44.007,81	143.112,19	5.024.741,14
P L T G U	43.196.209,89	956.661,34	6.300.307,70	174.737,70	613.909,01	51.241.825,64
P L T S	0,00	16.653,06	89.497,70	1.694,95	16.601,14	124.446,85
Jumlah	164.731.577,61	14.738.554,28	25.541.432,40	863.522,08	3.692.822,94	209.567.909,31

**) Termasuk Pelumas*

***) Termasuk PLTMG*

Tabel 38 : Beban Usaha Pembangkit Rata-rata per kWh 2023

Jenis Pembangkit	Beban Usaha Rata-rata per kWh (Rp/kWh)***)						
	Bahan Bakar *)	Pemeliharaan	Penyusutan Aset	Lain-lain	Pegawai	Beban Bunga	Jumlah
P L T A	37,05	58,38	205,20	4,34	25,30	134,23	464,50
P L T U	532,27	81,34	112,85	3,84	15,48	41,10	786,88
P L T D **)	7.388,85	664,45	393,39	16,36	176,55	108,74	8.748,35
P L T G	743,58	143,83	220,27	10,26	27,69	93,33	1.238,95
P L T P	972,11	31,29	118,89	10,21	33,20	54,99	1.220,68
P L T G U	1.176,17	26,05	171,55	4,76	16,72	77,94	1.473,18
P L T S	0,00	1.296,53	6.967,90	131,96	1.292,49	1.930,77	11.619,66
Rata-rata	786,76	82,06	142,21	4,81	20,56	58,79	1.095,19

**) Termasuk Pelumas*

***) Termasuk PLTMG*

****) Biaya Operasi Pembangkit sendiri (Milik PLN) termasuk proyek*

Catatan : Tabel 38 adalah Biaya Operasi Pembangkit sendiri (milik PLN) termasuk dari proyek

Tabel 39 : Rasio Keuangan 2023

Indikator	Satuan	2023
I. Indikator Keuangan		
- Rasio Tunai	%	35,87
- Rasio Rentabilitas	%	1,45
- Rasio Solvabilitas	%	39,48
- Rasio Likuiditas	%	82,30
II. Financial Covenant *)		
- CICR	Kali	3,67
- Financial Liabilities to Total Assets	%	23,72
- EBITDA Interest Coverage Ratio	Kali	4,69
III. Aktivitas Operasi (Financial)		
- Perputaran Aset Tetap	Kali	0,22
- Umur Piutang Langganan	Hari	28,49
- Perputaran Piutang Langganan	Kali	12,81
- Perputaran Material	Kali	3,61

**) Perhitungan Financial Covenant berdasarkan laporan keuangan dengan mengecualikan dampak ISAK 8 sebagaimana dinyatakan dalam indenture Global Bonds dan Perjanjian Perwaliamanatan Local Bonds.*

Tabel 40 : Jumlah Pegawai Menurut Kelompok Peringkat 2023

Satuan PLN/Provinsi	08'	08	09	10	11'	11	12'	12	13'	13	14'	14	15	16	17'	17	18	19	20	21	23	25	Jumlah
UID Aceh	-	2	166	112	87	165	108	17	55	64	36	11	8	9	2	1	-	2	-	-	-	-	845
UID Sumatera Utara	-	18	163	144	192	277	217	28	121	88	48	18	24	8	3	1	2	2	-	-	-	1	1.355
UID Sumatera Barat	-	22	125	101	106	137	123	27	79	66	15	7	15	2	4	-	1	-	-	-	-	-	830
UID Riau & Kepulauan Riau	-	13	105	162	76	154	86	32	109	69	23	10	13	1	1	1	5	-	-	1	-	-	861
UID Sumatera Selatan, Jambi dan Bengkulu	-	11	126	78	168	205	161	34	94	72	28	11	17	7	3	1	5	1	-	-	-	-	1.022
UIW Bangka Belitung	-	1	95	20	38	83	43	11	22	21	11	2	11	5	1	-	1	1	-	-	-	1	367
UID Lampung	-	3	59	83	79	127	95	17	56	30	16	4	10	4	2	1	-	-	1	-	-	-	587
UID Kalimantan Barat	-	1	85	135	89	134	82	15	57	64	13	6	11	4	3	1	1	-	-	1	-	-	702
UID Kalimantan Selatan dan Tengah	-	1	155	127	71	151	81	32	58	77	36	8	13	4	2	-	1	2	-	-	-	-	819
UID Kalimantan Timur dan Utara	-	63	101	161	92	94	69	15	39	38	24	7	9	8	-	1	1	-	-	-	-	-	722
UID Sulawesi Utara, Tengah dan Gorontalo	-	-	235	157	117	182	118	25	85	49	20	9	9	4	4	-	1	1	-	1	-	-	1.017
UID Sulawesi Selatan, Tenggara dan Barat	-	130	203	204	129	313	162	21	58	106	30	17	25	2	2	2	-	3	-	-	-	-	1.407
UIW Maluku dan Maluku Utara	1	40	269	161	89	135	38	35	49	60	34	8	10	1	3	1	2	-	-	-	-	-	936
UIW Papua dan Papua Barat	1	112	247	228	116	170	63	35	79	43	9	9	13	2	-	1	2	1	-	-	-	-	1.131
UID Bali	-	-	46	67	57	116	84	14	102	59	15	6	14	2	3	-	4	1	1	1	-	-	592
UIW Nusa Tenggara Barat	-	38	206	91	122	117	72	23	110	48	12	7	9	5	2	1	-	1	-	1	-	-	865
UIW Nusa Tenggara Timur	-	67	215	126	73	124	78	36	85	41	22	10	12	3	3	-	-	-	1	-	-	-	896
PT PLN Batam	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	513
PT PLN Nusa Daya*)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	155
PT Mandau Cipta Tenaga Nusantara	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	34
UIP3B Sumatera	-	102	609	187	213	250	263	37	120	78	28	12	20	10	4	1	1	1	-	-	-	-	1.936
UIP3B Sulawesi	-	11	184	93	69	152	78	16	31	38	13	6	16	4	1	1	-	1	-	-	-	-	714
UIP3B Kalimantan	-	11	112	112	50	109	61	11	39	42	14	4	8	4	1	3	-	1	-	-	-	-	582
Luar Jawa	2	646	3.506	2.549	2.033	3.195	2.082	481	1.448	1.153	447	172	267	89	44	17	27	18	3	5	0	2	18.888
UID Jawa Timur	-	-	288	245	220	387	304	65	349	181	73	28	28	15	5	4	2	3	1	1	-	-	2.199
UID Jawa Tengah & Yogyakarta	-	43	174	181	177	376	224	62	198	180	59	16	23	11	6	7	5	3	1	-	-	-	1.746
UID Jawa Barat	-	29	230	234	188	540	304	45	140	177	91	23	19	10	5	1	2	4	-	1	-	-	2.043
UID Banten	-	1	47	95	87	174	140	19	63	62	21	11	13	4	2	-	2	-	-	1	-	-	742
UID Jakarta Raya	-	21	128	88	131	242	230	56	168	138	77	25	17	8	5	4	4	1	-	1	-	-	1.344
PLN Indonesia Power	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.393
PLN Nusantara Power	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.842
UIT JBB	-	50	235	101	96	170	114	12	132	99	28	9	14	1	1	2	1	-	-	-	-	-	1.065
UIT JBT	-	24	512	167	181	316	190	33	134	87	16	11	12	7	2	-	1	3	-	-	-	-	1.696
UIT JBTB	-	1	349	125	135	186	122	15	114	80	23	6	14	5	3	-	1	1	-	-	-	-	1.180
Unit Induk Pusat Pengaturan Beban	-	0	41	22	67	117	113	16	52	59	17	5	9	2	4	-	2	2	-	-	-	-	528
UIK Tanjung Jati B	-	-	2	1	3	12	17	2	13	5	3	6	3	3	2	-	1	1	-	-	-	-	74
Jawa	-	169	2.006	1.259	1.285	2.520	1.758	325	1.363	1.068	408	140	152	66	35	18	21	18	2	4	-	-	22.852
Kantor Pusat	-	11	56	88	332	330	1.249	127	345	278	168	115	266	105	59	34	89	60	37	25	22	11	3.807
PLN Pusat Jasa	-	3	28	50	223	280	369	75	210	154	60	25	54	19	21	9	14	12	5	4	-	-	1.615
Unit Induk Pembangunan	-	71	160	105	412	353	468	62	246	170	56	35	92	33	11	5	20	7	4	6	1	-	2.317
Anak Perusahaan lainnya	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.766
Indonesia	2	900	5.756	4.051	4.285	6.678	5.926	1.070	3.612	2.823	1.139	487	831	312	170	83	171	115	51	44	23	13	51.245

**) Sebelumnya adalah PT PLN Tarakan*

Tabel 41 : Jumlah Pegawai Menurut Jenjang Pendidikan 2023

Satuan PLN/Provinsi	≤ D1-D3	S1	S2	S3	Jumlah
UID Aceh	512	309	24	-	845
UID Sumatera Utara	727	595	33	-	1.355
UID Sumatera Barat	484	328	18	-	830
UID Riau & Kepulauan Riau	599	247	15	-	861
UID Sumatera Selatan, Jambi dan Bengkulu	571	419	32	-	1.022
UIW Bangka Belitung	225	130	12	-	367
UID Lampung	299	274	13	1	587
UID Kalimantan Barat	442	247	13	-	702
UID Kalimantan Selatan dan Tengah	487	310	22	-	819
UID Kalimantan Timur dan Utara	483	220	19	-	722
UID Sulawesi Utara, Tengah dan Gorontalo	652	347	18	-	1.017
UID Sulawesi Selatan, Tenggara dan Barat	754	623	30	-	1.407
UIW Maluku & Maluku Utara	736	191	9	-	936
UIW Papua & Papua Barat	862	257	12	-	1.131
UID Bali	344	222	26	-	592
UID Nusa Tenggara Barat	610	243	12	-	865
UID Nusa Tenggara Timur	698	189	9	-	896
PT PLN Batam	-	-	-	-	513
PT PLN Nusa Daya*)	-	-	-	-	155
PT Mandau Cipta Tenaga Nusantara	-	-	-	-	34
UIP3B Sumatera	1.253	651	32	-	1.936
UIP3B Sulawesi	396	304	14	-	714
UIP3B Kalimantan	331	236	15	-	582
Luar Jawa	11.465	6.342	378	1	18.888
UID Jawa Timur	1.182	956	61	-	2.199
UID Jawa Tengah & Yogyakarta	975	706	65	-	1.746
UID Jawa Barat	1.160	837	46	-	2.043
UID Banten	358	359	25	-	742
UID Jakarta Raya	687	610	47	-	1.344
PLN Indonesia Power	-	-	-	-	5.393
PLN Nusantara Power	-	-	-	-	4.842
UIT JBB	617	407	40	1	1.065
UIT JBT	1.050	608	38	-	1.696
UIT JBTB	795	346	39	-	1.180
Unit Induk Pusat Pengaturan Beban	180	310	38	-	528
UIK Tanjung Jati B	18	43	13	-	74
J a w a	7.022	5.182	412	1	22.852
Kantor Pusat	690	2.495	612	10	3.807
PLN Pusat Jasa	487	974	154	-	1.615
Unit Induk Pembangunan	876	1.328	113	-	2.317
Anak Perusahaan lainnya	-	-	-	-	1.766
I n d o n e s i a	20.540	16.321	1.669	12	51.245

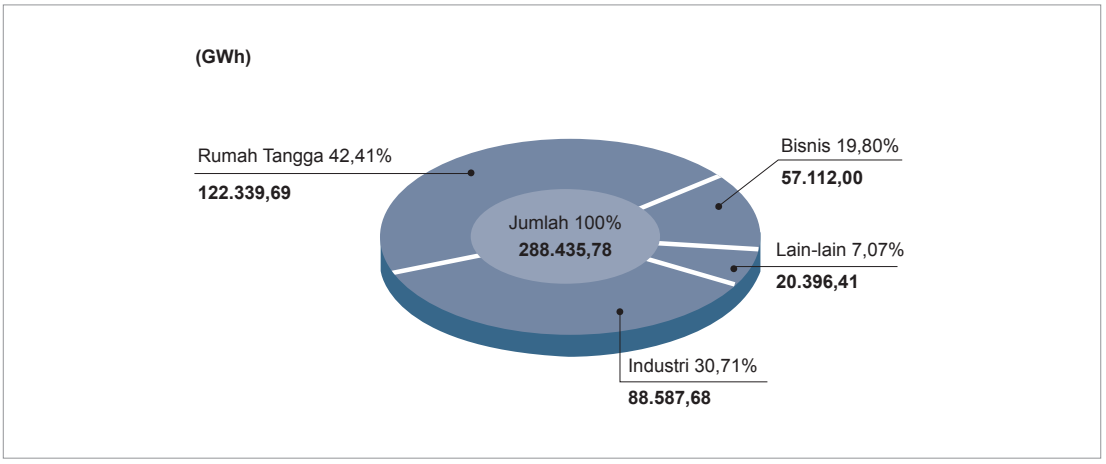
*) Sebelumnya adalah PT PLN Tarakan

Tabel 42 : Produktivitas Pegawai 2023

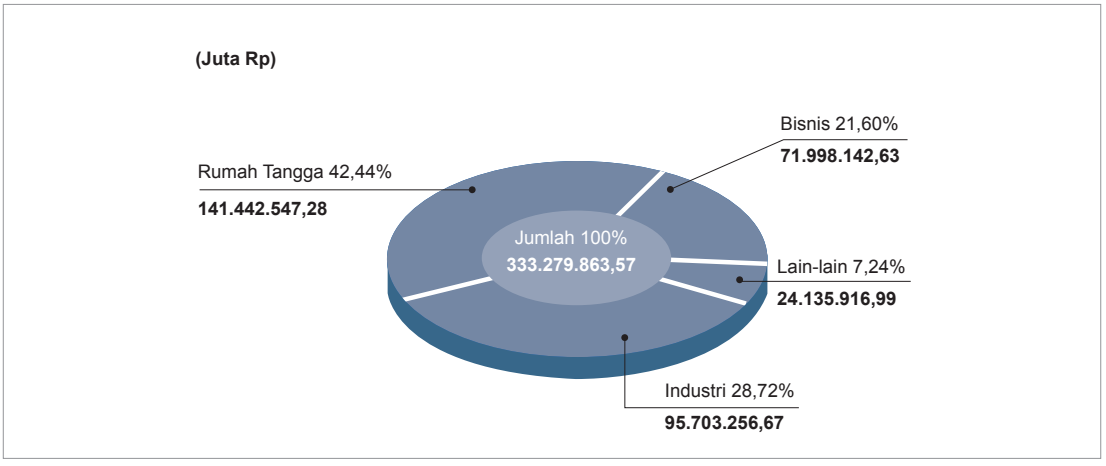
Satuan PLN/Provinsi	Pelanggan per Pegawai	kWh Terjual per Pegawai
UID Aceh	2.041	4.092.662,72
UID Sumatera Utara	3.294	9.205.047,97
UID Sumatera Barat	2.040	4.591.373,49
UID Riau dan Kepulauan Riau	2.915	10.699.372,82
UID Sumatera Selatan, Jambi dan Bengkulu	4.208	9.594.569,47
UIW Bangka Belitung	1.520	4.389.128,07
UID Lampung	4.489	9.815.860,31
UID Kalimantan Barat	2.165	4.713.091,17
UID Kalimantan Selatan dan Tengah	2.797	6.745.970,70
UID Kalimantan Timur dan Utara	2.065	7.017.894,74
UID Sulawesi Utara, Tengah dan Gorontalo	2.065	4.366.293,02
UID Sulawesi Selatan, Tenggara dan Barat	2.770	7.405.344,71
UIW Maluku dan Maluku Utara	847	1.765.042,74
UIW Papua dan Papua Barat	740	1.777.524,31
UID Bali	2.874	10.734.003,38
UIW Nusa Tenggara Barat	2.199	2.974.104,05
UIW Nusa Tenggara Timur	1.331	1.488.002,23
PT PLN Batam	719	6.256.900,58
PT PLN Nusa Daya*)	-	-
PT Mandau Cipta Tenaga Nusantara	-	-
UIP3B Sumatera	-	-
UIP3B Sulawesi	-	-
UIP3B Kalimantan	-	-
Luar Jawa	2.124	5.298.314,74
UID Jawa Timur	6.240	19.047.885,40
UID Jawa Tengah dan Yogyakarta	7.615	18.325.303,55
UID Jawa Barat	8.291	28.665.839,45
UID Banten	5.384	36.349.595,69
UID Jakarta Raya	3.888	27.524.069,94
PLN Indonesia Power	-	-
PLN Nusantara Power	-	-
UIK Tanjung Jati B	-	-
J a w a	4.215	15.567.118,97
Indonesia (Tanpa Anak Perusahaan)	2.304	7.400.394,12
PT Kantor Pusat	-	-
PLN Pusat Jasa	-	-
Unit Induk Pembangunan	-	-
Anak Perusahaan lainnya	-	-
I n d o n e s i a	1.740	5.628.564,35

**) Sebelumnya adalah PT PLN Tarakan*

Grafik 1. Energi Terjual per Kelompok Pelanggan (2023)

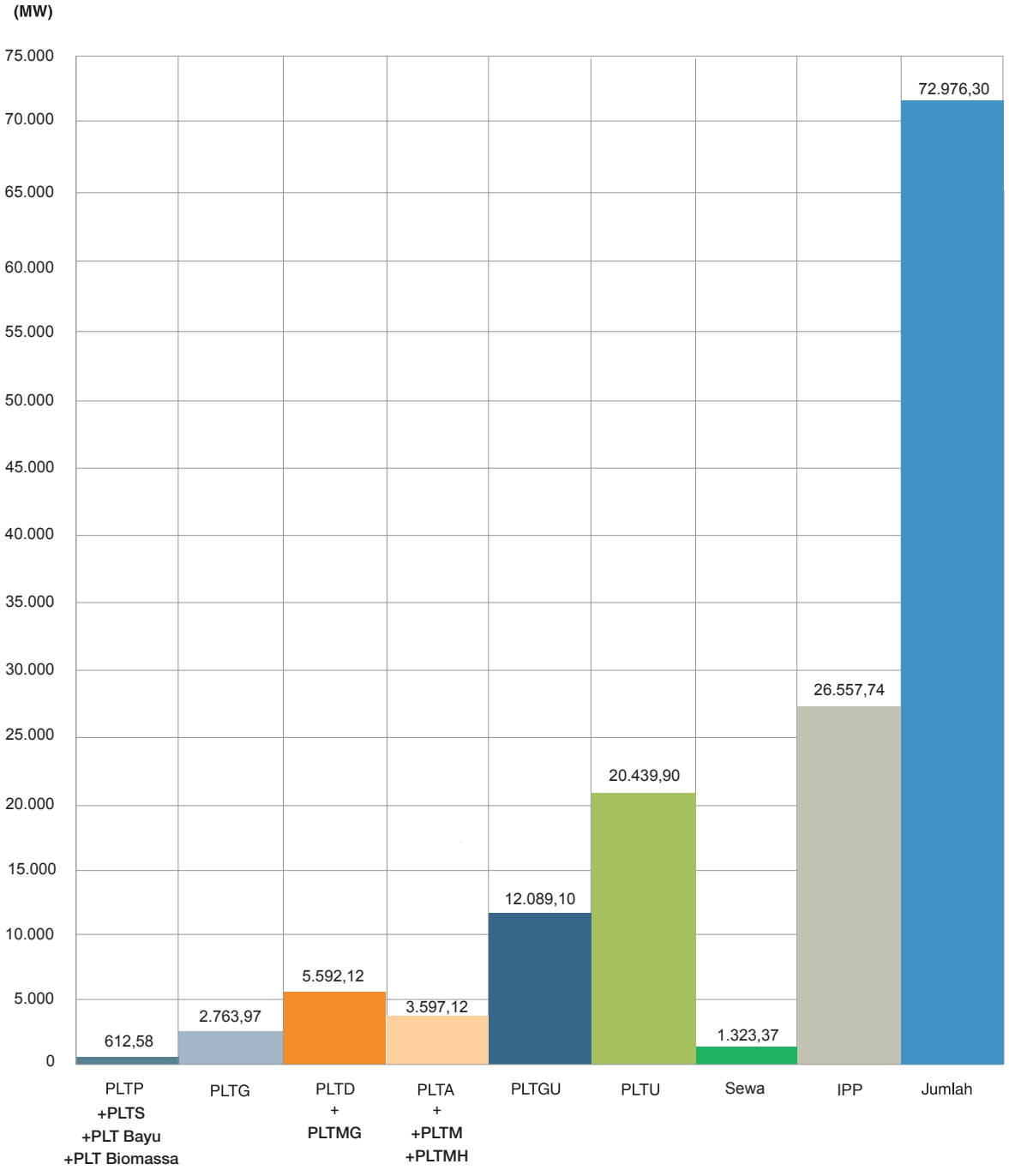


Grafik 2. Pendapatan (2023)

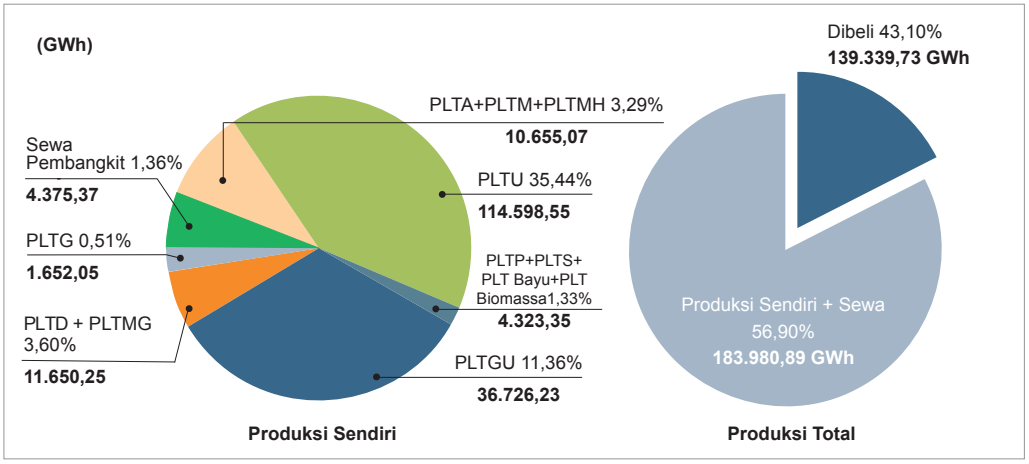


Catatan : Data diambil dari Aplikasi Pengelolaan Pelanggan Terpusat (AP2T)

Grafik 3. Kapasitas Terpasang (2023)



Grafik 4. Energi yang Diproduksi (2023)





DATA RUNTUN WAKTU 2015 - 2023

02

Tabel 43 : Faktor Beban, Faktor Kapasitas dan Faktor Permintaan (%) 2015 - 2023

Tahun	Faktor Beban	Faktor Kapasitas	Faktor Permintaan
2015	80,02	50,53	25,06
2016	62,62	51,92	49,55
2017	74,93	51,98	39,75
2018	78,64	52,73	37,20
2019	76,41	50,68	37,72
2020	78,32	49,54	34,61
2021	77,20	51,19	34,84
2022	84,11	50,93	32,28
2023	63,33	50,58	42,48

Tabel 44 : Jumlah Pelanggan per Kelompok Pelanggan 2015 - 2023

Tahun	Rumah Tangga	Industri	Bisnis	Sosial	Gdg. Kantor Pemerintah	Penerangan Jalan Umum	Jumlah	Δ %
2015	56.605.260	63.314	2.894.990	1.261.516	156.782	156.782	61.138.644	6,39
2016	59.243.672	69.629	3.239.764	1.354.010	169.478	205.940	64.282.493	5,14
2017	62.543.434	76.816	3.579.364	1.460.546	182.874	225.249	68.068.283	5,89
2018	66.071.133	88.185	3.750.666	1.559.997	198.113	249.303	71.917.397	5,66
2019	69.619.877	104.922	3.829.553	1.662.926	211.947	276.389	75.705.614	5,27
2020	72.606.681	130.722	4.001.917	1.746.074	218.408	296.231	79.000.033	4,35
2021	75.701.985	159.057	4.300.034	1.838.087	230.577	314.240	82.543.980	4,49
2022	78.327.897	179.553	4.640.585	1.920.615	236.629	330.919	85.636.198	3,75
2023	81.551.348	206.770	4.806.141	1.993.078	242.274	353.667	89.153.278	4,11

Tabel 45 : Daya Tersambung per Kelompok Pelanggan (MVA) **2015 - 2023**

Tahun	Rumah Tangga	Industri	Bisnis	Sosial	Gdg. Kantor Pemerintah	Penerangan Jalan Umum	Jumlah	Δ %
2015	51.654,89	25.024,02	22.477,28	3.861,60	2.560,54	1.003,90	106.582,23	6,55
2016	55.284,60	26.569,81	24.362,27	4.334,47	2.753,49	1.042,98	114.347,62	7,29
2017	59.257,37	27.584,67	26.197,72	4.897,48	2.979,73	1.100,66	122.017,63	6,71
2018	63.576,71	29.136,29	27.751,75	5.462,73	3.195,56	1.157,51	130.280,55	6,77
2019	67.877,52	30.433,91	29.180,45	5.993,45	3.360,50	1.230,70	138.076,53	5,98
2020	72.096,64	31.146,41	30.277,65	6.431,26	3.465,80	1.260,45	144.678,21	4,78
2021	76.566,84	33.151,51	31.974,04	6.954,42	3.624,93	1.294,22	153.565,96	6,14
2022	80.423,31	34.714,29	34.117,75	7.482,28	3.791,40	1.332,51	161.861,54	5,40
2023	85.318,86	36.698,11	36.060,99	8.066,67	3.989,14	1.374,66	171.508,42	5,96

Tabel 46 : Energi Terjual per Kelompok Pelanggan (GWh) **2015 - 2023**

Tahun	Rumah Tangga	Industri	Bisnis	Sosial	Gdg. Kantor Pemerintah	Penerangan Jalan Umum	Jumlah	Δ %
2015	88.682,13	64.079,39	36.978,05	5.940,98	3.717,16	3.448,11	202.845,82	2,14
2016	93.634,61	68.145,30	40.074,39	6.630,80	4.021,61	3.497,58	216.004,29	6,49
2017	94.457,38	72.238,37	41.694,79	7.095,37	4.121,26	3.526,55	223.133,72	3,30
2018	97.832,28	76.946,50	44.027,40	7.781,34	4.403,28	3.627,07	234.617,88	5,15
2019	103.733,43	77.878,65	46.901,25	8.621,83	4.750,29	3.632,71	245.518,17	4,65
2020	112.155,85	72.239,86	42.819,32	8.098,06	4.634,78	3.634,88	243.582,75	(0,79)
2021	115.370,05	80.904,45	44.440,85	8.665,99	4.707,97	3.544,95	257.634,25	5,77
2022	116.095,41	88.483,30	50.532,19	10.073,23	4.995,12	3.582,23	273.761,48	6,26
2023	122.339,69	88.587,68	57.112,00	11.496,10	5.285,12	3.615,19	288.435,78	5,36

Tabel 47 : Energi Terjual Rata-rata per Kelompok Pelanggan (kWh) 2015 - 2023

Tahun	Rumah Tangga	Industri	Bisnis	Sosial	Gdg. Kantor Pemerintah	Penerangan Jalan Umum	Jumlah
2015	1.567,00	1.012.089,00	12.773,00	4.709,00	23.709,00	18.526,00	3.454,00
2016	1.581,00	978.692,00	12.370,00	4.897,00	23.729,00	16.984,00	3.360,00
2017	1.510,00	940.408,00	11.649,00	4.858,00	22.536,00	15.656,00	3.278,00
2018	1.481,00	872.558,00	11.739,00	4.988,00	22.226,00	14.549,00	3.262,00
2019	1.490,00	742.252,82	12.247,19	5.184,73	22.412,63	13.143,47	3.243,06
2020	1.544,70	552.622,03	10.699,70	4.637,87	21.220,72	12.270,42	3.083,32
2021	1.524,00	508.650,67	10.335,00	4.714,68	20.418,21	11.281,03	3.121,18
2022	1.482,17	492.797,67	10.889,18	5.244,79	21.109,50	10.825,10	3.196,80
2023	1.500,15	428.435,85	11.883,13	5.768,01	21.814,64	10.222,02	3.235,28

Tabel 48 : Pendapatan per Kelompok Pelanggan (juta Rp) 2015 - 2023

Tahun	Rumah Tangga	Industri	Bisnis	Sosial	Gdg. Kantor Pemerintah	Penerangan Jalan Umum	Jumlah	Δ %
2015	74.228.270,00	73.225.020,00	47.485.994,00	4.826.716,00	4.923.417,00	5.155.124,00	209.844.540,00	12,44
2016	79.001.584,00	71.676.300,00	48.135.789,00	5.410.427,00	4.965.551,00	4.950.171,00	214.139.821,00	2,05
2017	99.747.380,00	78.652.788,00	51.935.757,00	5.827.691,00	5.269.214,00	5.154.027,00	246.586.856,00	15,15
2018	107.853.456,00	83.510.376,00	54.769.851,00	6.405.714,00	5.636.698,00	5.301.458,00	263.477.551,00	6,85
2019	114.009.150,67	85.696.114,71	59.196.245,28	7.164.127,64	6.135.914,18	5.315.507,93	277.517.060,40	5,33
2020	111.249.935,56	78.805.923,48	53.067.797,67	6.511.744,48	6.021.618,63	5.306.701,62	260.963.721,44	(5,96)
2021	118.139.629,65	87.880.138,90	54.870.079,54	6.987.979,19	6.086.666,66	5.129.814,60	279.094.308,54	6,95
2022	131.002.679,73	95.620.299,54	63.446.010,65	8.396.636,98	7.220.882,60	5.652.557,11	311.339.066,61	11,55
2023	141.442.547,28	95.703.256,67	71.998.142,63	9.564.544,40	8.392.360,09	6.179.012,50	333.279.863,57	7,05

Tabel 49 : Tarif Listrik Rata-rata per Kelompok Pelanggan (Rp/kWh) 2015 - 2023

Tahun	Rumah Tangga	Industri	Bisnis	Sosial	Gdg. Kantor Pemerintah	Penerangan Jalan Umum	Jumlah
2015	837,01	1.142,72	1.284,17	812,44	1.324,51	1.459,06	1.034,50
2016	843,72	1.051,82	1.201,16	815,96	1.234,72	1.415,31	991,37
2017	1.056,00	1.088,80	1.245,62	821,34	1.278,54	1.461,49	1.105,11
2018	1.102,43	1.085,30	1.243,99	823,21	1.280,11	1.461,64	1.123,01
2019	1.098,82	1.100,69	1.258,34	830,68	1.291,45	1.465,09	1.129,59
2020	991,92	1.090,89	1.239,34	804,11	1.299,22	1.459,94	1.071,36
2021	1.024,01	1.086,22	1.234,68	806,37	1.292,84	1.447,08	1.083,30
2022	1.128,40	1.080,66	1.255,56	833,56	1.445,59	1.577,94	1.137,26
2023	1.156,15	1.080,32	1.260,65	831,98	1.587,92	1.709,18	1.155,47

Tabel 50 : Jumlah Pelanggan per Jenis Tegangan 2015 - 2023

Tahun	Tegangan				Jumlah	Δ %
	Rendah	Menengah	Tinggi	Multiguna		
2015	61.052.745	115.077	80	78	61.167.980	6,39
2016	64.149.582	132.739	88	84	64.282.493	5,09
2017	67.922.448	145.742	93	-	68.068.283	5,89
2018	71.822.662	94.637	98	-	71.917.397	5,60
2019	75.600.176	105.337	101	-	75.705.614	5,27
2020	78.887.339	112.594	100	-	79.000.033	4,35
2021	82.419.243	124.627	110	-	82.543.980	4,49
2022	85.492.246	143.840	112	-	85.636.198	3,75
2023	89.024.231	128.920	127	-	89.153.278	4,11

Tabel 51 : Energi Terjual per Jenis Tegangan (GWh) 2015 - 2023

Tahun	Tegangan				Jumlah	Δ %
	Rendah	Menengah	Tinggi	Multiguna		
2015	123.076,75	66.825,79	12.654,35	288,94	202.845,83	2,14
2016	130.491,48	70.763,02	14.414,70	335,12	216.004,32	6,49
2017	133.030,86	73.495,63	16.607,23	-	223.133,72	3,30
2018	139.068,86	77.305,52	18.243,50	-	234.617,88	5,15
2019	147.692,30	80.301,73	17.524,10	-	245.518,13	5,03
2020	155.217,79	72.618,09	15.746,87	-	243.582,75	(0,79)
2021	160.365,97	78.719,41	18.548,88	-	257.634,25	5,77
2022	165.024,94	85.636,40	23.100,14	-	273.761,48	6,26
2023	175.583,63	90.132,35	22.719,80	-	288.435,78	5,36

Tabel 52 : Pendapatan per Jenis Tegangan (juta Rp) 2015 - 2023

Tahun	Tegangan				Jumlah	Δ %
	Rendah	Menengah	Tinggi	Multiguna		
2015	117.631.504,00	77.659.563,00	13.254.127,00	1.299.347,00	209.844.541,00	12,44
2016	123.459.196,00	75.683.817,00	13.954.290,00	1.042.518,00	214.139.821,00	2,05
2017	147.582.478,00	80.555.694,00	16.620.063,00	1.828.621,00	246.586.856,00	15,15
2018	158.754.942,00	84.596.718,00	18.232.665,00	1.893.225,00	263.477.551,00	6,85
2019	168.423.641,08	88.927.866,01	17.826.867,44	2.338.685,88	277.517.060,41	5,33
2020	163.202.835,59	79.422.038,12	15.893.150,12	2.445.697,60	260.963.721,43	(5,96)
2021	171.966.922,08	86.285.110,30	18.066.288,68	2.775.987,48	279.094.308,54	6,95
2022	191.472.215,14	95.255.648,83	21.714.574,73	2.896.627,91	311.339.066,61	11,55
2023	207.710.273,94	100.352.264,63	21.225.295,14	3.992.029,86	333.279.863,57	7,05

Tabel 53 : Pemakaian Sendiri dan Susut Energi **2015 - 2023**

Tahun	Pemakaian Sendiri *)		Susut Energi dan Pemakaian Sendiri					
			Transmisi		Distribusi		Jumlah	
	(GWh)	(%)	(GWh)	(%)	(GWh)	(%)	(GWh)	(%)
2015	8.258,56	4,67	5.248,08	2,33	16.810,27	7,62	22.589,01	10,00
2016	9.060,67	4,93	5.486,54	2,29	17.219,45	7,19	23.358,90	9,75
2017	9.233,26	5,50	5.865,60	2,39	15.619,45	6,53	22.147,47	9,02
2018	9.616,42	5,10	5.969,98	2,32	18.510,36	7,37	25.093,26	9,75
2019	9.910,95	5,12	6.073,34	2,26	19.006,53	7,24	25.822,86	9,60
2020	9.732,18	5,48	5.521,04	2,08	18.729,89	7,22	24.960,53	9,41
2021	9.959,33	5,44	5.501,33	1,97	18.519,97	6,77	25.143,66	9,00
2022	10.172,11	5,53	5.726,55	1,92	20.236,10	6,94	27.655,48	9,29
2023	9.998,01	5,43	6.284,73	2,01	20.569,14	6,71	28.773,22	9,18

**) Pemakaian sendiri untuk sentral*

Tabel 54 : Jumlah Unit Pembangkit *) **2015 - 2023**

Tahun	PLTA	PLTM	PLTMH	PLTU	PLTG	PLTGU	PLTP	PLTD	PLTMG	PLT Surya	PLT Bayu	PLTBm	Jumlah	Δ %
2015**)	232	-	-	114	72	65	15	4.655	-	58	7	-	5.218	4,21
2016	232	-	-	107	75	66	15	4.665	-	68	7	-	5.235	0,52
2017	240	-	-	104	97	69	15	4.801	-	57	6	-	5.389	2,94
2018	266	-	-	110	98	74	22	5.327	-	78	5	-	5.980	10,97
2019	243	-	-	133	68	73	18	5.350	-	96	5	1	5.987	0,10
2020	244	-	-	127	66	79	18	5.400	-	118	5	2	6.059	1,20
2021	162	12	72	126	66	79	18	5.258	193	150	5	2	6.143	1,39
2022	166	10	73	130	68	81	18	5.363	194	204	5	2	6.314	2,78
2023	56	106	91	135	63	90	18	5.428	189	263	5	2	6.446	2,06

**) Hanya pembangkit milik PLN*

Tabel 55 : Kapasitas Terpasang (MW) *) 2015 - 2023

Tahun	PLTA	PLTM	PLTMH	PLTU	PLTG	PLTGU	PLTP	PLTD	PLTMG	PLT Surya	PLT Bayu	PLTBm	Jumlah	Δ %
2015**)	3.566,15	-	-	21.117,15	2.981,31	8.894,11	550,89	3.175,79	-	8,86	0,99	-	40.295,25	11,89
2016	3.567,83	-	-	19.856,35	3.208,15	9.204,11	580,89	3.353,80	-	12,94	0,99	-	39.785,06	(1,26)
2017***)	3.583,15	-	-	19.530,50	3.075,83	9.022,54	550,89	3.880,02	-	7,98	0,88	-	39.651,80	(0,33)
2018	3.582,98	-	-	20.192,00	3.133,61	9.812,11	579,50	4.383,42	-	12,07	0,47	-	41.696,67	5,16
2019	3.583,98	-	-	20.750,50	3.188,90	10.708,76	579,50	5.029,31	-	14,65	0,47	-	43.856,58	5,18
2020	3.584,07	-	-	20.277,63	2.936,07	11.232,20	579,26	5.547,88	-	16,71	0,47	0,50	44.174,80	0,72
2021	3.504,42	37,68	45,62	20.365,00	2.936,07	11.408,00	579,26	3.532,61	2.033,77	21,34	0,47	0,50	44.464,75	0,66
2022	3.516,51	34,35	46,12	20.418,50	2.796,82	11.764,85	579,26	3.564,63	2.189,23	28,62	0,47	0,52	44.939,88	1,07
2023	3.142,85	409,43	44,84	20.439,90	2.763,97	12.089,10	579,26	3.521,21	2.071,31	32,33	0,47	0,52	45.095,19	0,12

*) Hanya pembangkit milik PLN

Tabel 56 : Daya Mampu (MW) *) 2015 - 2023

Tahun	PLTA	PLTM	PLTMH	PLTU	PLTG	PLTGU	PLTP	PLTD	PLTMG	PLT Surya	PLT Bayu	Jumlah	Δ %
2015**)	3.473,18	-	-	17.798,74	2.486,42	7.571,23	516,43	1.902,77	-	6,54	0,02	33.755,32	6,99
2016	3.410,62	-	-	17.811,40	2.669,80	7.754,23	523,28	2.292,49	-	9,28	0,30	34.471,39	5,33
2017	3.470,89	-	-	17.150,20	2.608,89	7.698,57	508,89	2.488,73	-	5,66	-	33.931,83	(1,57)
2018	3.471,05	-	-	17.138,73	2.605,46	8.937,52	541,54	2.750,86	-	7,20	0,08	35.452,44	4,48
2019	3.474,81	-	-	17.767,38	2.718,59	9.145,52	550,34	3.257,04	-	6,33	0,08	36.920,09	4,14
2020	3.511,37	-	-	17.714,10	2.404,59	10.036,51	550,34	3.844,82	-	11,73	0,08	38.073,54	3,12
2021	3.445,21	36,86	33,61	17.743,90	2.403,59	10.168,02	544,29	2.057,78	1.865,74	14,91	-	38.313,90	0,63
2022	3.456,01	33,76	33,67	17.755,40	2.267,62	10.276,05	545,10	2.012,59	2.015,97	22,64	0,02	38.418,81	0,27
2023	3.095,95	391,13	40,39	18.038,67	2.489,37	10.664,51	545,10	2.572,66	1.919,85	26,87	0,81	39.785,31	3,56

*) Hanya pembangkit milik PLN
**) Revisi daya mampu pembangkit

Tabel 57 : Energi yang Diproduksi (GWh) 2015 - 2023

Tahun	Dibangkitkan Sendiri														Dibeli *)	Jumlah	Δ %
	PLTA	PLTM	PLTMH	PLTU	PLTG	PLTGU	PLTP	PLTD	PLTMG	PLTBm	PLT Bayu	PLT Surya	Sewa Genset	Sub Jumlah			
2015	10.004,48	-	-	95.815,29	3.442,93	38.705,56	4.391,55	3.032,75	-	-	-	5,28	19.841,57	176.472,21	57.509,77	233.981,99	2,37
2016	13.885,59	-	-	97.153,33	3.871,76	41.908,11	3.958,10	3.062,34	2.612,37	-	5,85	-	17.351,52	183.808,97	64.801,55	248.610,52	6,25
2017	12.425,17	-	-	105.651,39	1.891,92	38.074,10	4.095,99	5.833,76	-	-	5,53	-	13.447,20	181.425,07	73.234,72	254.659,78	2,43
2018	10.728,68	-	-	113.902,01	3.210,32	38.762,01	4.012,81	7.573,83	-	-	4,21	-	10.504,60	188.698,46	78.386,92	267.085,38	4,88
2019	9.877,06	-	-	122.826,04	2.723,05	37.757,83	4.110,30	5.014,43	4.143,79	-	-	4,71	7.086,09	193.543,32	85.398,55	278.941,07	4,11
2020	11.948,81	-	-	114.284,12	2.360,16	30.097,84	4.186,37	3.043,16	6.696,28	-	-	5,57	5.070,12	177.692,43	97.158,74	274.851,17	(1,47)
2021	11.568,71	175,70	124,89	114.518,49	2.775,66	33.025,12	4.216,71	3.104,72	7.969,77	-	-	5,63	5.488,49	182.973,88	106.496,69	289.470,57	5,32
2022	12.874,20	172,79	128,02	115.316,09	2.145,76	32.945,45	4.138,19	3.209,67	8.556,26	-	-	9,09	4.323,52	183.819,03	124.183,27	308.002,30	6,40
2023	9.210,01	1.299,90	145,16	114.598,55	1.652,05	36.726,23	4.310,50	3.407,29	8.242,96	0,01	-	12,84	4.375,37	183.980,89	139.339,73	323.320,62	4,97

*) Termasuk proyek

Tabel 58 : Pemakaian Bahan Bakar 2015 - 2023

Tahun	Bahan Bakar Minyak (kilo liter)										Batu Bara (ton)	Gas Alam (MMSCF)	Biomass (ton)
	HSD	IDO	MFO	Bio Diesel	Olein	Bio HSD	HFO	Bio Fame	CPO	Jumlah			
2015	4.372.743	2.244	904.266	-	-	-	-	-	-	5.473.892	48.125.940	456.494	-
2016	3.331.125	915	947.027	-	-	-	-	-	-	4.667.032	50.556.446	505.125	-
2017	2.579.123	580	718.462	-	-	-	-	-	-	3.598.223	54.711.847	447.072	-
2018	2.780.973	28	946.516	-	-	-	-	-	-	4.055.804	60.481.245	465.419	-
2019	2.748.816	329	371.618	-	-	-	-	-	-	3.118.762	67.008.829	479.776	-
2020	2.503.318	26	166.602	-	-	-	-	-	-	2.669.946	66.683.392	378.246	9.731
2021	617.916	329	171.313	-	-	1.537.538	120.023	643.724	1	3.090.844	68.474.268	397.765	282.628
2022	380.155	104	176.213	-	-	1.694.279	18.353	718.807	-	2.987.910	70.444.162	381.620	585.705
2023	361.691	799	221.071	-	-	1.793.904	-	847.487	-	3.224.953	69.222.936	417.039	990.777

Catatan:
- Data pemakaian bahan bakar Bio HSD, HFO, Bio Fame, CPO mulai tahun 2019
- Nilai pemakaian bakar Bio HSD, HFO, Bio Fame dan CPO pada tahun 2019-2020 tergabung di HSD

Tabel 59 : Harga Satuan Bahan Bakar 2015 - 2023

Tahun	Bahan Bakar Minyak (Rp/liter) *)				Batu Bara	Gas Alam	Panas Bumi
	HSD	IDO	MFO	Rata-rata	(Rp/kg)	(Rp/MMSCF)	(Rp/kWh)
2015	6.951,23	6.400,37	5.086,56	6.395,47	662,46	105.917,94	748,71
2016	5.725,51	4.715,78	3.783,04	4.855,19	611,23	101.123,24	722,41
2017	7.239,41	5.639,44	5.358,30	6.259,85	782,61	106.480,22	737,81
2018	9.419,48	8.422,00	4.125,75	7.421,62	767,08	119.115,94	841,42
2019	7.854,87	7.039,06	6.427,18	7.568,67	766,60	115.521,08	828,71
2020	5.829,21	5.303,47	4.806,53	5.746,55	917,18	101.650,07	845,66
2021	7.206,85	5.952,44	6.846,57	7.841,61	763,65	88.104,56	831,85
2022	11.157,28	27.046,27	7.937,60	13.123,49	865,71	111.751,82	937,06
2023	14.390,62	13.137,85	8.277,16	14.490,83	1.027,42	106.206,48	522,32

**) Harga satuan BBM (HSD, IDO dan MFO) termasuk ongkos angkut dan harga biodiesel*

Tabel 60 : Panjang Jaringan Transmisi (kms) 2015 - 2023

Tahun	Tegangan					Jumlah	% Pertumbuhan
	25 - 30 kV	70 kV	150 kV	275 kV	500 kV		
2015	4,16	4.279,05	30.833,64	1.512,71	5.053,00	41.682,56	4,44
2016	60,33	4.669,32	32.423,02	1.856,48	5.056,27	44.065,42	5,72
2017	100,95	5.035,05	35.801,96	2.889,25	5.073,79	48.901,00	10,97
2018	100,95	5.341,98	39.304,50	3.312,47	5.218,38	53.278,27	8,95
2019	100,95	5.397,06	44.563,86	3.647,65	5.249,52	58.959,05	10,66
2020	100,95	5.655,64	46.680,19	3.647,65	5.249,74	61.334,18	4,03
2021	100,95	5.878,97	48.733,87	3.647,64	6.445,35	64.806,79	5,66
2022	100,95	5.910,21	51.395,60	3.828,11	6.970,92	68.205,81	5,24
2023	101,33	6.747,14	69.075,92	4.572,67	7.194,43	87.691,48	28,57

Tabel 61 : Panjang Jaringan Tegangan Menengah dan Tegangan Rendah (kms) 2015 - 2023

Tahun	Tegangan Menengah			Jumlah	Tegangan Rendah
	6 - 7 kV	10 - 12 kV	15 - 20 kV		
2015	5,36	3,12	342.970,50	342.978,98	500.119,41
2016	5,43	3,12	359.738,69	359.747,24	527.493,83
2017	-	-	373.825,50	373.825,50	546.595,79
2018	-	-	388.953,99	388.953,99	564.505,52
2019	-	-	401.421,90	401.421,90	578.433,47
2020	-	-	414.800,15	414.800,15	591.465,00
2021	-	-	423.807,51	423.807,51	598.316,55
2022	-	-	430.509,15	430.509,15	603.152,94
2023	-	-	438.900,17	438.900,17	609.282,99

Tabel 62 : Neraca (juta Rp) 2019 - 2023

Keterangan	2023	2022	2021	2020	2019
ASET TETAP					
- Jumlah A T	1.423.711.513	1.355.295.882	1.288.198.530	1.321.938.430	1.284.315.938
- Akumulasi Penyusutan	(106.761.876)	(62.939.849)	(33.792.415)	(95.020.433)	(70.853.977)
- Akumulasi Rugi Penurunan Nilai	(3.759.262)	(3.674.774)	(2.716.757)	(208.422)	(210.303)
Jumlah A T (Bersih)	1.313.190.376	1.288.681.259	1.251.689.358	1.226.709.575	1.213.251.658
P D P dan ATTB	135.780.245	144.367.723	175.369.000	175.178.912	187.433.460
Aset Hak Guna	30.574.504	29.005.193	29.762.537	31.193.985	-
Aset Tidak Lancar Lainnya	32.643.618	29.434.865	34.153.751	27.020.379	20.486.494
Piutang dari Pemerintah	-	2.587.938	18.254.891	17.275.490	-
Investasi pada Asosiasi dan Ventura Bersama	26.526.781	24.243.468	17.810.839	14.112.585	10.300.765
Aset Pajak Tangguhan	540.694	427.448	264.705	195.289	2.215.963
AKTIVA LANCAR					
- Kas & Bank	55.920.541	51.503.096	37.968.399	54.735.434	46.598.783
- Piutang dari Pemerintah	22.446.998	18.882.562	8.300.000	819.067	-
- Investasi Sementara	913.670	533.332	297.720	366.708	334.153
- Piutang Usaha	26.840.955	24.757.282	23.802.386	21.278.416	25.130.538
- Persediaan	17.862.312	17.534.804	10.393.419	10.277.289	12.934.233
- Aset Lancar Lainnya	7.399.010	6.180.306	5.149.451	9.751.591	66.368.966
Jumlah Aktiva Lancar	**131.383.486**	**119.391.382**	**85.911.375**	**97.228.505**	**151.366.673**
JUMLAH AKTIVA	**1.670.639.704**	**1.638.139.276**	**1.613.216.456**	**1.588.914.720**	**1.585.055.013**
MODAL	1.015.631.399	991.450.566	981.607.123	939.812.592	929.380.413
Jumlah Modal	1.015.631.399	991.450.566	981.607.123	939.812.592	929.380.413
LIABILITAS JANGKA PANJANG	511.812.872	501.617.259	485.070.853	499.472.600	496.376.447
- Liabilitas Pajak Tangguhan	58.228.739	48.427.461	45.576.375	31.746.600	28.121.540
- Pinjaman Jk Panjang	363.181.243	367.419.545	377.669.316	407.280.550	417.282.895
- Liabilitas Jk Panjang Lainnya	27.571.852	20.731.673	13.737.435	5.835.997	133.754
- Liabilitas Manfaat Pekerja	62.831.038	65.038.580	48.087.727	54.609.453	50.838.258
LIABILITAS JANGKA PENDEK	143.195.433	145.071.451	146.538.480	149.629.528	159.298.153
- Utang usaha	57.147.527	51.083.262	47.904.756	39.148.555	52.002.783
- Pinjaman Jk Pendek	33.037.450	41.565.592	41.537.787	43.319.666	35.935.599
- Liabilitas Jk Pendek Lainnya	45.128.076	43.111.481	46.774.944	58.201.596	66.127.304
- Liabilitas Manfaat Pekerja	7.882.380	9.311.116	10.320.993	8.959.711	5.232.467
Jumlah Liabilitas Jk Panjang & Jk Pendek	**655.008.305**	**646.688.710**	**631.609.333**	**649.102.128**	**655.674.600**
JUMLAH MODAL & LIABILITAS	**1.670.639.704**	**1.638.139.276**	**1.613.216.456**	**1.588.914.720**	**1.585.055.013**

Tabel 63 : L a b a R u g i (juta Rp) **2019 - 2023**

K e t e r a n g a n	2023	2022	2021	2020	2019
PENDAPATAN USAHA					
- Penjualan Tenaga Listrik	333.191.062	311.057.224	288.862.726	274.898.464	276.061.925
- Biaya Penyambungan	1.288.284	857.468	493.437	312.725	6.934.597
- Subsidi Pemerintah	68.636.731	58.831.960	49.796.949	47.988.114	51.711.774
- Pendapatan Kompensasi	73.991.897	63.649.821	23.392.162	17.904.508	22.253.517
- Lain - lain	10.276.090	6.735.470	4.426.733	4.311.826	2.644.067
Jumlah Pendapatan Operasi	**487.384.064**	**441.131.943**	**366.972.007**	**345.415.637**	**359.605.880**
BEBAN USAHA					
- Bahan Bakar & Minyak Pelumas	164.731.578	151.376.726	118.419.490	106.014.285	136.084.482
- Pembelian Tenaga Listrik *)	154.831.184	130.230.383	103.553.472	96.250.367	83.563.991
- Sewa	1.874.862	2.793.187	4.772.014	5.502.571	3.617.376
- Pemeliharaan	29.518.324	23.948.698	22.600.774	21.940.509	22.328.178
- Kepegawaian	32.355.934	24.884.860	25.092.756	24.965.707	25.908.771
- Penyusutan Aset Tetap	43.967.082	40.992.657	41.441.271	39.142.580	35.318.071
- Penyusutan Hak Guna	3.347.165	3.063.978	-	-	-
- Lain-lainnya	9.557.861	8.903.313	7.239.348	7.192.146	8.620.069
Jumlah Beban Usaha	**440.183.990**	**386.193.802**	**323.119.125**	**301.008.165**	**315.440.938**
LABA USAHA	47.200.074	54.938.141	43.852.882	44.407.472	44.164.942
Penghasilan (Beban) Lain-lain - Bersih	1.513.051	2.841.675	(3.719.419)	1.916.966	(3.667.666)
Keuntungan (Kerugian) Kurs Mata Uang Asing	3.723.639	(19.790.474)	2.676.145	(7.742.152)	9.486.326
Penghasilan Keuangan	953.515	687.495	787.231	1.125.519	755.103
Beban Keuangan	(21.010.355)	(17.135.165)	(20.375.755)	(27.415.886)	(24.619.495)
LABA (RUGI) SEBELUM PAJAK	**32.379.924**	**21.541.672**	**23.221.084**	**12.291.919**	**26.119.210**
BEBAN PAJAK PENGHASILAN	**(10.308.466)**	**(7.126.952)**	**(10.046.207)**	**(6.298.491)**	**(21.797.080)**
LABA TAHUN BERJALAN	**22.071.458**	**14.414.720**	**13.174.877**	**5.993.428**	**4.322.130**

Tabel 64 : Aset Tetap dan Penyusutan (juta Rp) 2019 - 2023

Tahun	Saldo	Akumulasi Penyusutan	Nilai Buku 2023
2019	1.433.688.124	(215.711.010)	1.217.977.114
2020	1.338.905.004	(102.773.842)	1.236.131.162
2021	1.275.858.119	(21.452.005)	1.254.406.114
2022	1.355.295.882	(62.939.849)	1.288.681.259
2023	1.423.711.513	(106.761.876)	1.313.190.376

Tabel 65 : Piutang Langganan (juta Rp) 2019 - 2023

Tahun	Umum	TNI & POLRI	Non TNI & POLRI	PEMDA	BUMN	Jumlah
2019	21.667.905,37	807.914,95	332.955,27	1.046.119,14	783.233,77	24.638.128,49
2020	18.955.712,94	960.996,15	283.989,82	855.399,46	491.381,49	21.547.479,86
2021	21.938.749,45	698.113,57	326.006,59	829.596,21	622.366,78	24.414.832,60
2022	22.681.906,97	662.136,52	395.637,22	1.000.014,22	656.233,13	25.395.928,06
2023	23.287.241,55	622.856,25	427.529,61	1.031.729,37	701.089,88	26.070.446,65

Tabel 66 : Penjualan, Piutang dan Kecepatan Rata-rata Penagihan Piutang 2019 - 2023

Tahun	Penjualan (Juta Rp)	Piutang (Juta Rp)	Rata-rata (hari)
2019	277.517.060,41	24.638.128,49	32,40
2020	260.963.721,43	21.547.479,86	30,14
2021	279.094.308,54	24.414.832,60	31,93
2022	311.339.066,61	25.395.928,06	29,77
2023	333.279.863,57	26.070.446,65	28,55

Tabel 67 : Biaya Operasi Pembangkit per Jenis Pembangkit (juta Rp) *) **2019 - 2023**

Tahun	PLTA	PLTU	PLTD	PLTG	PLTP	PLTGU	PLTS	Jumlah
2019	3.733.532,17	73.588.295,53	25.205.660,45	18.316.690,97	4.096.028,34	46.919.171,99	-	171.859.379,45
2020	3.251.636,89	66.240.919,95	17.214.040,78	14.595.312,58	4.272.648,63	35.826.463,19	48.797,69	141.401.022,03
2021	3.315.028,28	71.840.474,77	20.612.686,15	13.344.252,01	4.260.437,93	38.666.589,57	57.926,49	152.097.395,20
2022	3.696.716,16	81.130.541,42	33.977.586,28	19.274.125,14	4.710.965,74	45.024.836,49	76.923,38	187.891.694,60
2023	3.513.131,61	97.214.691,33	35.367.589,60	17.081.483,13	5.024.741,14	51.241.825,64	124.446,85	209.567.909,31

**) Biaya Operasi Pembangkit merupakan Biaya Pembangkit Milik Sendiri dan Proyek*

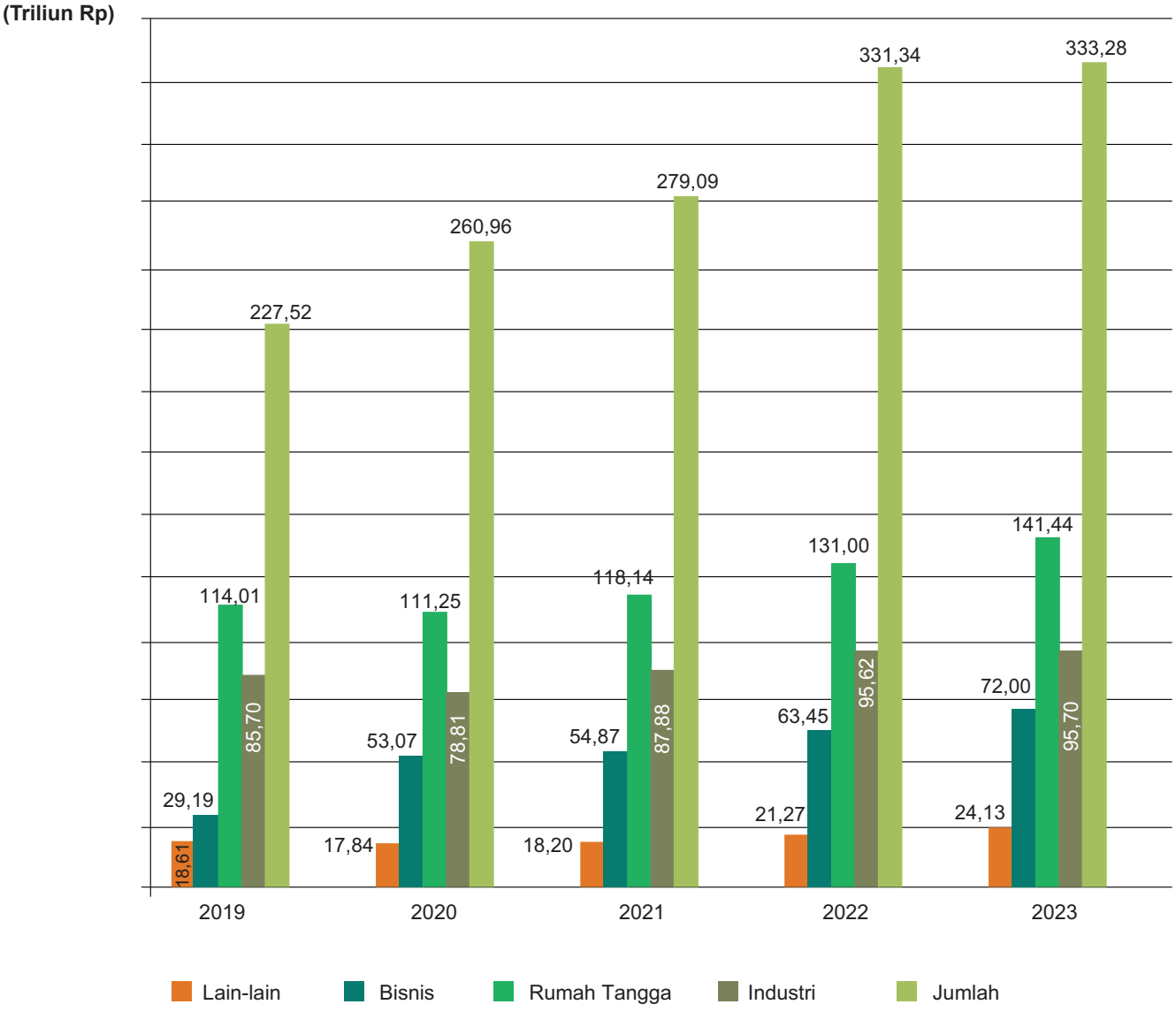
Tabel 68 : Biaya Pembangkitan Rata-rata (Rp/kWh) **2019 - 2023**

Tahun	PLTA	PLTU	PLTD	PLTG	PLTP	PLTGU	PLTS	Rata-rata
2019	599,71	653,12	3.308,26	2.570,03	1.191,25	1.357,75	-	2.999,73
2020	438,57	636,55	4.746,32	1.611,79	1.107,89	1.322,23	11.817,73	3.097,30
2021	398,28	667,88	5.905,80	1.247,92	107,15	126,09	1.284,44	1.391,08
2022	373,22	737,52	5.978,77	1.837,37	118,74	143,97	1.034,52	1.460,59
2023	464,50	786,89	8.748,35	1.238,95	1.220,69	1.473,18	11.619,66	1.095,19

Tabel 69 : Rasio Keuangan 2019 - 2023

Indikator	Satuan	2023	2022	2021	2020	2019
I. Indikator Keuangan						
- Rasio Tunai	%	35,87	35,87	26,11	36,82	0,29
- Rasio Rentabilitas	%	1,45	1,45	1,34	0,64	0,47
- Rasio Solvabilitas	%	39,48	39,48	39,15	40,90	41,37
- Rasio Likuiditas	%	82,30	82,30	58,63	64,92	95,02
II. Financial Covenant						
- CICR	Kali	3,67	4,43	3,03	2,74	3,11
- Financial Liabilities to Total Assets	%	23,72	24,97	25,52	27,75	28,65
- EBITDA Interest Coverage Ratio	Kali	4,69	5,89	4,38	3,16	3,32
III. Aktivitas Operasi (Financial)						
- Perputaran Aset Tetap	Kali	0,22	0,22	0,20	0,19	0,20
- Umur Piutang Langganan	Hari	28,49	28,49	28,48	30,89	32,35
- Perputaran Piutang Langganan	Kali	12,81	12,81	12,82	11,85	11,28
- Perputaran Material	Kali	3,61	3,61	3,80	3,16	5,02

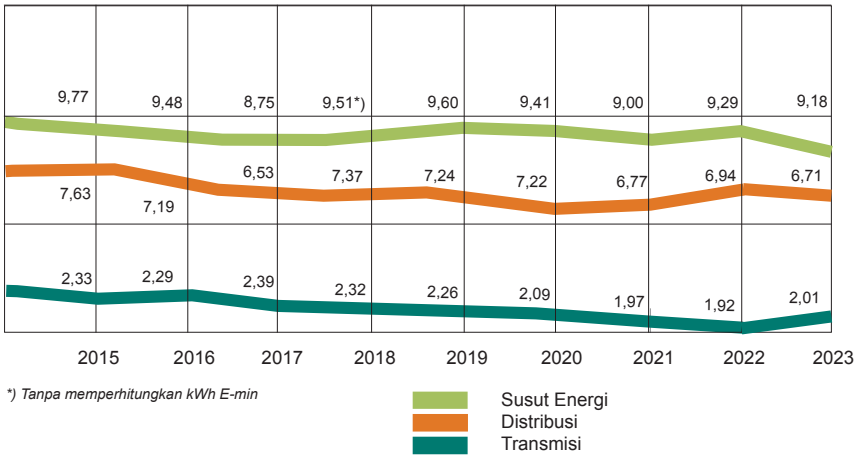
Grafik 5. Perkembangan Pendapatan (2019 - 2023)



Catatan: Data diambil dari Aplikasi Pelanggan Terpusat (AP2T)

Grafik 6. Perkembangan Susut Energi + PS (2015 - 2023)

(%)



*) Tanpa memperhitungkan kWh E-min



DATA REPELITA (KEADAAN AKHIR TIAP REPELITA)

03

Tabel 70 : Jumlah Pelanggan 2023

Jenis Pelanggan	Akhir REPELITA VI (1998)	2003*)	2008	2013	2018	Tahun 2023
- Rumah Tangga	24.902.763	29.997.554	36.025.071	50.116.127	66.071.133	81.551.348
- Industri	43.088	46.818	47.536	55.546	88.185	206.770
- Bisnis	847.940	1.310.686	1.716.046	2.418.431	3.750.666	4.806.141
- Lain-lain	639.698	796.358	1.055.433	1.406.104	2.007.413	2.589.019
Jumlah	26.433.489	32.151.416	38.844.086	53.996.208	71.917.397	89.153.278

**) Data meneruskan tahun REPELITA ke VI (1998)*

Tabel 71 : Laju Pertumbuhan Rata-rata Jumlah Pelanggan Per Tahun (%) 2023

Jenis Pelanggan	REPELITA VI *	1999/2003**)	2004/2008	2009/2013	2014/2018	2019/2023
- Rumah Tangga	10,97	3,79	3,73	6,85	5,69	4,30
- Industri	1,62	1,70	0,31	3,18	9,73	18,66
- Bisnis	11,89	9,16	5,67	7,14	9,20	5,11
- Lain-lain	8,94	4,48	5,80	5,92	7,39	5,23
Jumlah	10,93	3,99	3,86	6,83	5,90	4,39

**) s.d. akhir tahun 1999*
***) Data meneruskan tahun REPELITA ke VI (1998)*

Tabel 72 : Daya Tersambung (MVA) 2023

Jenis Pelanggan	Akhir REPELITA VI (1998)	2003*)	2008	2013	2018	Tahun 2023
- Rumah Tangga	15.887,50	22.467,94	29.334,55	45.214,25	63.576,71	85.318,86
- Industri	10.698,91	12.413,55	14.531,35	21.544,30	29.136,29	36.698,11
- Bisnis	5.665,04	7.824,56	11.941,56	19.931,50	27.751,75	36.060,99
- Lain-lain	2.344,39	2.884,01	4.278,07	6.404,80	9.815,80	13.430,47
Jumlah	34,595.84	45,590.06	60,085.53	93,094.85	130,280.55	171,508.42

**) Data meneruskan tahun REPELITA ke VI (1998)*

Tabel 73 : Laju Pertumbuhan Rata-rata Daya Tersambung per Tahun (%) 2023

Jenis Pelanggan	REPELITA VI *	1999/2003**)	2004/2008	2009/2013	2014/2018	2019/2023
- Rumah Tangga	11,93	7,19	5,48	9,07	7,05	6,06
- Industri	5,90	3,03	3,21	8,29	6,24	4,73
- Bisnis	14,20	6,68	8,83	10,84	6,85	5,38
- Lain-lain	5,43	4,26	8,22	8,43	8,92	6,47
Jumlah	9,73	5,68	5,68	9,19	6,95	5,65

*) s.d. akhir tahun 1999
**) Data meneruskan tahun REPELITA ke VI (1998)

Tabel 74 : Energi Terjual (GWh) 2023

Jenis Pelanggan	Akhir REPELITA VI (1998)	2003*)	2008	2013	2018	Tahun 2023
- Rumah Tangga	24.865,45	35.753,05	50.184,17	77.210,71	97.832,28	122.339,69
- Industri	27.995,54	36.497,25	47.968,85	64.381,39	76.946,50	88.587,68
- Bisnis	8.655,96	13.223,84	22.926,29	34.498,38	44.027,40	57.112,00
- Lain-lain	3.744,46	4.966,81	7.939,50	11.450,53	15.811,69	20.396,41
Jumlah	65.261,41	90.440,95	129.018,81	187.541,01	234.617,87	288.435,78

*) Data meneruskan tahun REPELITA ke VI (1998)

Tabel 75 : Laju Pertumbuhan Rata-rata Energi yang Terjual per Tahun (%) 2023

Jenis Pelanggan	REPELITA VI *	1999/2003**)	2004/2008	2009/2013	2014/2018	2019/2023
- Rumah Tangga	13,25	7,61	7,02	9,01	4,88	4,60
- Industri	8,54	5,54	5,65	6,19	3,69	3,09
- Bisnis	17,04	8,90	11,66	8,54	5,02	5,67
- Lain-lain	7,61	5,87	9,94	7,60	6,68	5,35
Jumlah	11,09	6,79	7,38	7,79	4,59	4,25

*) s.d. akhir tahun 1999
**) Data meneruskan tahun REPELITA ke VI (1998)

Tabel 76 : Susut Energi (%) 2023

Fungsi	Akhir REPELITA VI (1998)	2003**)	2008	2013	2018	Tahun 2023
Transmisi	2,35	2,46	2,17	0,92	2,32	2,01
Distribusi	9,99	14,41	8,29	3,00	7,37	6,71
Jumlah	12,34	16,88	10,67	4,03	9,75	8,57

***) Data meneruskan tahun REPELITA ke VI (1998)*

Tabel 77 : Kapasitas Terpasang (MW) 2023

Jenis Pembangkit	Akhir REPELITA VI (1998)	2003**)	2008	2013	2018	Tahun 2023
- PLTA	3.006,76	3.167,93	3.504,28	3.519,49	3.582,98	3.597,12
- PLTU	6.770,60	6.900,00	8.764,00	15.554,00	20.192,00	20.439,90
- PLTG	1.347,41	1.224,72	2.496,69	2.893,88	3.133,61	2.763,97
- PLTGU	6.560,97	6.863,22	7.370,97	8.814,11	9.812,11	12.089,10
- PLTP	360,00	380,00	415,00	568,00	579,50	579,26
- PLTD*)	2.535,02	2.670,42	3.042,72	2.847,78	4.383,42	5.592,52
- PLT Surya	-	-	-	7,94	12,07	32,33
- PLT Bayu**)	-	-	0,26	0,42	0,47	0,47
- PLT Biomas	-	-	-	-	-	0,52
Jumlah	20.580,76	21.206,29	25.593,92	34.205,63	41.696,67	45.095,19

**) Kapasitas Terpasang PLTD termasuk PLTMG*
***) Data meneruskan tahun REPELITA ke VI (1998)*

Tabel 78 : Laju Pertumbuhan Rata-rata Kapasitas Terpasang per Tahun (%) 2023

Jenis Pembangkit	REPELITA VI *	1999/2003****)	2004/2008	2009/2013	2009/2013	2019/2023
- PLTA	5,81	1,06	2,11	0,09	0,36	0,08
- PLTU	6,59	0,38	5,13	12,58	5,77	0,26
- PLTG	7,58	(1,27)	19,34	3,70	1,69	(2,42)
- PLTGU	11,20	1,00	1,62	3,90	2,23	4,30
- PLTP	11,25	1,11	1,80	6,90	0,50	(0,01)
- PLTD	3,88	1,09	2,71	(0,60)	9,20	5,19
- PLTMG **)	-	-	-	-	-	-
- PLT Bayu***)	-	-	32,00	53,08	12,20	-
- PLT Surya	-	-	-	195,90	14,08	22,04
Jumlah	7,48	0,60	3,89	6,06	4,13	1,60

**) s.d. akhir tahun 1999*
***) Sejak tahun 2004*
****) Sejak tahun 2007*
*****) Data meneruskan tahun REPELITA ke VI (1998)*

Tabel 79 : Energi yang Diproduksi (GWh) 2023

Jenis Pembangkit	Akhir REPELITA VI (1998)	2003*)	2008	2013	2018	2023
Diproduksi sendiri :						
- PLTA	9.649,00	8.472,16	10.739,97	13.009,55	10.728,68	10.655,07
- PLTU	30.512,37	42.178,01	52.352,96	80.926,10	113.902,01	114.598,55
- PLTG	1.395,50	2.486,25	5.310,75	5.916,51	3.210,32	1.652,05
- PLTGU	24.940,78	28.409,31	35.730,72	36.423,42	38.762,01	36.726,23
- PLTP	2.616,80	2.958,63	3.390,66	4.345,09	4.012,81	4.310,50
- PLTD	5.306,55	5.541,39	5.704,52	3.212,13	7.573,83	3.407,29
- PLTMG	-	-	110,24	381,75	-	8.242,96
- PLT Bayu	-	-	-	5,48	4,21	-
- PLT Biomass	-	-	-	-	-	0,01
- PLT Surya	-	-	-	-	-	12,84
- Sewa Genset	543,61	2.435,17	4.706,94	19.745,72	10.504,60	4.375,37
Sub Jumlah	74.964,61	92.480,92	118.046,84	163.965,75	188.698,46	183.980,89
Dibeli	2.938,76	20.538,76	31.389,66	52.222,79	78.386,92	139.339,73
Jumlah Produksi	77.903,37	113.019,68	149.436,51	216.118,54	267.085,38	323.320,62

**) Data meneruskan tahun REPELITA ke VI (1998)*

Tabel 80 : Laju Pertumbuhan Rata-rata Energi yang Diproduksi per Tahun (%) 2023

Produksi	REPELITA VI *	1999/2003****)	2004/2008	2009/2013	2014/2018	2019/2023
Produksi Sendiri :						
- PLTA	3,11	(1,98)	5,39	8,07	(1,99)	0,85
- PLTU	8,05	6,82	4,56	9,30	7,12	0,23
- PLTG	(8,61)	14,56	21,49	5,16	(2,75)	(11,32)
- PLTGU	24,15	2,72	4,83	0,77	1,42	(0,38)
- PLTP	17,30	2,73	2,85	5,42	(1,46)	1,46
- PLTD	3,66	0,98	(20,10)	(10,36)	23,45	(12,31)
- PLTMG **)	-	-	(1,82)	94,60	(3,04)	16,86
- PLT Bayu***)	-	-	(20,00)	1481,62	(25,87)	(20,00)
- PLT Biomass	-	-	-	-	-	-
- PLT Surya ***)	-	-	-	60,00	(24,49)	24,41
- Sewa Genset	-	40,48	15,65	35,38	(10,97)	(14,55)
Sub Jumlah	10,44	4,31	5,01	6,83	2,89	(0,42)
Dibeli	23,86	51,15	8,98	10,98	8,54	12,23
Jumlah Produksi	10,92	7,75	5,75	7,67	4,34	3,93

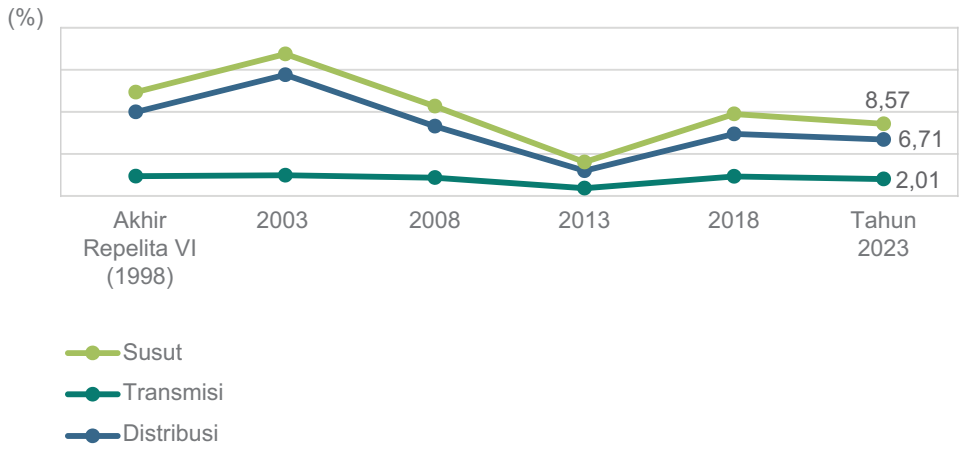
**) s.d. akhir tahun 1999*

***) Sejak tahun 2004*

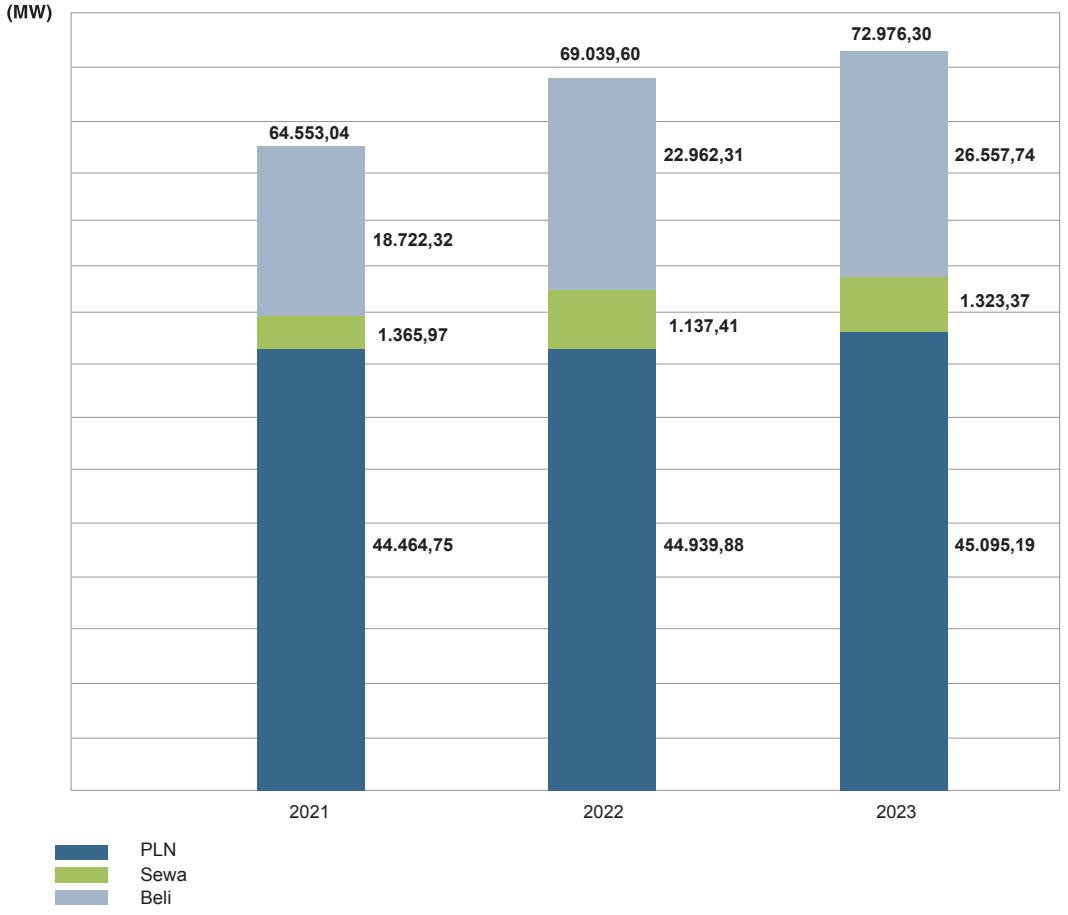
****) Sejak tahun 2007*

*****) Data meneruskan tahun REPELITA ke VI (1998)*

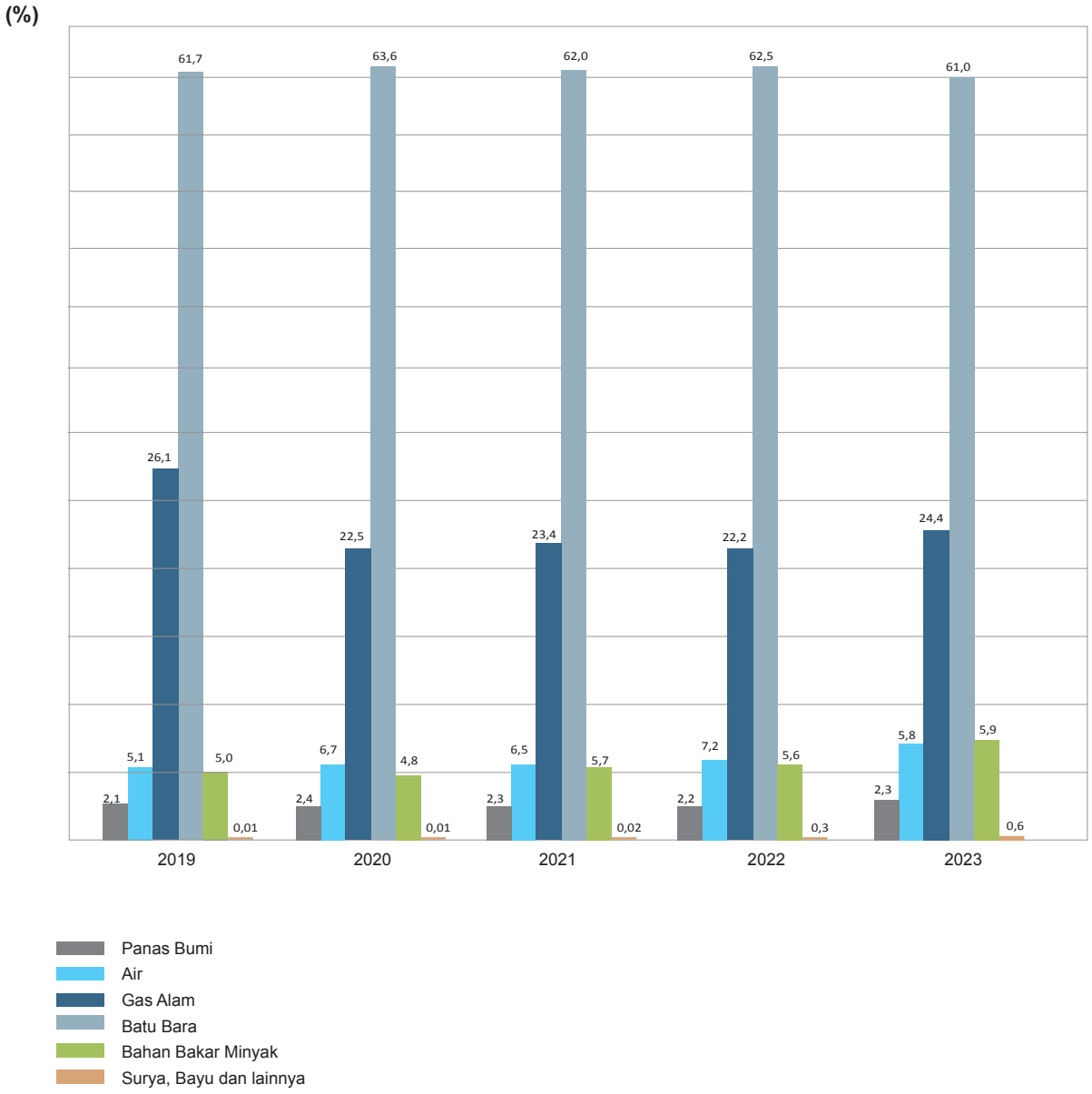
Grafik 7. Perkembangan Susut Energi



Grafik 8. Kapasitas Terpasang Nasional

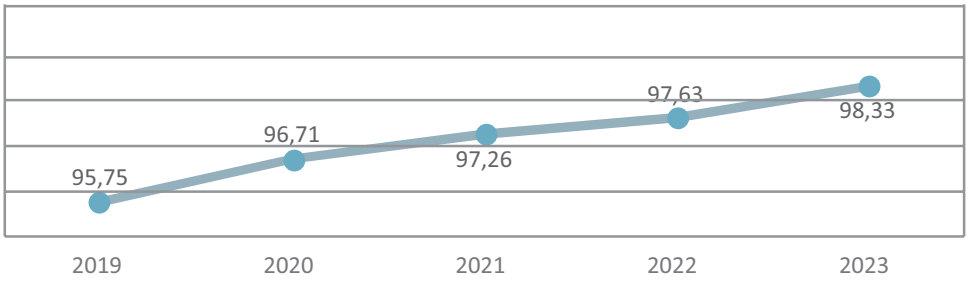


Grafik 9. Bauran Energi Tahun 2019 - 2023



Grafik 10. Rasio Elektrifikasi *)

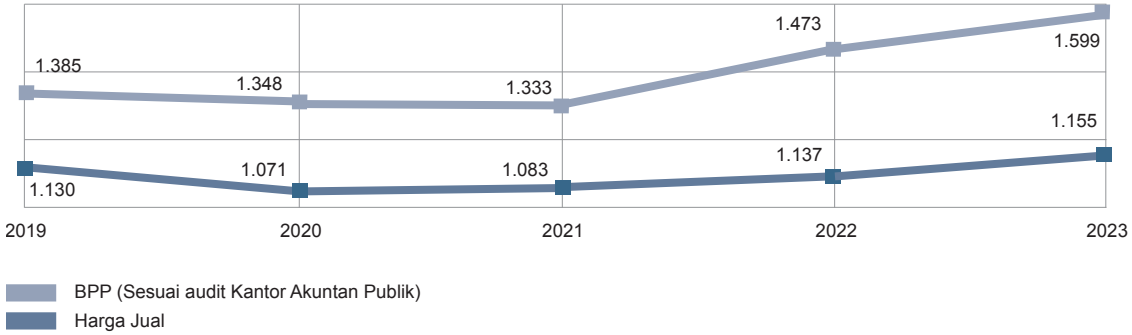
(%)



*) Tidak termasuk pelanggan Non-PLN

Grafik 11. Biaya Pokok Penyediaan Tenaga Listrik (BPP) dan Tarif Listrik Rata-rata

(Rp/kWh)



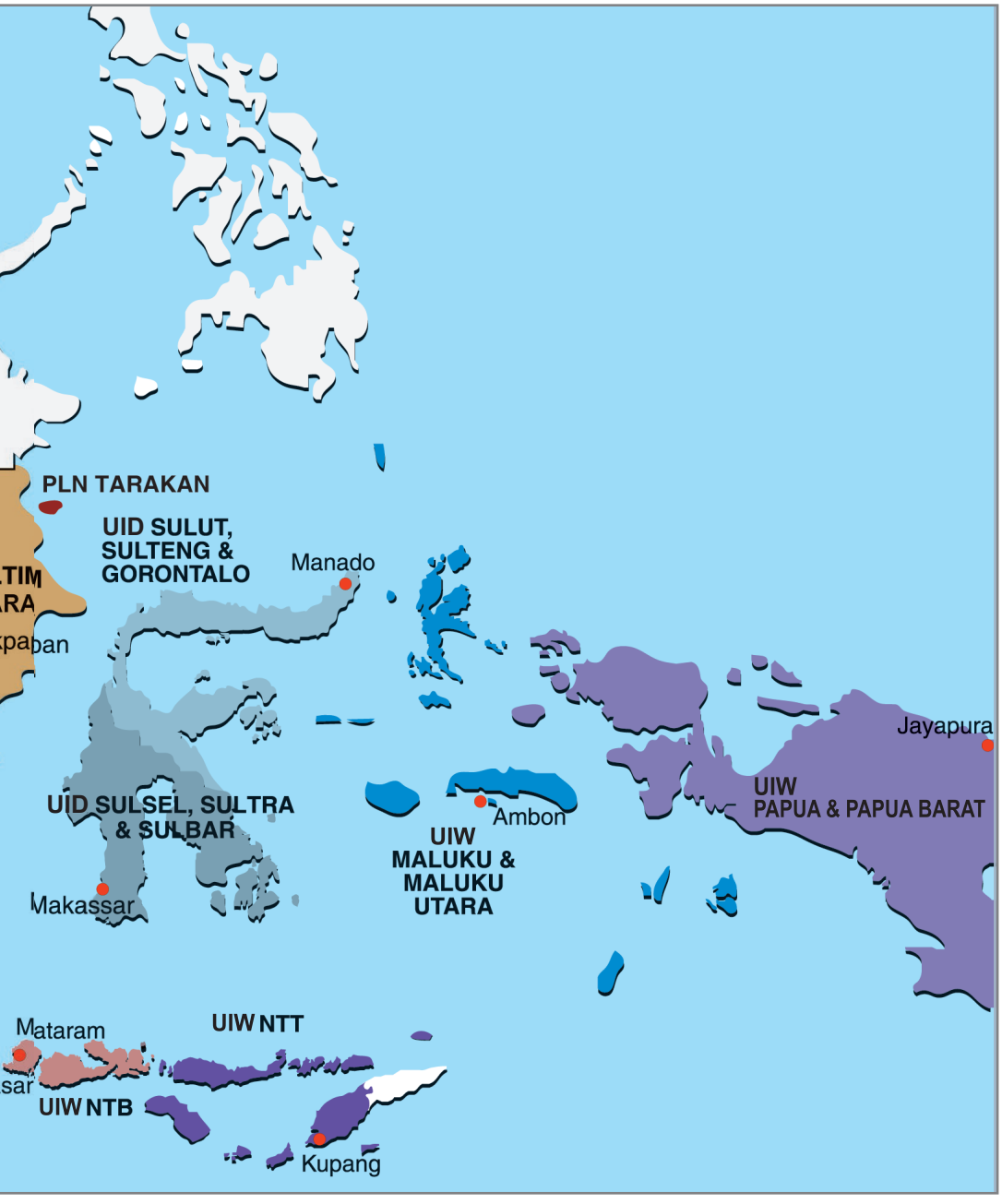


WILAYAH KERJA & LETAK KANTOR WILAYAH PLN

04

Wilayah Kerja dan Letak Kantor Wilayah PLN




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Manado
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Makassar
Ambon
UIW MALUKU & MALUKU UTARA
Jayapura
UIW PAPUA & PAPUA BARAT
Mataram
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Kupang

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Review

A Review of Photovoltaic Module Failure and Degradation Mechanisms: Causes and Detection Techniques

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Abstract: With the global increase in the deployment of photovoltaic (PV) modules in recent years, the need to explore and understand their reported failure mechanisms has become crucial. Despite PV modules being considered reliable devices, failures and extreme degradations often occur. Some degradations and failures within the normal range may be minor and not cause significant harm. Others may initially be mild but can rapidly deteriorate, leading to catastrophic accidents, particularly in harsh environments. This paper conducts a state-of-the-art literature review to examine PV failures, their types, and their root causes based on the components of PV modules (from protective glass to junction box). It outlines the hazardous consequences arising from PV module failures and describes the potential damage they can bring to the PV system. The literature reveals that each component is susceptible to specific types of failure, with some components deteriorating on their own and others impacting additional PV components, leading to more severe failures. Finally, this review briefly summarises PV failure detection techniques, emphasising the significance of electrical characterisation techniques and underlining the importance of considering more electrical parameters. Most importantly, this review identifies the most prevalent degradation processes, laying the foundation for further investigation by the PV research community through modelling and experimental studies. This allows for early detection by comparing PV performance when failures or degradation occur to prevent serious progression. It is worth noting that most of the studies included in this review primarily focus on detailing failures and degradation observed in PV operations, which can be attributed to various factors, including the manufacturing process and other external influences. Hence, they provide explanations of these failure mechanisms and causes but do not extensively explore corrective actions or propose solutions based on either laboratory experiments or real-world experience. Although, within this field of study, there are corresponding studies that have designed experiments to suggest preventive measures and potential solutions, an in-depth review of those studies is beyond the scope of this paper. However, this paper, in turn, serves as a valuable resource for scholars by confining PV failures to critically evaluate available studies for preventative measures and corrective actions.

Keywords: PV module failure; PV module degradation; failure detection; degradation monitoring; failure mechanisms; degradation mechanisms; PV module lifetime

check for updates

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1. Introduction

Among different renewable energy sources, solar energy is the most prevalent renewable source in most regions of the world due to its cost-effective implementation and simple installation [1]. The cost of photovoltaic (PV) systems has declined rapidly over time [2]. Between 1990 and 2020, Germany's PV investment for a 10 kW system dropped by nearly

92.6% from EUR 14,000 to EUR 1036 per kW [3]. In the U.S., the decline in the wholesale price for multi-crystalline modules was roughly 95% between 2008 and 2018. Figure 1 shows the average annual addition of solar energy over other renewable energy sources for the past three years.

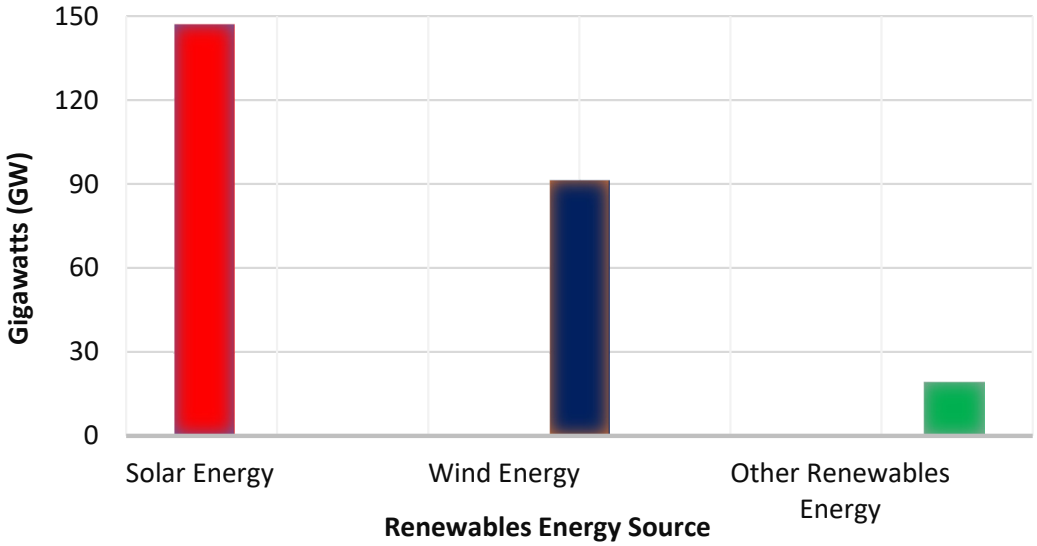


Figure 1. Average annual renewable capacity addition of renewable energy sources between 2020 and 2022 [4].

The conversion efficiency of the solar cell has progressed rapidly [5]; nowadays, it converts nearly 26% of the solar spectrum within the wavelength range from 350 nm to 1150 nm into electrical energy [6]. PV cells are serially connected to maximise energy production. Then, they are packaged into modules using a polymer coating, the encapsulant, and covered by a protective layer, predominantly made from glass [7,8]. After being encapsulated, the PV module is ready to use and guaranteed by manufacturers to have a 25-year lifetime with an expected degradation rate of 0.8% of power per annum [9–11]. This degradation rate was derived following extensive experimental studies and assessments that have been conducted. That is, failures found in previously deployed PV modules, such as encapsulant and solar cell defects, prompted the development of these studies. For instance, the National Renewable Energy Laboratory (NREL) developed accelerated stress tests to examine degradation rates, validating the superior quality and long-term reliability of PV modules [12]. However, despite these measures, there are still reports of abnormal degradation rates in PV modules due to a variety of failures. Abnormal degradation rates dramatically reduce reliability and increase the cost of PV operation. Harsh weather conditions and manufacturing defects are among the major factors influencing degradation rates. Consequently, higher degradation rates pose a barrier to favouring PV applications over other energy sources [13,14].

The need to review PV failures and degradation has encouraged researchers to engage in comprehensive research investigating and analysing experiments and real-world industry studies available in the literature. Köntges et al. [15] reviewed PV failures based on their emergence in the operational life cycle. Jordan and Kurtz [16] reviewed PV failures based on a severity scale, where Scale 1 referred to no effect on the PV system and Scale 10 referred to destructive effects on PV power that pose safety risks. Madeti and Singh [17] differentiated between reversible PV failures (temporary) such as shading from snow covering or dust accumulation and irreversible failures (permanent) such as encapsulant discolouration, reviewing applicable detection techniques on the DC and AC sides of the PV system. Pillai and Rajasekar [18] focused on detection techniques for PV failures and segregated failures based on their occurrence due to environmental stress factors and electrical (e.g., line to line, line to ground) and physical appearance, whether damaging the PV module or the

connected devices and accessories. A recent review by Osmani et al. [19] followed a similar direction as Pillai and Rajasekar [18], focusing more on detection techniques with limited exposure to the failure mechanisms occurring on the PV module. Despite the solid analysis in the aforementioned published reviews [15–19], the literature still lacks an in-depth state-of-the-art review that provides detailed information on failures encountered in the PV module itself and its components (from protective glass to backsheet), exploring their mechanisms and root causes.

In response, the review in this paper takes a different approach from other reviews by exploring and illustrating PV failures and degradation mechanisms based on PV module components. This review begins by evaluating the degradation rates reported in the literature in Section 1. In Section 2, it focuses on PV module failures and degradation mechanisms based on PV module components, incorporating a discussion and observation to identify the root causes of their occurrence and raise awareness of their consequences on safety and energy loss. Sections 3 and 4 provide a brief survey of the classification categories of PV failures and how they are affected by environmental stressors. This review concludes by discussing common detection techniques for PV failure and degradation mechanisms in Section 6. Future directions are proposed to explore available solutions and corrective actions to ensure the reliable and safe operation of PV generation, assisting PV investors in reducing revenue loss.

1.1. Degradation Rate

A study by Jordan et al. [20] examined PV modules that operated for 20 years and found the degradation rate was within the normal range; a 0.8% drop in the rated power per annum. However, several studies, e.g., [21–25], found that the degradation rate might vary depending on many factors such as material properties, environmental stress, installation, design and type of connections, and whether the PV system is connected to the electrical grid or standalone. Another study by Jordan et al. [26] examined several degradation rates from 40 countries; the findings agreed with [21–24] in that these factors significantly affect the degradation rate. It can be noted from Colvin et al. [27] that the median degradation rate of grid-connected PV systems was higher than that of standalone PV systems deployed in the years before 2000, but became lower after 2000. In addition, these factors were also described by Köntges et al. [15], including damage during transportation, which was found to degrade the PV module more rapidly.

Degradation rates of more than 1% per annum have been reported across PV modules deployed in India [28]. Previous to this, Quansah et al. [29] monitored PV modules that operated for 16 years in northern Ghana, particularly off-grid-connected, monocrystalline systems, and found that the annual degradation rate reached 1.54%. The average temperature of north Ghana could reach 30 °C, combined with an intermediate humidity level of 43%, which is close to the weather conditions in India. Degradation rates within these ranges represent double the expected loss in potential power generation. Table 1 lists the reported degradation rates from some recent studies.

Table 1. Degradation rates of PV systems reported within the last two years.

Degradation Rate	Type of PV (Poly-Si, Mono-Si)	Connection (Grid or Standalone)	Lifetime (Years)	Weather Condition	Country	Ref.
Between 0.9% and 1.1%. The rate increased to up to 5.9% with visible failure modes.	Poly-Si	Grid	6	Subtropical climate with moderate humidity level and high temperature.	India	[29]
Modules with no visual defect have around 1% whereas modules with defects may reach 4.2%.	Poly-Si	Grid	10	Semi-desert climate, considerably hot and dry weather.	India	[30]

Table 1. *Cont.*

Degradation Rate	Type of PV (Poly-Si, Mono-Si)	Connection (Grid or Standalone)	Lifetime (Years)	Weather Condition	Country	Ref.
0.6% to 1.2% for modules with no visual defect and 1.4% to 1.9% for modules with defects.	Mono-Si	Standalone	Between 0 and 5	Dry equatorial climate. The average temperature is 28 °C and 30 °C and the average humidity is between 60% and 75%.	Ghana	[31]
0.75% to 1.65% for modules with no visual defect and 1% to 2% for modules with defects.	Poly-Si	Standalone	Between 6 and 10.	Wet semi-equatorial climate. The average temperature ranges between 26 °C and 30 °C and the average humidity is between 70% and 80%.		
The average fluctuates from 0.92% to 1.05%. Modules with defects can reach 3.22%.	Mono-Si	Standalone	10	Hot accompanied by high relative humidity; up to 85.6%.	U.S.	[32]
1.54% in mono-si and 2.72% in poly-si.	Both Types	Standalone	11	Dry and hot climate, with frequent sandstorms located in the desert.	Algeria	[33]
The average rate of 20 deployed modules is 1.04%.	Mono-Si	Standalone	11	Warm with a high relative humidity range; the average is 67%.	Algeria	[34]
The average rate of 10 deployed modules is 2.04%.	Poly-Si	Standalone	14	Moderate climate with considerably high relative humidity, which can reach 83% in the winter months.	Germany	[35]
Between 0.57 and 1.33% based on extracted data and statistical analysis.	Poly-Si	Grid	5	Desert climate, considerably hot and dry. Frequent sandstorms result in dust accumulation on the PV system.	Djibouti	[11]
0.98%	Poly-Si	Not stated	10	Cold and humid, average temperature range between −6.7 °C and 21 °C, average humidity range between 30% and 99%.	Norway	[36,37]
1.33%	Poly-Si	Not stated	20	PV modules were operated for 10 years in humid and cold weather and then kept inside a research centre for 10 years for examination purposes.		

Furthermore, some PV failures, such as cell cracks, propagate rapidly [33,34]; if undetected, they will cause a significant cost loss that may reach up to 10 times the equipment cost [38]. This is because some undetected failures may lead to fire and catastrophic damage to the entire PV system [39]. For instance, critical degradation in some PV modules in an array system leads to mismatch, increasing the PV module's temperature and subsequently leading to fire [40,41]. Critical degradation in PV modules was also highlighted as initiating fire in a research project based in Germany [39]. Fire can also be caused by hotspot failure, primarily driven by other failure mechanisms that elevate the operating temperature to a hazardous level, and eventually cause a fire [42,43]. There have been 80 fire incidents

involving PVs in the United Kingdom alone [44]. The fire caused by PV failures not only results in power reduction and cost losses, but it may sadly lead to fatalities; twenty-two casualties related to fire incidents stemming from PV failures were reported in the UK by BRE National Solar Centre [44]. Additionally, hydrogen reactions during PV fires cause toxic and life-threatening gases, namely hydrogen fluoride and hydrogen chloride [45]. Figure 2 shows a fire incident triggered by a hotspot failure on a module in China.

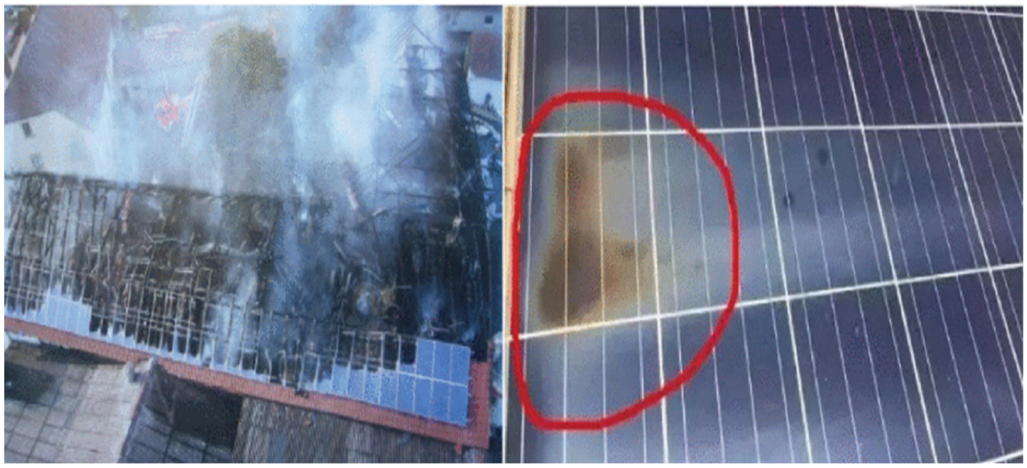


Figure 2. Fire incident in PV array initiated by hotspot failure [45].

According to Sepanski et al. [39], PV modules do not catch fire abruptly; fires are often sparked by critical degradation mechanisms that can be detected in advance.

1.2. Definition of PV Failure

Photovoltaic failure is not defined uniformly in the literature. Some definitions indicate that a drop of 80% in maximum output power is considered a PV failure [46]. Others claim a 20% drop in maximal power is a PV failure [47]. Durand and Bowling [48] defined failure as a drop of more than 50% in maximum power output. However, the International Electrotechnical Commission (IEC) stated that a 50% drop in maximum power output must be accompanied by safety hazards to ascertain failure in the PV module [49]. This discrepancy in defining the term explains the reason why Jordan et al. [16] used the term "degradation mode" instead of "failure" when reviewing the literature. Despite discrepancies in defining the "failure" term, the authors of this paper use both terms: failure and degradation. The term "failure" is universally described in the literature as any unusual changes in the PV module's appearance, function, and reliability [46,50], whereas the term degradation describes the wear-out process of the PV module during its ordinary life cycle. In most cases, the degradation process, if within the expected range of 0.8% drop of rated power per annum, does not harm the PV system unless it exceeds this range and moves to a critical phase [38,51].

2. Failures of the PV Module Components: Discussion and Observations

A PV module consists of solar cells, solder, an encapsulant, protective glass, and a backsheet, see Figure 3. The most common raw material for the PV cell is silicon. Although silicon is not the ideal element for power conversion efficiency, its properties have been extensively studied and well understood by the market before the development of solar cells [5,52].

Silicon is highly purified and drawn into single crystal ingots before being sliced into wafers ranging between 0.2 to 0.5 mm thick. Residuals of crystalline silicon created during the slicing process vary based on the slicing technology. They are frequently used as crystalline ribbons to reduce manufacturing costs [5]. Once the wafer is connected to the ribbon, the solar cell is ready for testing.

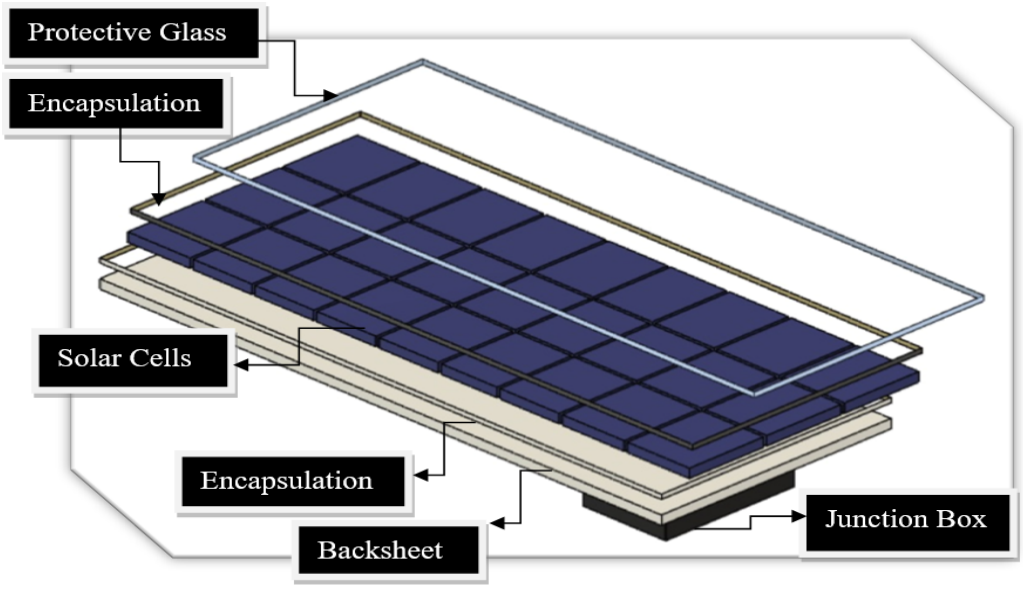


Figure 3. PV module components designed using Fusion 360 software. (The software is from Autodesk and is called Fusion 360. The version is 2.0 and Autodesk are located in San Francisco, CA, USA).

2.1. Protective Glass

The protective glass in the PV module is made from tempered glass that contains a small proportion of iron oxide, not exceeding 0.05%, to allow for the transmission of sun light [53]. It is manufactured and designed to resist environmental stress factors such as a drastic change in temperature.

Gürtürk et al. [54] validated glass properties by measuring its optical transmittance and energy efficiency. They investigated two types of PV glass, one of which was rated to have a 1% higher solar transmittance. One in each type was used as a control glass and tested at a constant temperature. The others were tested at an elevated temperature that reached 120 °C. Their results showed no significant impact on energy efficiency, only a slight variation, not exceeding 2.06% at most. Afridi et al. [55] artificially formed a hotspot via shading with temperature rising to 200 °C in glass/glass and backsheet/glass PV modules and proved that the front glass of those two types was not broken or shattered despite the occurrence of severe damage like burn marks, specifically in the glass/glass PV module type. Belhaouas et al. [34] inspected twenty PV modules equipped with two different types of glass after 11 years of deployment in Bouzareah, Algeria: eight with float glass and the other twelve with textured glass. Their visual inspection showed more optical failures such as delamination in the float glass types, albeit all PV modules suffered from discolouration. Moreover, the electrical parameters of PV modules with float glass type displayed reduced values compared to those with textured glass, except for the open-circuit voltage. Nonetheless, all twenty PV modules experienced nearly the same degradation rate, at 1.04% per year.

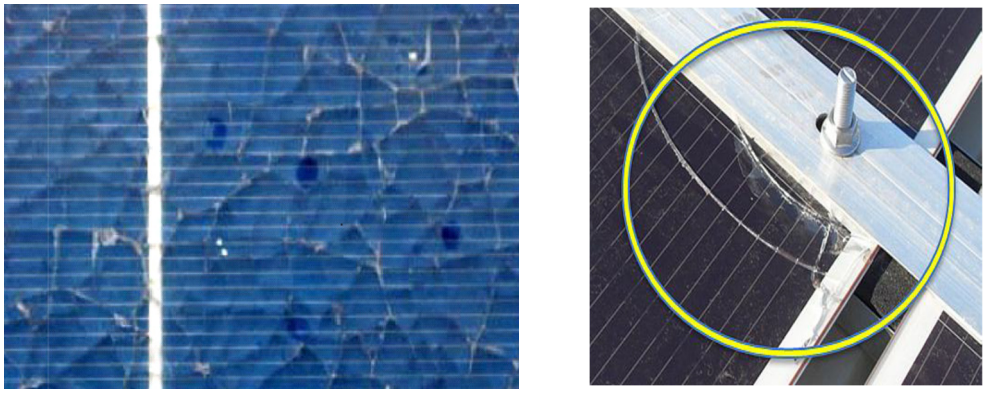
A reduction in light transmittance is the primary failure that occurs in PV glass and is potentially caused by glass breaking or shattering or by harsh weather conditions like ultraviolet exposure and dust accumulation [56,57]. A lab experiment by Tagawa et al. [58] explored dust accumulation on glass and its effect on transmittance. Their results revealed a dramatic coarseness increment that resulted in a 32% reduction in glass transmittance after 44 min of accumulation. To protect against harmful UV wavelengths, some PV glass is doped with cerium as an additive [59]. However, King et al. [60] discovered, in a laboratory experiment, that doping cerium reduces optical transmission by up to 2%. Kempe et al. [61] conducted further experiments on the impact of removing cerium from protective glass and found that excluding cerium can raise optical transmittance

by approximately 1.8% [18], which drives some manufacturers to abandon cerium in the production of PV glass. However, excluding cerium from PV glass is extremely risky; it can cause a substantial rise in the rate of delamination failure by a factor of three [61]. Consequently, when it comes to cerium, Kempe et al. [61] determined that excluding cerium will not boost electrical efficiency, and if excluded, there is a need to coat the glass with anti-reflective substances to filter out damaging ultraviolet wavelengths, predominantly below 350 nm.

Glass shattering can be the result of poor PV module transportation or incorrect manufacturing processes involving excessive clamping force [22,62–64]. Some weather conditions also contribute to PV glass degradation and failures. A study by Bora et al. [65] analysed the failure modes of PV modules in different weather conditions in India. They showed that PV modules deployed in hot areas were vulnerable to glass breakage within five years of operation. Shattering or breakage of the module's glass allows water vapor to enter the solar cells, creating short circuits and safety risks like electrical shock [30]. This is why glass breakage failure ranked 9 out of 10 in terms of severity as it affects safety severely [30].

In addition, the temperature at the glass's breaking point increases, which may cause hotspot failure [15]. In an investigation study by Chandel et al. [66], a PV module with glass breakage had developed hotspot failures with resulting significant power loss, which was also identified by Băjenescu and Titu-Marius [67]. Typically, a hotspot forms in a PV module when some cells receive less illumination than others, resulting in those cells dissipating energy rather than producing energy, i.e., the energy produced by the fully illuminated solar cells is dissipated by the less illuminated ones, increasing the latter cells' temperature and causing them to operate in reverse bias [68]. Hotspot failures are not only driven by broken glass failures but also driven by shading and mismatch failures [69]. Shading failure is a common PV failure that is strongly linked with hotspot formation [70,71]. When hotspots occur, they cause permanent damage to the solar cells or other module parts, such as metal connection, EVA encapsulation, or protective glass [72,73]. Jordan et al. [16] rated PV failures based on their severity, where one is low, and ten is considered the most severe; they listed hotspots to have the highest severity rate among all PV failures.

However, Ndiaye et al. [22] investigated a PV module with broken glass operating for five years and found no hotspot that led to significant power loss. This may indicate that glass breakage was not the cause of the failure, but a subsequent consequence due to weak protection. Bansal et al. [30] investigated a PV module operating for 10 years in a mega-plant and found that glass breakage was almost certainly combined with solar cell cracking and significant power loss as a result of weak protection, see Figure 4.



(**a**) (**b**)

Figure 4. (**a**) Example of PV module with shattered protective glass [74]. (**b**) Broken glass due to installation fault by over-tightening a bolt [15].

2.2. Encapsulant

Various encapsulating substances have been used in photovoltaic modules, such as polydimethylsiloxane (PDMS) and thermoplastic polyurethane (TPU) [8,75–77]. Manufacturers evaluate their advantages and disadvantages in terms of properties including reliability and cost before selection. For instance, PDMS demonstrates better immunity to environmental stress factors, which favoured it in the early trials of PV encapsulation [78]. Recently, manufacturers such as DuPont developed a PV encapsulant classified as an ionomer which offers 25 times more protection against potential-induced degradation (PID) failure than the typical encapsulant, ethylene-vinyl acetate (EVA). Dow Chemicals, another manufacturer, developed polyolefin-based encapsulants and has claimed they have greater electrical resistance as well as moisture protection when compared to EVA and ionomers [79,80]. Azam et al. [81] explored the degradation rate of four modules, two of which were laminated with polyvinyl butyral (PVB) encapsulant, under an accelerated ultraviolet test and found they had a 50% lower degradation rate compared to EVA.

Despite the superior protection features against environmental stress factors in more advanced encapsulating materials, EVA is still used in more than 75% of all PV modules due to its cost effectiveness [82,83]. The cost of PVB material, for instance, is about 50% more per m^2 than its competitor, EVA [81]. The majority of EVA composition is vinyl acetate, with the remainder being a combination of ethylene, antioxidants, and curing agents [84,85].

However, from the historical research carried out in 1981 by Lathrop et al. [86] at Clemson University until recent literature reviews, e.g., [87,88], EVA encapsulant is the primary cause of PV degradation mechanisms. Aboagye et al. [31] recently inspected polycrystalline and monocrystalline PV modules deployed in three locations in Ghana with different weather conditions, all of which showed defects in EVA encapsulants. The same findings were noted for 43 monocrystalline PV modules mounted for ten years in Nordic weather conditions, specifically in Grimstad, Norway [36]. Nearly all 43 modules suffered from encapsulant defects, namely delamination or discolouration. In Florida, United States, 156 PV modules were inspected after 10 years of deployment and also revealed the same results as [31,36]: all 156 modules exhibited encapsulant delamination failure.

Encapsulant wear-out can result in low optical performance in PV modules, which causes a reduction in the electrical output owing to decreased light absorption and extreme light reflection [89]. The encapsulant discolouration effect begins with a drop in the short-circuit current (I_{SC}). The drop in I_{SC} can be as much as 40%, albeit it is not regarded as a PV failure, as it may not pose a safety hazard [49]. Still, discolouration leads to more severe failures like delamination and corrosion as a result of the release of acetic acid. The released acetic acid in turn is characteristically found responsible for the corrosion of contacts that frequently occurs after the initiation of discolouration failure [90].

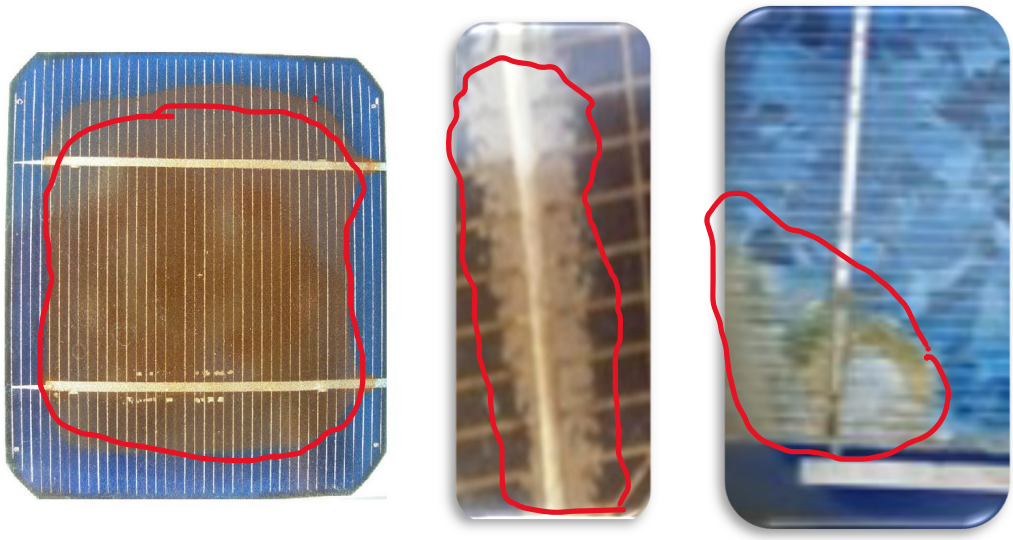
With that in context, delamination can cause a substantial decrease in the amount of light absorbed, thereby leading to a significant drop in I_{SC}. Bubble formation is one of the primary triggers of encapsulant delamination; it is formed initially during the lamination process of encapsulation due to a higher localised ratio of released volatile organic compounds [91,92]. The area affected by bubbles in the PV module operates at hotter temperatures and potentially leads to burn marks [93]. A study by Rajput et al. [94] analysed the degradation mechanism of 90 monocrystalline PV modules operated for 22 years in India; it was found that the PV modules affected by more bubbles had more power loss.

Despite ultraviolet radiation occupying a relatively small percentage in the solar spectrum, less than 4%, it is considered a major reason for the degradation of PV encapsulant material [95,96]. Due to its shorter wavelength, ultraviolet radiation possesses greater energy that can gradually degrade the encapsulant, decomposing its polymeric bonds [97]. The UV spectrum is divided into three types: UV-A, UV-B, and UV-C. In deployments, PV modules are not exposed to ultraviolet type-C but ultraviolet type-B radiation. Hence, the latter is regarded as the primary trigger of the degradation mechanism in EVA [98–100].

Even with the implementation of UV-blocking glass, the degradation of EVA remains significant when exposed heavily to UV-B, particularly in conjunction with other stressors such as high temperatures and humidity [61,101]. Consequently, a chemical process is instigated, resulting in the creation of acetic acid and aldehyde, which leads to a gradual darkening of the EVA material from clear to dark brown in severe instances [101,102].

Miller et al. [76] examined five types of encapsulants, exploring the degradation process after exposing them to an artificial ultraviolet source and different combination levels of humidity and temperature. Their experiments revealed that encapsulants had higher degradation rates when they were exposed to lower humidity and higher temperatures, displaying faster yellowing. Experiments for exposing PV encapsulant to ultraviolet sources with stressors were also conducted by Arularasu [103] and showed similar results to Miller et al. [76].

To account for the degree of encapsulant yellowing, a "yellowing-index" terminology, published by the International Organization for Standardization (ISO) [104], is used. Yellowing index is defined as the alteration of polymer colour toward yellow [104]. Nevertheless, Oliveira et al. [105] discovered that early degradation of EVA cannot be spotted as it may start before its colour turns yellow, i.e., the yellowing index has not experienced any modifications. This ambiguity has driven more investigations, for example [59,106,107], to explore the initial stage of EVA degradation. See Figure 5 for examples.



(**a**) (**b**) (**c**)

Figure 5. (**a**) Brown discolouration of PV cell [108]. (**b**) PV module affected by delamination [66]. (**c**) PV module affected by delamination that led to corrosion [109].

The latter might be the one of reasons for Ferrara and Philipp [110] stating there is no distinct correlation between the shift in EVA's colour and the solar cell's electrical performance. However, Rosillo and Alonso-Garcia [111] demonstrated through experimentation that an increase in the yellowness index reduces the major electrical parameter maximum power output. The results of their study are consistent with the well-known research conducted by Pern et al. [112], which examined the electrical performance of solar cells for five different colours of EVA (clear, yellow-brown 1, yellow-brown 2, brown, and dark brown). The researchers concluded that as the EVA colour darkened, there was a gradual decrease in maximum power output, with the greatest reduction observed in the dark brown colour [99].

In addition, Dechthummarong et al. [113] took measurements of PV modules before and after they were mounted for 15 years to ascertain whether the insulation resistance still complied with the IEC 61215 standard [114]. The researchers categorised EVA discolouration into four colours: light yellow, yellow, brown, and dark brown. Their findings revealed

that the modules with light yellow and yellow discolouration exhibited healthier performance with superior efficiency when compared to the brown and dark brown EVA modules. Surprisingly, the insulation resistance of all PV modules met the IEC 61215 standard, even though modules with brown and dark brown discolouration were more vulnerable to failure from corrosion, delamination, and EVA bubble formation. An investigation conducted by Diniz et al. [115] also found that modules with brown discolouration were associated with more severe and safety-related failures, including corrosion.

2.3. Solar Cells

Solar cells are connected in series and then encapsulated, typically with EVA, to provide adhesion between the solar cells and the protective glass. Failure of the solar cell mainly occurs due to the very thin profile of the silicon wafer. These thin wafers are very brittle and are prone to cracking easily during manufacturing or transportation.

Generally, microcracks of the cell cannot be detected by the naked eye. Consequently, they may spread and distribute to other cells in the module [15]. When the cracks prevent more than 8% of the cell from functioning, it may lead to a hotspot [15,116]. The active area of the cracked cell may be forced to operate in reverse bias, eventually causing a hotspot failure. Moreover, cracks are subject to expansion and seeding more cracks, especially under environmental and mechanical stress factors like hot, cold, and windy climate conditions [117–120]. Consequently, they accelerate the ageing process, showing a higher degradation rate [15]. Buerhop et al. [121] reported that PV modules with cracked cells had a greater than 10% power loss after six years of operation when compared to healthy ones. A study by Siruvuri et al. [122] developed a deep learning model based on four attributes—crack type (edge or centre), size, orientation angle (angle in degrees of the crack: horizontal vs. vertical cracks), and ambient temperature—to forecast the impact of crack severity on power loss. The outcome results were analysed and evaluated, revealing that power loss increased with increasing crack size and temperature but decreased with increasing orientation angle. However, with regards to angle orientation, their results contradicted the results of Dhimish et al. [123], where horizontal cracks were more gentle than vertical cracks or so-called parallel to busbar [124].

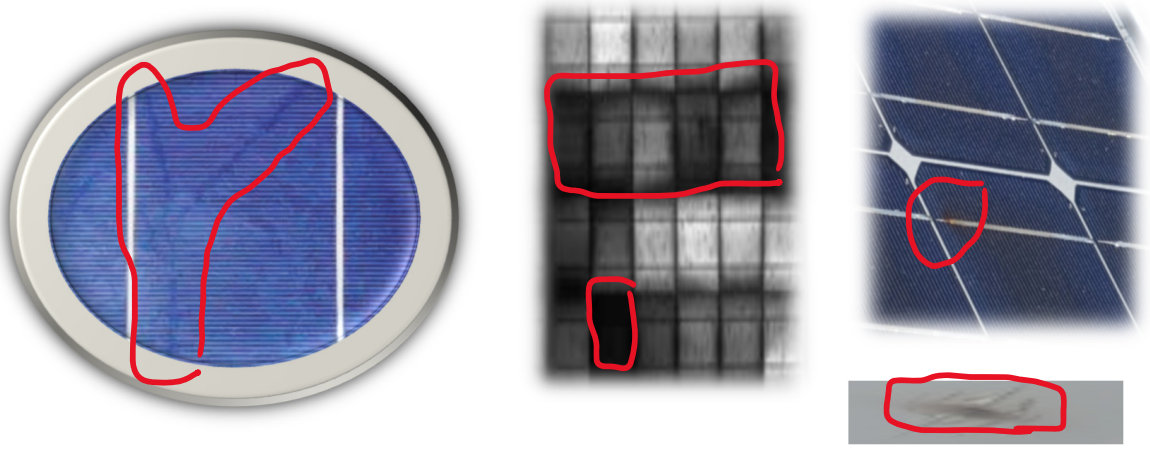
Conversely, snail track failure can be detected by the naked eye; this failure is so named because it is shaped like a snail's trail. Dolara et al. [125] indicated that most snail track failures are linked to the existence of cracked cells. They also compared four PV modules with a snail track against a healthy one. In their findings, maximum power output dropped in all PV modules with a snail track, one of which had a power loss of 40% of rated power. This reduction in maximum power was caused primarily by a significant reduction in I_{SC}, despite a slight increment in open-circuit voltage (V_{OC}). This association between cracked cells and snail tracks was also stressed in a recent investigation conducted in Indonesia [126]. Duerr et al. [127] found that four degradation mechanisms trigger snail track failures, depending on the combination of the encapsulant materials, and on that basis, snail tracks should be described and categorised under PV failures rather than a single degradation mechanism.

Potential-induced degradation (PID) is another PV failure mode. First observed in Germany in 2005 [128], it degrades PV wafers and leads to the development of hotspots [13,14]. It is formed owing to polarisation differences between the PV module frame and the module's cells. Thus, it mostly occurs in PV plants and farms where PV frames are grounded as a protective technique against fire ignition [129]. If undetected, it may lead to 100% power loss within a few years [56]. A report based in Germany stated that PID failure progresses rapidly with the release of acetic acid due to EVA discolouration [130]. Moreover, in a lab experiment by Pingel et al. [131], the PV module was found unlikely to recover from PID when operated at higher temperatures. With the rise of bifacial PV module deployment in the last decade, Molto et al. [132], reviewed the PID failure displayed in these module types. Although bifacial modules joined the PV market recently, over 30 scientific papers on such failures have been published in the literature. The review analysis of Molto et al. [132]

came up with four classifications of PID failures: PID-s, Na-penetration-PID, PID-p and PID-c. Both PID-s and Na-penetration were caused by the leaning and movement of Na-Na-positive ions to the polarised cells. Involvement of Na^+ ions were also found in PID-c type, which was also classified into three categories, whereas PID-p was related to the deterioration of the PV surface. Recovery of all types was found to be possible either fully or partially via dark storage or ultraviolet lighting, particularly for PID-p, but was found to be irreparable for the PID-c type [132].

Another failure that solar cells might experience is through disconnection of solar cell busbars or ribbons. This type of failure occurs because of a manufacturing defect; it is also driven by excessive heat due to long partial shading and can produce excessive leakage current. When undetected, it increases cell temperature and forms a hotspot [133]. Such failures can be detected by an infrared (IR) camera or by monitoring the output *I*–*V* curve. When this failure occurs, the output power typically decreases by ~35%. With progression, the power will decrease by ~46% [33]. Consequently, the solder bond will become extremely hot, leading to burn marks and discolouration of the EVA encapsulant [134]. In the worst-case scenario, the protective glass will be broken, with visible burn marks on the PV module's backsheet blocking the current path and initiating an electrical arc and fire, causing irreversible damage [15].

Colvin et al. [135] explored interconnection failures depending on cut location in the PV module and irradiance. They investigated cuts in busbars that connect cells in the centre of the PV module and cuts in outer busbars (at the edge). Results showed that outer busbar cuts are more severe and reduce module power output by nearly double compared to cuts in centred busbars. Their findings were justified by the fact that alternative busbars that can carry the captured photocurrents are limited to one when cuts occur at the outer busbar, whereas in inner cuts, there is more than one alternative busbar that can act in place. Majd et al. [136] explored failure immunity in three common interconnection types in PV modules through FEM simulation: the first one is the conventional interconnection known as front-to-back interconnection; the second type is the light-capturing type, which is named due to the recapturing of lost photons via reflection; the third type is the multi-busbar, which uses its rounder shape to reflect the lost light to the cell. Among the three, the multi-busbar type showed 15 per cent higher immunity against ribbon and busbar failures. Examples of various failure types are shown in Figure 6.



(**a**) (**b**) (**c**)

Figure 6. (**a**) PV module affected by snail track failure [127]. (**b**) PID failure detected by electroluminescence image [137]. (**c**) Hotspot burned the cell solder bonding and exhibited burn marks on the backsheet [138].

Thus, as with most PV failures, early detection is essential to assure a reliable and safe operation of the PV system.

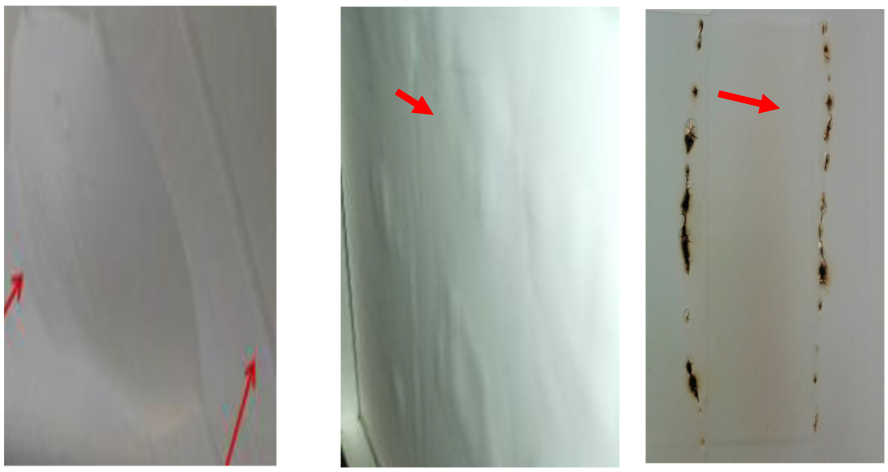
2.4. Backsheet

The backsheet is the last protection layer of the PV module that provides construction support to the PV module. It shields the module's electrical parts from short-circuit failure, ensuring perfect electrical insulation from various environmental stress factors such as water ingress from high relative humidity [139]. Failures and degradation in the backsheet can appear as cracks, discolouration, delamination, bubbles, and burn marks [130].

The major cause of burn mark failures are hotspots, and this may lead the PV module to catch fire. For this purpose, a study conducted by Cancelliere and Liciotti [95] investigated fire reactions with four material arrangements on the basis of a PET (polyethylene terephthalate) backsheet: three layers (PET/PET/primer), four layers (PET/aluminium/PET/primer), three layers (fluoro-coating/PET/EVA), and PET layer with an outside and inside coating. Two backsheets—PET monolayer with an inside and outside coating and the four-layer backsheet (PET/aluminium/PET/primer)—reacted slower to fire and had fewer damaged areas with no or less harm to the EVA encapsulant. However, the monolayer with an inside and outside coating backsheet is favoured over the other as aluminium is electrically conductive and may result in less power production. PET backsheets were also compared for cracking against backsheets made of PP (polypropylene) by Oreski et al. [140]. That comparative study employed an accelerated stress test to explore if PP backsheets have the same immunity as PET backsheets. They found that PP exhibited cracking after the same exposure time as PET, which makes it a reliable substitution for PV backsheets. Further to this, Elfaqih et al. [141] suggested mixing PP backsheets with 5% carbon fibre to provide greater strength and longer reliability against failure. They came up with their proposal after they investigated PP and PPCF (PP supported with carbon fibre) and found that the PPCF backsheet has higher tensile strength.

Investigations of PV module backsheets deployed in outdoor conditions were also conducted by Pascual et al. [142]. In their study, PV modules were deployed in an 8 MW plant. All of them were from the same manufacturer but with two backsheet types: PVF (fluorinated) and polyamide. The PV modules were deployed in 2011 and investigated after six years of operation. Visual inspection revealed that 14% of modules with polyamide backsheets suffered from cracks. Furthermore, polyamide backsheets were susceptible to chalking, which is the decomposition of backsheet material into white powder and is considered a warning sign of abnormal degradation [143]. More than 90% of inspected PV modules with polyamide backsheets degraded by chalking, while none of the PVF backsheets did. The strength of the PVF backsheet might be one of the reasons that has driven research efforts, e.g., [144,145], to search for effective ingredients to be used in accelerated stress tests.

Regarding cracking, Mühleisen [146] developed a solution based on polyurethane paint to be coated at the early onset of backsheet cracking. The coating was examined for nearly two years in outdoor conditions and was also tested under accelerated stress tests. Their results showed a significant reduction in crack progression in coated backsheets compared to uncoated ones. The study of Mühleisen [146] is not the first of its kind, as Beaucarne et al. [147] also fabricated a coated solution of a flowable silicone sealant that can act in place to avoid early replacement of PV modules. They applied the solution on PV modules operated for less than 8 years with heavy backsheet cracks. These modules included four types of backsheet: co-extruded polyamide, PVF, PVDF, and PET. The cracked backsheet modules were tested for insulation resistance and none of them passed the required standard level. After applying the coating, all of them were restored to a healthy level of insulation resistance even after applying accelerated stress tests for a thousand hours. Examples of backsheet issues are shown in Figure 7.



(**a**) (**b**) (**c**)

Figure 7. (**a**) Backsheet bubbles [130]. (**b**) Backsheet delamination [130]. (**c**) Burn marks caused by a hotspot in the backsheet [138].

2.5. Junction Box and Bypass Diodes

A junction box (J-box) is attached to the PV module through adhesive material to regulate and provide a safe flow of the collected photocurrents into the PV module [148]. To guarantee the correct flow path of the current, bypass diodes are also installed inside the J-box in different configurations: overlap and non-overlap [149]. Failures in the J-box are mainly caused by low wiring quality, blown bypass diodes, corrosion, and poor bonding to the PV module (delamination), caused primarily by high humidity [87]. Failure of the J-box may result in zero output of electricity, as was found by Bakir [150] in a recent assessment of a 23 MW PV plant mounted in Turkey. As of the writing of this paper, many studies, e.g., [151,152], have come up with novel techniques to monitor and protect J-boxes from failures. Most J-box failures allow for the ingress of water vapor, causing serious safety issues, such as initiating an electrical arc or causing hotspots [15]. Ong et al. [153] listed J-box failures among the root causes of fire ignition in PV modules. Han et al. [21] investigated the condition of 177 monocrystalline PV modules that operated for 22 years in a humid climate with an average temperature of 27.5 °C. Most of the junction boxes of the modules had been seriously damaged and needed replacing.

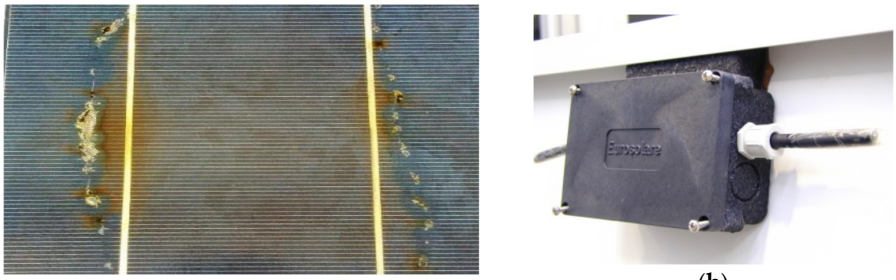
Furthermore, junction boxes can degrade at a faster rate when exposed to large variations in ambient temperature during the year. Daher et al. [154] evaluated the reliability of a 9-year PV system (270 modules) installed off-grid that was expected to produce 62 kW in Ali Adde town, Djibouti. The PV system was exposed to the town's high temperatures with dramatic variation from winter (average temperature is 26.7 °C) to summer with an average of 38 °C. Out of 270 modules, 39% were diagnosed with adhesive junction box failure.

On the other hand, cold climates with high relative humidity like that of Grimstad, Norway, led to the corrosion of junction boxes [36]. J-boxes and metal parts of PV modules operating in so-called floatovoltaics structures, such as PV systems deployed on the water in a floating construction, are also at higher risk of corrosion [155]. This urged Ghosh [156] to recommend that J-boxes should have a protection rating of IP67 when attached to PV modules mounted in a water-based environment. Unsurprisingly, dust has also been found to corrode the PV module's junction box. Tabet et al. [157] inspected a module operating in a dusty environment for six years, finding that the J-box failed because of corrosion. This is in agreement with the finding of Lin and Zhan [158] that water-dissolvable salts represent more than 59% of dust composition, in which, whenever stuck to metal, they react and cause corrosion, primarily in humid environments.

Several PV failures were found to form hotspots, making it necessary to protect the PV module. One means of protection is to use a bypass diode, although it has been criticised

for being neither safe nor effective [72,159,160]. The existence of a bypass diode enables the current to flow over the defective solar cells, thereby protecting the PV module from thermal increases and hotspots. This is one of the main explanations why some PV manufacturers, such as AE-Solar, a German PV manufacturer, attach a bypass diode to each PV cell [161]. One of the recurrent reasons for blown bypass diodes is the increase in their temperature due to long-term shading [162,163]. Also, it was indicated by Bansal et al. [87] that those bypass diodes that were exposed to overirradiance, in particular over 1400 Wm^{-2}, are expected to be blown due to excessive currents.

Failure to detect poor bypass diodes may lead to serious safety issues [163,164]. Since bypass diodes are used to avoid PV failures that lead to hotspotting, whenever they fail, the module loses its means of protection, becomes vulnerable, and, in the worst scenario, initiates fire [41,165]. Bakir [166] used an infrared imaging detection technique where he attached thermal cameras to a drone to be flown over three solar plants that ranged between 2 and 3.5 MW. One of the plants had three PV modules with failed bypass diodes and as a result, their operating temperature increased by an average of 19.7 C. It was shown by Ghosh et al. [167] that the operating temperature of PV cells undergoing shading failure decreases by nearly 50% when bypass diodes are functioning. Their experimental study aimed to explore if total cross-tied (TCT) array configurations were effective in preventing hotspots by allowing the bypass diodes to respond promptly in cases of shading. The study also showed that bypass diodes were only functioning if more than one cell was affected by shading and, therefore, further investigations are required to pinpoint the optimal configuration of PV arrays that is able to activate bypass diodes even in the case of one shaded cell, such as situations of fouling by bird droppings. Examples of these failures are shown in Figure 8.



(**a**) (**b**)

Figure 8. (**a**) Failed bypass diodes leading to hotspots [138]. (**b**) Poor bonding of J-box [137].

To conclude this Section 2, PV failures can be classified based on the components affected. The same PV failure mechanism can be seen or experienced in more than one component due to the similarity of the materials; e.g., EVA is present in encapsulants and also in backsheets. Furthermore, EVA defects are usually considered an early sign of PV module degradation and failure as EVA, alongside PV glass, represents the first defence line against weather stressors. Unlike snail tracks in PV cells, corrosion is another failure mechanism that can attack more than one component, such as solar cell solders, bypasses, and junction boxes, especially in humid environments.

The hotspot failure mechanism is considered the most severe failure and leads to catastrophic consequences. It deteriorates all PV module components if undetected, and a PV module affected by an elevated level of hotspots cannot reverse the degradation and often requires replacement. Thus, identifying the initial stages of PV degradation can prevent potential hazards through proactive maintenance. Sometimes, it is even more effective to substitute a PV module that displays the early onset of deterioration as it will guarantee all deployed modules in PV plants continue generating the healthier (expected) power, regardless if their condition complies with the IEC 61215 standard [114]. Table 2 lists the PV failures reported in investigational studies within the last two years, classifying them on a PV component basis.

Table 2. PV failures reported in investigational studies within the last two years.

Component Impacted	Defect (Failure)	Type of PV (Poly-Si, Mono-Si)	Operational Time (Year)	Failure Detail	Country	Ref.
Protective glass	Breakage	Mono-Si	16 and 13	Two occurrences owing to poor transportation and vandalism.	Indonesia	[126]
		Poly-Si	20	None of the 43 PV modules affected by breakage of glass.	Norway	[36,37]
		Not Stated	Not Stated	52 modules affected in three PV plants ranging from 2 to 3 MW.	Turkey	[166]
		Poly-Si	6	Rare occurrences of glass breakage accompanied by cracked cells and dark EVA discolouration. Potential causes: hotspot, harsh weather (high wind speed and dust), and incorrect installation.	India	[29]
		Poly-Si	10	Less than 1% out of 2078 investigated modules. Possible causes: wind, hotspots, and handling.	India	[30]
EVA	Discolouration	Poly-Si	5 [(a)], 9 [(b)], 5 [(c)], and 10 [(d)]	Dark [(a)], light yellow [(b)], dark [(c)], and brown [(d)].	Ghana	[31]
		Mono-Si	15 [(a)] and 5 [(b)]	Light yellow [(a)] and light brown [(b)].		
		Both types	16 and 13	Not specified.	Indonesia	[126]
		Poly-Si	20	Nearly all investigated (43 PV modules) affected.	Norway	[36,37]
		Mono-Si	10	2 out of 156 PV modules displayed brown discolouration.	U.S.	[32]
		Both types	11	Prevalent among all PV modules, resulting in up to 18% reduction in short-circuit current and potentially brown discolouration [168].	Algeria	[33]
		Poly-Si	6	Rare occurrences of light discolouration in 10 MW PV plant.	India	[29]
		Mono-Si	11	Brown discolouration was detected in 10% of the PV modules.	Algeria	[34]
		Poly-Si	10	Roughly 14% of the 2078 investigated modules were affected by yellow and brown discolouration.	India	[30]

Table 2. *Cont.*

Component Impacted	Defect (Failure)	Type of PV (Poly-Si, Mono-Si)	Operational Time (Year)	Failure Detail	Country	Ref.
EVA	Delamination	Both types	8y-poly and 15y-mono	Rare occurrence with fewer than 4 modules impacted out of 104 of all types.	Ghana	[31]
			16 and 13	Several occurrences, especially in the 12-year PV system.	Indonesia	[126]
		Poly-Si	10	Dominant among the 43 PV modules, mainly at the cell edge.	Norway	[36,37]
		Both types	10	Rare occurrences, only 11 out of 2078 investigated modules; potential cause was weather condition.	India	[30]
		Mono-Si	10	All investigated (156) PV modules were influenced near the busbar; root cause expected to be heat resulting from busbar resistance.	U.S.	[32]
		Both types	11	Potential cause: desert weather.	Algeria	[33]
		Mono-Si	11	25% of modules experienced delamination, some at the centres and others at the edges.	Algeria	[34]
Solar cells	Cracks	Mono-Si	5 and 15 years	Extremely rare: only two of 104 modules were affected. Possible cause was unknown.	Ghana	[31]
		Poly-Si	20	Prevalent among the 43 PV modules, predominantly at the cell edge.	Norway	[36,37]
		Mono-Si	10	Few cracks were detected in PV modules inspected by EL imaging.	U.S.	[32]
		Poly-Si	14	Results from EL imaging showed that 9 out of 10 modules have crack cells.	Germany	[35]
	Corrosion	Both types	20	12 out of 104 modules were affected.	Ghana	[31]
	Snail Track	Both types	5	Rare occurrence, with fewer than 4 modules impacted out of 104 of both types. Claimed to be caused by manufacturing process.	Ghana	[31]
			16 and 13	Several occurrences, especially in the 12-year PV system.	Indonesia	[126]

Table 2. *Cont.*

Component Impacted	Defect (Failure)	Type of PV (Poly-Si, Mono-Si)	Operational Time (Year)	Failure Detail	Country	Ref.
Solar cells	Snail Track	Mono-Si	11	2 out of 20 modules suffered from snail tracks, one of which was inked with cracked cells.	Algeria	[34]
		Mono-Si	10	30 out of 156 PV modules displayed snail track.	U.S.	[32]
		Poly-Si	10	Roughly 1.5% of 2078 investigated modules were affected, with snail track often linked with cracked cells.	India	[30]
	PID	Poly-Si	20	One investigated by EL imaging; cell crack seems to be the cause of PID.	Norway	[36,37]
	Hotspot	Poly-Si	20	One investigated by IR imaging; suspected to derive from cracks.		
		Mono-Si	10	10 modules suffered from hotspots and displayed burn marks on the backsheet.	U.S.	[32]
		Not stated	Not stated	One module was detected in a 2.7 MW PV plant.	Turkey	[166]
		Poly-Si	6	Suspicion in one module of one module. Potential cause: mismatch.	India	[29]
		Poly-Si	14	3 out of 10 modules showed hotspotting, detected by IR.	Germany	[35]
		Poly-Si	10	Detected in 10 out of 2078 investigated modules.	India	[30]
Backsheet	Chalking	Mono-Si	11	1 out of 20 modules.	Algeria	[34]
	Discolouration	Both types	8	Nearly 14 modules were affected out of 104 of both types, specifically those lacking mounting support.	Ghana	[31,37]
		Poly-Si	10	11 out of 2078 investigated modules failed with burning and cracks. Possible causes are hotspots and failed J-boxes.	India	[30]
	Delamination	Mono-Si	10	29 out of 156 PV modules suffered from backsheet delamination failures like bubbles.	U.S.	[32]

Table 2. *Cont.*

Component Impacted	Defect (Failure)	Type of PV (Poly-Si, Mono-Si)	Operational Time (Year)	Failure Detail	Country	Ref.
J-Box	Corrosion	Mono-Si	16	Several occurrences.	Indonesia	[126]
	Delamination	Both types	13	Poor installation was potentially the cause.	Indonesia	[126]
		Mono-Si	11	1 module had a detached J-box.	Algeria	[34]
	Burning	Poly-Si	10	Only detected in 2 out of the 2078 investigated modules.	India	[30]
	Bypass diodes	Not stated	Not stated	Detected in 8 modules in a 2.7 MW PV plant.	Turkey	[166]

(a), (b), (c), (d): These refer to the operating times given in the preceding column and using the same superscripts.

3. Classification of Crystalline Photovoltaic Module Failures

Failures can be classified into different criteria based on severity, location of the failure, and occurrence time (whether it occurs early after installation or in the last years of warranty). Kuitche et al. [169] classified failure types based on severity level; the severity of failure was mathematically estimated using Equation (1) [169].

$$RPN = S \times O \times D \quad (1)$$

where RPN is defined as risk priority number used as a rating guideline.

S is the severity rating and it is rated from 1 to 10, where 1 refers to no apparent defect and 10 indicates no operation.

O is failure occurrence and it is rated from 1 to 5, where 1 indicates failure is less likely to occur and 5 indicates a frequent occurrence of at least once per month.

D is the detection of the failure and is rated from 1 to 10. One indicates the failure will be easily detected, and ten means it is less likely to be spotted.

Similarly, Jordan et al. [16] adopted Equation (1) to extract a classification method based on severity. They ranked the severity from 1 to 10, where 1 indicates there is no effect on the performance of the PV module and 10 points to a severe impact on performance accompanied by a safety hazard. Within their classification, hotspot failure ranked 10, and a minor delamination failure rated 1. Tsanakas et al. [56] classified PV failure differently based on optical and electrical shortages. Failures that can be visually identified were categorised as optical failures and those that require measurements of their parameters were categorised as electrical failures. On the other hand, Kontges et al. [15] classified PV failures into three categories based on the expected time of occurrence in the PV lifecycle: infant-life, mid-life, and wear-out failures. Infant-life failures are the ones that appear in the early life of PV operation. Mid-life failures arise after eight years of operation, whereas wear-out failures are failures that emerge just before the end of the module's expected lifetime. A recent review by Hong and Pula [170] classified PV failures based on connections: whether the failure represents a ground or line-to-line fault. A list of PV failure classifications is summarised in Table 3.

Table 3. Photovoltaic failure list classified by three different reviews.

Photovoltaic Failure	**Classified by Jordan et al. [16]. Classification Categories: Severity 1 to 10**	**Classified by Tsanakas et al. [56]. Classification Categories: (a) Optical; (b) Electrical; (c) Not Classified.**	**Classified by Köntges et al. [15]. Classification Categories: (a) Infant-Life; (b) Mid-Life; (c) Wear-Out.**	**Classified by Hong and Pula [170]. Classification Categories: (a) Mismatch; (b) Ground; (c) Line; (d) Arc; (e) Other.**
Hotspot	10	Electrical	Not Classified	Other
Encapsulant Delamination	Minor Delamination: 1 Major Delamination: 5	Optical	Mid-Life	Mismatch
Encapsulant Discolouration	3	Optical	Mid-Life	Mismatch
Solder Bonding	8	Electrical	Wear-Out	Ground and Arc
Glass Breakage	5	Optical	Infant-Life	Other
Cracked Cell	5	Electrical	Mid-Life	Other
Bypass-Diode	5	Not Classified	Mid-Life	Other
Junction Box	5	Electrical	Infant-Life	Arc

4. Effect of Environmental Stress Factors on PV Degradation

Each manufactured component in the industry has a tolerance rating in relation to environmental stress factors, which include temperature, humidity, wind, ultraviolet light, snow, and dust. PV module components are no exception in this regard [171]. Harsh weather, including, but not limited to, high and low temperatures, high relative humidity, dust storms, snowstorms, and high UV index, are aspects of environmental stress factors that reduce the PV module's efficacy and trigger degradation early in its lifespan. For instance, increases in ambient temperature above 25 °C reduces the power production of PV modules [172,173].

Such failures as potential induced degradation, encapsulant discolouration, and delamination were listed to be triggered by high ambient temperature by Köntges et al. [15]. Humidity triggers the adhesion of the module's backsheet and raises safety concerns in PV systems when water vapor penetrates the module's conductive parts and junction box [15,21]. Humidity makes a significant contribution to the corrosion of the J-box as it first deteriorates the bond force of cohesive material and secondly allows water to breach and react with metal [174]. Dust particles and snow were reported to cause shading failures and reduce power output significantly [3]. Both extreme cold and hot climates were found to increase the degradation rate of PV modules as well as increase the expansion of cracked cells [30,137,175].

Santhakumari and Sagar [174] reviewed the literature focusing on failures related to weather conditions and their contribution to the degradation of photovoltaic system components, including batteries, cables, and inverters. Their review concluded that high ambient temperature, relative humidity, dust, sandstorms, and hailstorms highly trigger PV failures, causing optical and electrical losses. These environmental stress factors were found to trigger encapsulant degradation, corrosion, and glass breakage. The review [174] also addressed some of the experiments that have been conducted to tackle harsh environmental stress factors. For instance, sprinkling water on PV panels was an efficient technique to reduce the operating temperature of the PV module. The kinds of failure classified by Santhakumari and Sagar [174] as triggered by high relative humidity were also found by Chandel et al. [66] in monocrystalline PV modules deployed in a humid environment in India, with a nearly doubled degradation rate of 1.4%.

Dust accumulation is another environmental stress factor that decreases power output by limiting light transmission to the PV surface. It occurs in locations where dust storms are common, such as parts of the Middle East and Africa. Dust particles either scatter light in the atmosphere or accumulate on the PV module surface [176]. When dust scatters in the atmosphere, it reduces the irradiation reaching the Earth's surface and converts it to diffuse irradiance, slightly reducing the overall power. In contrast, dust accumulation on the PV surface directly impacts power output and is thus a more obvious effect warranting further investigation. It has motivated researchers who live in harsh weather environments to conduct more studies during dust storms [177], while others have set up lab experiments to investigate different dust particle properties on PV modules [178,179].

Saidan et al. [177] compared electrical parameters between PV modules at different periods of dust accumulation. They concluded that the reduction in short-circuit current and power output became greater after longer periods of dust accumulation. That is, I_{SC} was decreased by fourfold when dust accumulated for one month compared to one day. This is in agreement with Said and Walwil [180], who investigated dust accumulation on PV modules deployed in Dharan, Saudi Arabia; I_{SC} was more reduced in a more extended time of dust accumulation.

Many factors need to be considered to address PV dust and snow accumulation; tilt angle is one of them. Sayigh et al. [181] experimented with PV modules operated in the field for 38 days at different tilt angles ranging between 0° and 60°. They found that dust accumulation increased dramatically when the tilt angle decreased, causing a reduction in the PV transmittance. This was also tested and confirmed by Said and Walwil [180]. Both Elminir et al. [182] and Said and Walwil [180] showed that dust accumulation increased

fivefold at a tilt angle of 0° compared to a tilt angle of 90°. Properties of dust particles, weather conditions, and dust adhesion force also play a vital role in tackling the dust accumulation problem. For example, adhesion force for larger dust particles was higher than for smaller ones [179,180].

A lab experiment conducted by Mehmood et al. [178] identified the material components of the dust particles found in Dhahran, Saudi Arabia, and their mud characteristics when they reacted with moisture on two PV surfaces: glass and polycarbonate. The dust particles collected from the PV module's surface were mixed with different concentrations of deionised water, applied to the glass and polycarbonate, and then dried for two days. Their results showed that the glass's transmittance was reduced by 9% more than that of the polycarbonate.

It is essential to assess the weather conditions for targeted geographical locations when installing a PV system, studying the risks and economic feasibility of extra application of immune material against existing weather stressors. Some weather stressors, like high UV index and humidity, require advanced materials to be overcome, while others may only require continuous monitoring, such as regular cleaning of dust and snow. Hence, early planning and assessment ensure a reliable operation of the PV system, as well as reduce the risk of lost revenue for PV operators by ensuring maximal power generation. For instance, allowing a PV surface to remain unclean in a dusty environment was reported to cause a decrease in power generation by 18% in just one month of dust accumulation [177]. Table 4 lists some recent studies that highlighted weather conditions' effect on PV.

Table 4. PV studies that highlighted weather conditions within the last two years.

Weather Condition	Weather Highlight	Failure Modes Detected or Explored and Component Affected	Type of PV (Poly-Si, Mono-Si)	Lifetime (Years)	Country	Ref.
Subtropical climate with moderate humidity level and high temperature.	Hot	Glass breakage, EVA discolouration, soiling, cracked cell, hotspot.	Poly-Si	6	India	[29]
Semi-desert climate, considerably hot and dry weather.	Hot	Glass breakage, EVA discolouration, soiling, EVA delamination, cracked cell, snail track, metal corrosion, backsheet cracks and burns.	Poly-Si	10	India	[30]
Dry equatorial climate. The average temperature is between 28 °C and 30 °C and the average humidity is between 60% and 75%.	Dry and hot	EVA discolouration, metal corrosion, backsheet defects.	Mono-Si	Between 0 to 5	Ghana	[31]
Wet semi-equatorial climate. The average temperature ranges between 26 °C and 30 °C and the average humidity is between 70% and 80%.	Hot and humid	EVA discolouration, EVA delamination, metal corrosion, backsheet defects.	Poly-Si	Between 6 and 10.		

Table 4. *Cont.*

Weather Condition	Weather Highlight	Failure Modes Detected or Explored and Component Affected	Type of PV (Poly-Si, Mono-Si)	Lifetime (Years)	Country	Ref.
Desert climate hot and dry with moderate to high relative humidity throughout the year.	Dust	Experimental study to address dust effect. Soiling reduced power production by 9% within 30 days.	Mono-Si	Not stated	Oman	[183]
Dry, hot in the summer and moderate temperature with frequent rainfall in the winter.	Dust	PV modules were kept for 6 months for soiling evaluation, result showed 20% power loss despite rainy days in 2 months.	Mono-Si	Not stated	Iran	[184]
Dry, hot in the summer and moderate temperature in the winter.	Dust	PV modules were kept for 6 months for soiling evaluation, an average of 18% of power loss was recorded.	Mono-Si	Not stated	Iraq	[185]
Cold, frequently accompanied by snowstorms.	Cold and snowing	Analysis model to forecast PV production expected 80% power loss if the snow thickness is 60 mm.	Not stated	Not stated	China	[186]
One city has dry and hot weather, whereas the other has lower temperatures.	Hot	Comparison between two PV systems installed in two cities. The one installed in the Mediterranean climate is superior, despite the high humidity level.	Both	Not stated	Morocco	[187]
Hot accompanied by high relative humidity up to 85%.	Hot and humid	EVA discolouration and delamination, snail track, metal corrosion, backsheet cracks and burns, hotspot.	Mono-Si	10	U.S.	[32]
Dry and hot climate, with frequent sandstorms, located in the desert.	Dry and hot	EVA discolouration and delamination, metal corrosion.	Both	11	Algeria	[33]
Hot with a high relative humidity range; average is 67%.	Hot and humid	EVA discolouration and delamination, snail track, metal corrosion, soiling, backsheet chalking, J-box delamination.	Mono-Si	11	Algeria	[34]

Table 4. *Cont.*

Weather Condition	Weather Highlight	Failure Modes Detected or Explored and Component Affected	Type of PV (Poly-Si, Mono-Si)	Lifetime (Years)	Country	Ref.
Moderate climate with considerably high relative humidity which can reach 83% in the winter months.	Humid	EVA discolouration and delamination, cracked cell, metal and bypass corrosion, hotspot, PID.	Poly-Si	14	Germany	[35]
Cold and humid; average temperature range between −6.7 °C and 21 °C; average humidity range between 30% and 99%.	Cold	Glass breakage, EVA discolouration and delamination, cracked cell, metal corrosion, hotspot.	Poly-Si	10	Norway	[36,37]

5. Detection Methods for Failures in PV Modules

Depending on the connection type of the PV system, whether it is grid-connected or standalone, failures occur on two different sides of the connection: DC and AC. They often occur on the DC side when the system is standalone, whereas they may exist on the AC side when connected to the grid. Distinguishing them can be achieved by monitoring the system's power output; it reduces and rarely leads to a blackout in DC failure but causes a total blackout when a failure occurs on the AC side [17].

Madeti and Singh [17] reviewed the literature and classified all failure detection techniques into two groups: (a) fault detection based on the ground, which involves monitoring sensors, and (b) fault detection based on a space monitoring system. The latter group is cost-effective owing to the lack of instrumental sensors, but depending on weather conditions, its accuracy can be reduced dramatically. The sensors employed in ground-based techniques are set to observe major electrical parameters, such as current, voltage, and power. These parameters vary based on the PV system's connection type; for instance, grid impedance exists in grid-connected systems, but not in standalone systems [17].

Each type of PV failure requires a different tactic to be detected. For example, detection tactics employed in optical failures are different from those employed in electrical failures. Optical failures may be seen by the naked eye, whereas electrical losses require instruments to monitor, store data, and perform analyses. Furthermore, detection techniques for failures on the AC side, e.g., failure of PV converter and power blackout of the grid, are utterly different from those on the DC side [17]. This review will briefly examine the failure detection techniques proposed for the DC side (PV module components).

According to Pillai and Rajasekar [18], for a detection technique to be effective, it should meet the following criteria: (1) able to detect failures without interfering with power or causing blackout, (2) able to pinpoint the failure, (3) cost-effective and flexible, (4) simple in structure, and (5) can be applied to a variety of PV systems. Madeti and Singh [17] classified failure detection techniques on the DC side into six categories: electrical characterisation, infrared imaging, visual inspection, ultrasonic inspection, electroluminescent imaging, and lock-in thermography. A similar classification was presented by Santhakumari and Sagar [174], but with fewer details and a different terminology; e.g., electrical characterisation was referred to as indoor testing using a solar simulator. Twelve detection techniques were listed under electrical characterisation in Madeti and Singh [17]; five of them were reviewed in more detail by Mellit et al. [188]. Those five techniques were signal and processing, *I–V* characteristic analysis, power loss analysis, voltage and current monitoring, and machine learning detection techniques.

5.1. Visual Inspection

The first step to detect PV failures is to view the PV modules from different angles. Visualising techniques are demonstrated and reviewed by the international standard IEC 61215 [189]. The standard considers broken, cracked, and misaligned module surfaces as well as bubbles of the encapsulant as significant defects. Failures such as delamination, mild discolouration, corrosion, J-box failure, and shading could be visualised by the naked eye without employing other detection techniques [87,188]. Furthermore, some researchers, e.g., [150,190], proposed the use of drones with installed cameras to visualise PV plants more effectively.

5.2. Infrared Imaging

Infrared imaging is a detection technique based on the solar cell's reversed biased circulating current in a PV module [191]. In the case of failure, the solar cell dissipates heat which an infrared camera can detect, see Figure 9. Hotspots, as well as microcrack failures, sometimes cannot be seen by the human eye. However, they may be caught by infrared imaging. Predicting failure before it takes place is a major advantage of this technique. On the other hand, one drawback is expensive staffing costs [18]. The working principle is usually started by storing images of a healthy PV module to compare them to a faulty module when needed. This technique can detect hotspots, breakage of solar cells, disconnection, and PID failures [87].

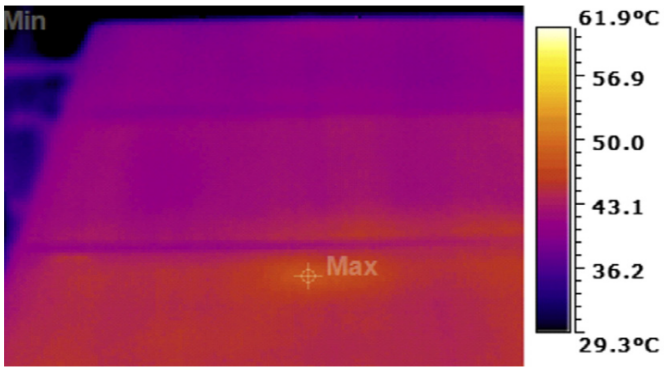
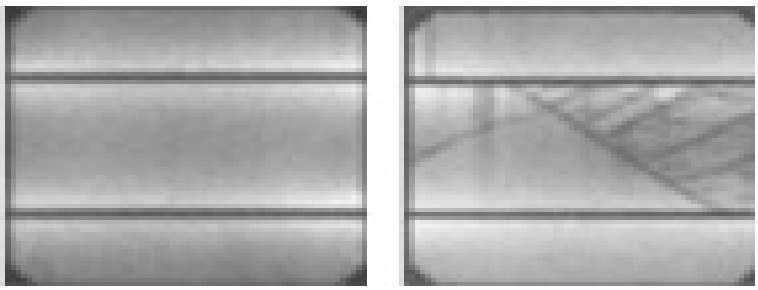


Figure 9. Infrared imaging to discover high-temperature cells in a PV module [18].

5.3. Electroluminescence Imaging

This technique is used to detect a potential cracked cell by pinpointing the low contact area of a PV module [192]. The working principle of this technique is to look into the recombination losses (shunt defects) created by a current injected into the solar cell's metallic contact [193–195]. In addition to detecting cracked cells, snail tracks and PID failures can also be seen using EL imaging [87], see Figure 10 for examples. The lock-in thermography detection technique has nearly the same working principle as EL but was found to be superior and more sensitive in detecting failures [122].



(**a**) (**b**)

Figure 10. (**a**) EL imaging of a healthy monocrystalline solar cell. (**b**) EL imaging of a cracked monocrystalline solar cell [196].

5.4. Ultrasonic Inspection

The ultrasonic inspection detection technique compares the frequency signals of a healthy and a faulty cell obtained by an ultrasonic transducer [197–199]. Resonance frequency tends to decrease when detecting a defective cell [198,200], see Figure 11 for example. The ultrasonic technique is mainly used to detect cracked cells in a PV module. An advantage of this method is that it infers the severity level of the cell crack based on the range of the frequency's bandwidth [198].

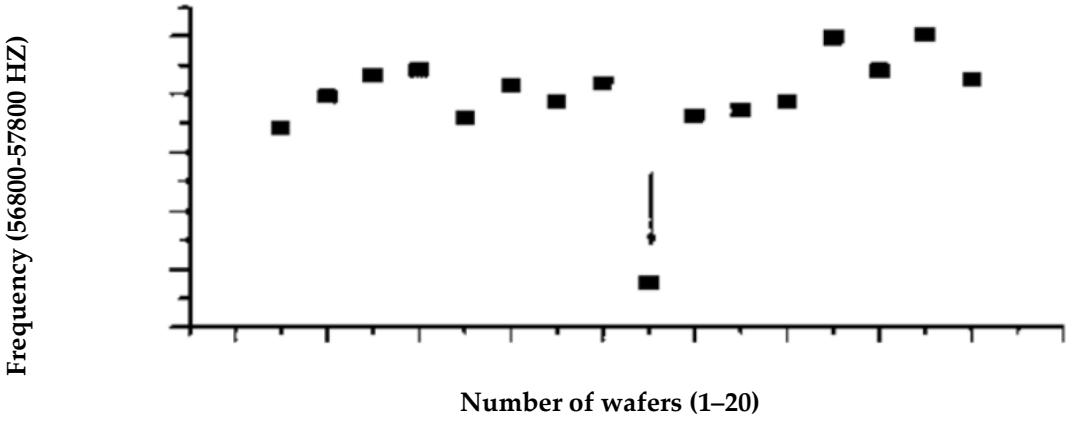


Figure 11. Ultrasonic inspection of several cell wafers showing cell no. 11 has an abnormal reduction in frequency, indicating a crack failure [197].

5.5. Electrical Characterisation

Electrical characterisation has been claimed to be the most common detection technique for PV failures [201]. This detection technique focuses on monitoring and spotting any changes in the PV system's electrical parameters. It was reviewed by Mellit et al. [188] and referred to as a signal-processing approach that involves protection devices such as over-current protection devices. Pillai and Rajasekar critically reviewed protection devices [18], explaining the limitations and drawbacks of detecting a failure instantly, particularly under low irradiance, which may lead to serious safety issues and catastrophic failure. For instance, a delayed response from over-current protection devices during a PV failure leads to an electric arc or fire [188].

I–V curves, power losses, and PV module temperature can all be used to detect PV failures. For instance, if the temperature of the PV module increases due to a hotspot failure, sensors can be put in place to detect abnormal increases [202], and further, insulation monitoring devices can evaluate the resistance between the current-carrying conductor and the ground to detect ground failure [203]. Fuses are able to calculate the residual system's current [204].

One technique of using residuals to detect failures requires the simulation of a healthy PV module to obtain the maximum voltage (V_m), maximum current (I_m), and power values and then compare these values with the actual measured data. Residuals (the difference between the simulation and the experimental values) indicate the existence of a PV failure. Depending on the residual extent, the type of failure can be predicted [205,206]. Harrou et al. [206] used this method as an indicator of abnormal changes in a PV system. However, they concluded the monitored parameters were insufficient to detect extreme degradation and partial shading failures.Garoudja et al. [205] used the residual technique and reached the same result as Harrou et al. [206], predominantly for shading failures. Thus, it is more effective to include other *I–V* parameters as an indicator such as short-circuit current and fill factor.

One obstacle preventing the accurate detection of PV failures is obtaining noisy data from measurements. Harrou et al. [206] focused on detecting four types of PV failures on the DC side: open circuit, short circuit, partial shading, and degradation failures. In order to detect those failures accurately, they used a wavelet-based multiscale tool to separate the

noisy measurement data. Garoudja et al. [205] also concluded that using wavelet-based multiscale anti-noise techniques increased the accuracy of PV failure detection. Noisy data seem to be an obstacle in Ali et al. [207], who ended up suggesting to separate them using noise separation devices or working out efficient ways for noise separation. However, with advanced technologies at present, artificial intelligence (machine and deep learning) in particular, noisy data have been tackled in many recent studies, e.g., [208,209]; that is, the accuracy of PV failure detection was robust even with the presence of noisy data.

5.5.1. Detection Techniques Using *I–V* Curve Parameters

The *I–V* curve, see Figure 12, shows the output combinations between voltages and currents, delivering the values of major parameters: short-circuit current, open-circuit voltage, maximum power output, and fill factor. Modelling of healthy or expected *I–V* curves and power output via engineering modelling programs is also classified under electrical characterisation and was referred to as "model-based difference measurements" by Pillai and Rajasekar [18]. One of the reasons for simulating the *I–V* curve, instead of obtaining it experimentally, is the risk associated with performing faulty operation scenarios in a real PV plant, which may get out of control [210].

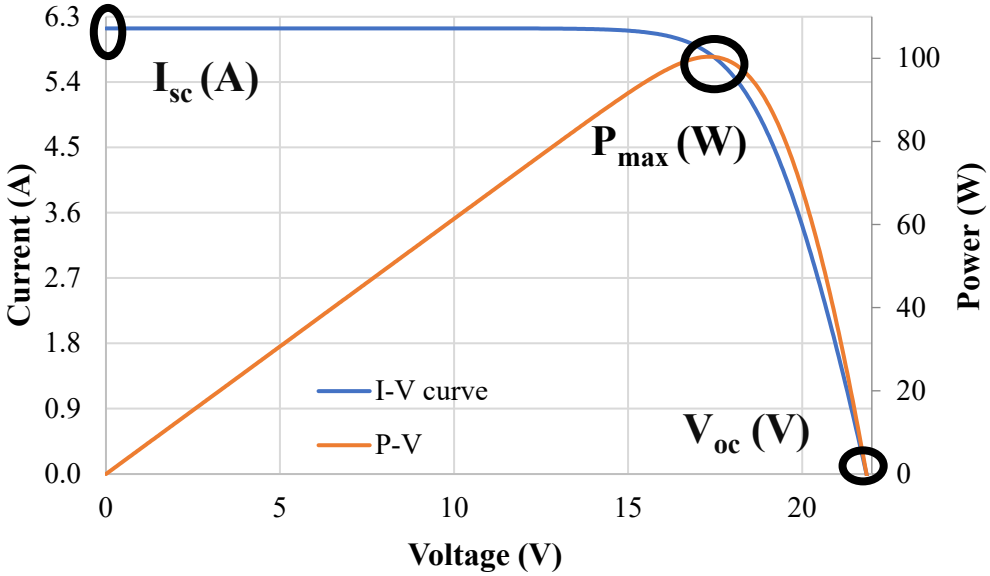


Figure 12. Current–voltage and power–voltage curves display the major parameters of a solar cell; I_{sc}, current at zero volts; V_{OC}, voltage at zero amps; and P_{max}, maximum power output. The circles show the location of short circuit current, open circuit voltage and maximum power point.

Chen et al. [211] investigated four failure modes and recorded their impacts on the *I–V* curve. Short-circuit failure was found to decrease both P_{max} and V_{OC}. Degradation failure could be observed when a reduction in the *I–V* slope accompanied a gradual decrease in P_{max}. I_{SC} was decreased in open-circuit failure. In case of partial shading failures, the *I–V* curve was distorted, forming multiple P_{max} points; one before shading and one after shading. Ali et al. [207] fabricated three shading scenarios on a PV string that contained three polycrystalline modules; firstly, one-third of two modules were shaded; secondly, three cells in each module were shaded; and lastly, half of the cells in each module were shaded. As a result, *I–V* curves were distorted, and V_{OC} decreased in all three scenarios. The greatest value was seen in the third scenario, with a 68% reduction.

Köntges et al. [15] agreed with Ali et al. [207] that shading failures distort the *I–V* curve, creating multiple P_{max} points. They also listed the effect of various PV failures on the *I–V* curve; I_{SC} is affected mainly by optical failures and losses of transparency, EVA discolouration, glass breakage and shattering, and EVA delamination. It is also affected by disconnected soldering of the cells, PID, and cracked cells in the PV module. On the

other hand, V_{OC} is affected by defective bypass diodes, PID, and disconnected soldering of the cells. The fill factor is affected by delamination, corrosion, and cracked cells. All PV failures were found to reduce P_{max}, except for bypass defects.

The awareness of the electrical characterisation's boundaries assists in training supervised machine learning algorithms by looking for deviations from their previous relationships to detect PV failure and degradation. Chine et al. [212] implemented artificial neural networks (ANN) to detect eight types of faults related to shading caused by snow and soiling. A probabilistic neural network (PNN) algorithm was implemented to predict and classify three failure mechanisms by Garoudja et al. [210] and was found to be superior and more efficient than ANN, even in the presence of noise. The substantial number of published studies that proposed or developed artificial intelligent models to detect PV failures demanded a review to arrange, compare, and classify them. Researchers in recent years were aware of this gap and many reviews were conducted as a result, e.g., [170,213–217].

5.5.2. Detection of Degradations and Failures Using Shunt and Series Resistance

Modelling of the *I*–*V* curve's major parameters, e.g., short-circuit current and open-circuit voltage, via mathematical equations assists in extracting the values of other key parameters [218,219], namely series resistance and shunt resistance. As most PV failure and degradation modes will severely impact these parameters, quantifying them will significantly enhance detection models of PV defective modes [220]. Nonetheless, the precise extraction of series and shunt resistance values is challenging [218,219] and thus many researchers, e.g., [221–225], have developed approaches to optimise extraction techniques to estimate their range values. While accurate parameter extraction might be challenging, estimating their values' range is still vital for the healthy operation of PV modules.

Shunt resistance offers a pathway for photogenerated current, allowing it to bypass the PV equivalent circuit, whereas series resistance infers the solar cell component resistance altogether, such as the cell base and busbar resistance. Series resistance increases in the presence of PV failures or degradation. It has been claimed that degradation mechanisms influencing series resistance are the most prevalent degradation mechanisms after EVA discolouration [226]. Moreover, these have greater severity; Wohlgemuth and Kurtz [42] stated that increases in series resistance in PV modules may lead to disastrous consequences, resulting in fires. In contrast, a higher value of shunt resistance indicates a safe operation of the PV cell as it directs most of the generated photocurrents to flow through one healthy path [71,227]. However, when current is lost through alternative paths, R_{sh} reduces significantly, which ultimately leads to a severe drop in overall power production [71,227,228].

Kaplani and Kaplanis [229] investigated PV panels that were deployed for twenty years. They discovered that an 80% reduction in R_{sh} and a 50% increment in R_s were strongly linked to the PV panel's degradation, leading to 11% power loss. Furthermore, power degradation occurred as a result of several failures that directly impacted and reduced shunt resistance, including soldering defects, microcracks, shading, and hotspots [230,231]. Most of these failures were found to directly impact and increase series resistance, too [226,232,233]. It can be noted that the majority of PV defects summarised by Tsanakas et al. [56], particularly the electrical ones, have been found in the literature to decrease R_{sh} and increase R_S. Based on this, as well as on other findings, e.g., [88,220], shunt as well as series resistance appear as strong predictors of PV failures and deterioration. Optical failures such as EVA delamination were found to lower shunt resistance and increase series resistance. Gxasheka et al. [234] compared the parameters of five deployed PV modules. The one affected by delamination had approximately 50% lower shunt resistance accompanied by a 61% increment in series resistance.

The effect of encapsulant discolouration, the most prevalent EVA defect, was also determined by Rajput et al. [235] to decrease shunt resistance. However, a study by Sinha et al. [231] compared two module pairs that operated for 20 years in India; one in each pair had brown EVA discolouration. They assumed there was no evident link found between brown EVA discolouration and shunt resistance decrement. This is perhaps due to the

PV module receiving less illumination when EVA is discoloured [168] and, as stated by Ruschel et al. [236], shunt resistance increases when solar illumination decreases. However, this can be applied if EVA experiences the same discolouration level across the PV module. Otherwise, different levels of EVA discolouration might have the same effect as minor shading and will lead eventually to decreased shunt resistance.

On the other hand, electrical failures which are unlikely to be spotted by the naked eye [56], such as microcrack failures, were found by Zhang et al. [237] to decrease R_{sh} significantly. In their study, low shunt resistance was spotted in the short-circuit current slope in the *I*–*V* curve of a module with cracked cells, whereas the increment in series resistance was minor unless the range of irradiance was between 250 and 475 W m^{-2} [238]. Saavedra et al. [133] also experimentally investigated PV modules with cracked cells and reached the same conclusion as Zhang et al. [237], but noted a greater increment in R_S. Potential-induced degradation was also directly linked with shunt resistance reduction and series resistance increment [238–240]. Myer and Dyk [70] simulated a PV module that consisted of 36 cells with 30% of the cells under shading failure to analyse the effect of shading on electrical parameters. In their findings, both shading and hotspots, when present, significantly lowered shunt resistance.

Degradation and many PV failures were associated with low shunt resistance and increased series resistance, making it vital to explore their behaviours when the solar cell degrades. A MATLAB study conducted by Dhass et al. [241] showed that a reduction in shunt resistance caused a significant decrease in short-circuit current compared with open-circuit voltage. Another software program was employed by Dyk and Meyer [242] for shunt resistance reduction effects. They found that a decrement in shunt resistance reduced P_{MAX}, V_{OC}, and fill factor, with a slight increase in I_{SC}. Conversely, Sarkar [243] simulated the effect of a reduction in R_{sh} using SPICE and showed that a reduction in shunt resistance leads to a greater decrement in open-circuit voltage instead of short-circuit current. It can be noted that the outcome discrepancies were due to the studies [241–243] relying on simulation software programs.

Several practical experiments have also been conducted and published in the literature; back in 1969, Kennerud [244] investigated a cadmium sulphide (CdS) solar cell, applying the Newton–Raphson technique to solve the *I*–*V* equations. Then, he manipulated the electrical parameters, including R_{sh} and R_s, to examine their influence on *I*–*V* characteristics. The findings were experimentally verified and it was demonstrated that a decrease in shunt resistance was associated with a reduction in open-circuit voltage, while increasing series resistance was linked to a reduction in fill factor. Rummel et al. [245] fabricated a twelve-cell monocrystalline module to explore the effect of 24 scenarios of shunt resistance levels at different irradiance levels, falling from 1000 W m^{-2} down to 90 W m^{-2}. A significant drop in the module's efficiency was observed after reducing shunt resistance, particularly at the lowest shunt resistance level. With the assistance of electroluminescence (EL) imaging techniques, Roy and Gupta [228] investigated images of solar cells exhibiting low shunt resistance levels linked with faulty operations such as hotspots. Shunt resistance was reduced artificially to six levels from 0.3 kΩ to 0.001 kΩ. The results showed darker images for cells with reduced R_{sh}, with the level of darkness becoming more intense with the lowest levels of shunt resistance.

To sum up, it can be noticed from the literature that numerous studies have been conducted to explore the effects of shunt and series resistance as they are directly linked to most PV failures. Despite that, not as many studies employ them as indicators or predictors in the detection of PV failures or degradation, and the studies that do so are predominantly related to series resistance. Al Mahdi et al. [246,247] filled the gap in knowledge of shunt resistance in terms of PV degradation by developing a lab experiment that gradually and artificially decreased the shunt resistance of polycrystalline solar cells to propose a detection model. It was found that critical degradation of PV cells occurred when shunt resistance decreased to 100 Ω cm^2. Further experimental investigations for employing shunt and series resistance are needed to arrive at comprehensive and robust detection techniques for

PV failures. Table 5 lists the most recent review studies about some detection techniques of PV failure mechanisms.

Table 5. Most recent review studies of some detection techniques.

Detection Technique	Highlight	Ref.
Infrared Imaging (IR)	How PV benefits from IR and what can be done to expand IR application in PV with the assistance of machine learning models.	[191]
Electroluminescence (EL) and Deep Learning	A brief review of EL imaging in detecting microcrack failure modes with useful comparison to IR technique and the feasibility of using them in artificial intelligence models.	[248]
Machine Learning	Review of ML studies underlining their accuracy in detecting PV failure modes and highlighting common models, namely super vector (SVM) and neural network (ANN).	[249]
Deep Learning	Comparing deep learning models, their pros and cons, as well as proposing a future path for enhancement.	[250]
Electrical Characterisation	Reviewing and comparing detection techniques in grid-connected PV plants.	[251]

6. Conclusions

This review has captured a body of knowledge by highlighting the global growth in PV module deployment, stressing the need for understanding the reported PV failure behaviours and how they are initiated. When they occur, they lead to higher degradation rates, causing a significant reduction in power output and, in the worst-case scenario, may become catastrophic. Most literature reviews of PV failures are based on the severity and frequency of occurrence of failures. This review takes a different perspective and focuses on failure mechanisms based on PV module components, reviewing each component's susceptibility to failures.

Looking into the literature in depth allows for extracting the root cause of some failure and degradation mechanisms. For instance, UV, one of the environmental stress factors, is considered the root cause of the most common degradation, i.e., encapsulant EVA discolouration, which is responsible for the emergence of most optical failures, such as corrosion and delamination. Shading, glass breakage, and soldering defects, on the other hand, can cause hotspot failures. Most PV degradation mechanisms may lead to disastrous consequences, including human fatalities, when undetected or neglected.

In terms of failure detection techniques, it was pointed out that these should be simple, applicable to most PV systems, cost-effective, accurate, and able to detect failures at low solar irradiance levels. Typically, detection starts with visual inspection and then employs more instrumental methods such as infrared imaging. However, these devices are costly, require more labour, and are time-consuming and uncomprehensive, i.e., designed only to detect limited types of failures. In contrast, electrical characterisation, which includes monitoring the power or the *I*–*V* curve, infers most PV failures from shifts in the produced parameters. That would explain why it is the most common detection technique. Electrical characterisation detection techniques were detailed in several reviews, but there is a gap in engaging shunt and series resistance. This review details their effect, evaluating the possibilities for using them in electrical characterisation. This in turn paves the road for future studies to investigate *I*–*V* measurements under changes in shunt and series resistance, thereby enabling the development of models in a simple, applicable, comprehensive, and novel way to facilitate early intervention and avoid catastrophic deterioration.

Another future direction involves reviewing the available studies for preventive measures and recommended corrective actions for the failures listed in this review, evaluating their cost and feasibility of implementation in PV modules.

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Abbreviations

AM1.5G	Standard solar spectrum
EVA	Ethylene vinyl acetate
FF	Fill factor of the solar cell
G	Solar irradiance
I_{01}	First saturation current of the solar cell
I_{02}	Second saturation current of the solar cell
I_m	Maximum current output at the solar cell's current–voltage curve
I_{SC}	Short-circuit current of the solar cell
IR	Infrared imaging
I–V	Current–voltage curve of the solar cell
J-box	Junction box, a component of photovoltaic modules
PDMS	Polydimethylsiloxane, a type of polymer used as an encapsulant in photovoltaic modules
PET	Polyethylene terephthalate, a plastic material used as the backsheet in photovoltaic modules
PID	Potential-induced degradation
P_{max}	Maximum power output, the maximal power produced by the solar cell
PV	Photovoltaic
RPN	Risk priority number used for rating guidelines
R_{sh}	Shunt or parallel resistance of the photovoltaic solar cell
R_s	Series resistance of the solar cell
SPICE	Simulation program with integrated circuit emphasis
STC	Standard test condition
TPU	Thermoplastic polyurethane
UV	Ultraviolet
V_{OC}	Open-circuit voltage of the solar cell
V_m	Maximum voltage output at the solar cell's current–voltage curve

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Perancangan Sistem Pembangkit Listrik Tenaga Surya (PLTS) *Off-Grid* Pada Gedung Perkuliahan

Design of Off-Grid Solar Power Plant System (PLTS) in Lecture Building

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Abstract

Off-Grid Solar Power Plant (PLTS) system planning at Building F of the Sumatra Institute of Technology, South Lampung Regency, Lampung Province is one of the efforts or strategies in reducing the use of conventional electrical energy from the main supplier, namely the State Electricity Company (PLN), and helping to succeed the government's efforts to increase the consumption of new and renewable energy. In PLTS system planning, the aspects that will be analyzed in this research are technical aspects with the help of PVsyst software to collect data regarding technical indicators such as performance ratios and energy production generated by *Off-Grid* PLTS. In this research, the required land area is 52 m2 from a total of 930 m2 of available land. The simulation results show that the planned rooftop solar system has a capacity of 10.8 kWp using 24 units of AE SOLAR MC144 430-450 W type solar modules, with the capacity of each module being 450 Wp. The PLTS system uses 1 inverter with the type Victron Quattro 48/15000 (15 kW) with a capacity of 15,000 W and uses a battery with the type LUNA2000-15- S0 which has a capacity of 15 kW in each unit. In this study, the solar module received solar irradiation of 4,616 kWh/m2 per day and 1,684 kWh/m2 per year. The production obtained in this study amounted to 14,475 kWh per year. The percentage of the Performance Ratio (PR) value produced by the designed OffGrid PLTS system is 73.01%.

Keywords *Off-Grid;* PVsyst, Performance Ratio (PR); PLTS

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1. PENDAHULUAN

Penggunaan energi listrik di Indonesia mencapai 1285 kWh perkapita pada tahun 2023 dimana total ini meningkat 9,55% dari tahun 2022 yang sebesar 4,45% (Maisarah, Andiny, & Safuridar, 2024). Data tersebut menunjukkan bahwa kebutuhan akan terus meningkat setiap tahunnya. Salah satu solusi yang dapat diberikan dalam prihal ini adalah memanfaatkan energi terbarukan dari proses alam yang berkelanjutan dan dapat diperbaharui untuk mengurangi ketergantungan terhadap penggunaan pada bahan bakar fosil. Indonesia memiliki potensi besar dalam memanfaatkan energi terbarukan tersebut terutama pada potensi energi surya karena terletak di garis khatulistiwa sehingga mendapatkan paparan sinar matahari sepanjang tahun yang mencapai 112.000 GWp atau setara dengan 89.600.000 MW (Octavia, Hutama, Tampoy, & Rohmana, 2023). Adapun teknologi dan infrastruktur yang dapat mendukung penggunaan energi surya adalah dengan mengimplementasikan pembangkit listrik tenaga surya (PLTS) (Yuwono, Diharto, & Pratama, 2021).

Penggunaan PLTS sebagai transisi energi terbarukan dapat dilakukan sebagai bagian dari pergeseran energi ke arah yang lebih ramah lingkungan. Proses mengonversi sinar matahari secara langsung menjadi panas atau listrik untuk memenuhi permintaan energi manusia disebut pemanfaatan energi surya. Hal ini dapat diterapkan dalam skala besar maupun skala rumah tangga dengan memasang panel surya (Faizal, Rumbayan, & Silimang, 2021).

Menurut Dewan Energi Nasional (DEN), untuk mendukung pengembangan PLTS atap, pemerintah membuat Permen ESDM No. 26 Tahun 2021, yang menggantikan Permen ESDM Tahun 2018 tentang Penggunaan Sistem PLTS Atap oleh Konsumen PT PLN (Persero) (Bayu & Windarta, 2021). Ketentuan Ekspor kilowatt-jam listrik ditingkatkan dari 65% menjadi 100% (Ardiansyah, Yandri, Khwee, 2023). Berdasarkan data yang tercantum dalam rancangan RUEN, Provinsi Lampung memiliki potensi energi surya mencapai 2.238 megawatt (MW) (Indonesia, 2017).

Menurut data dalam Rencana Umum Energi Daerah (RUED) Provinsi Lampung, kebutuhan energi terus mengalami peningkatan setiap tahun seiring dengan pertumbuhan jumlah penduduk. Pemerintah Provinsi Lampung telah merancang Rencana Umum Energi Daerah (RUED) yang meliputi strategi pemanfaatan energi terbarukan, khususnya energi surya. Dokumen ini bertujuan untuk memaksimalkan potensi energi daerah guna mencapai target bauran energi terbarukan sebesar 23% pada 2025 dan meningkat menjadi 31% pada 2050 (Lampung, 2023).

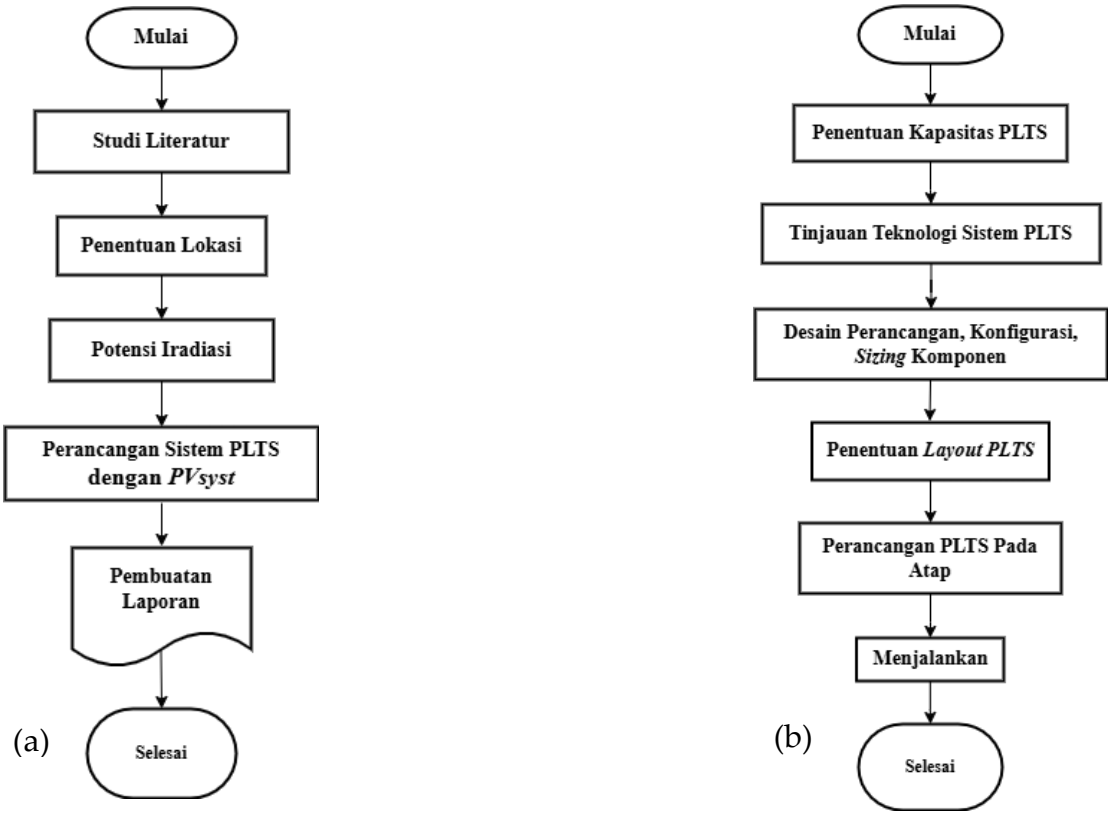
Salah satu bentuk pemanfaatan energi surya di Provinsi Lampung adalah melalui pembangunan PLTS Atap *Off-Grid*, yang dapat digunakan pada gedung perkantoran, fasilitas pendidikan, maupun kebutuhan rumah tangga secara mandiri. PLTS *Off-Grid* adalah jaringan pembangkit listrik tenaga matahari yang beroperasi secara mandiri tanpa terhubung ke jaringan listrik utama (PLN) (Anwar, Yunianto, & Purnomo, 2023). Jaringan tersebut bekerja dengan mengonversi energi matahari menjadi listrik dengan panel surya, namun listrik yang dihasilkan tidak disalurkan ke jaringan PLN. Sebaliknya, energi listrik tersebut digunakan secara langsung untuk memenuhi permintaan pribadi dengan tidak mengandalkan sumber listrik lain. Selain itu, sistem *Off-Grid* juga sering dimanfaatkan sebagai alternatif di wilayah yang belum teraliri oleh jaringan listrik utama. Manfaat pembangunan PLTS *Off-Grid* terletak pada penggunaan sumber daya terbarukan, yaitu sinar matahari, untuk menghasilkan energi listrik tanpa menimbulkan emisi gas rumah kaca atau polusi, sehingga lebih ramah lingkungan.

Dalam penelitian ini, peneliti memilih Gedung F di Institut Teknologi Sumatera, Lampung Selatan, Provinsi Lampung, sebagai lokasi penerapan sistem PLTS *Off-Grid*. Gedung F dipilih karena belum terintegrasi dengan PLTS yang telah tersedia di Institut Teknologi Sumatera dan masih bergantung pada sumber energi konvensional. Oleh karena itu, diperlukan pasokan listrik tambahan yang dihasilkan oleh PLTS. Energi listrik yang dihasilkan akan dimanfaatkan untuk area publik dan fasilitas pendukung dengan perkiraan penggunaan selama 24 jam. Pemilihan sistem PLTS *Off-Grid* pada Gedung F dipilih sebagai solusi alternatif guna memenuhi kebutuhan listrik di kawasan gedung perkuliahan. Berdasarkan data dari Global Solar Atlas, lokasi Gedung F Institut Teknologi Sumatera memiliki tingkat iradiasi sebesar 4.616 kWh/m² per hari.

2. METODE

Metode deskriptif digunakan dalam penelitian ini untuk menganalisis, dan menjelaskan aspek teknis dan implementasi PLTS *Off-Grid* pada Gedung F. Penelitian ini bertujuan untuk menggambarkan kondisi eksisting, kebutuhan energi, desain an kinerja sistem PLTS secara sistematis (Putri, Kartini, Joko, & Tjahyaningtijas, 2025). Adapun aspek yang akan dipastikan pada sistem antara lain mencakup potensi sumber energi, analisis kebutuhan energi pada gedung F, menentukan kapasitas sistem PLTS *Off-Grid* yang sesuai, serta evaluasi potensi dan efisiensi sistem dalam memenuhi kebutuhan listrik gedung. Selain itu, berdasarkan analisis teknis, perancangan dan pemilihan komponen PLTS seperti panel surya, baterai, inverter dan

juga sudut kemiringan serta orientasi arah panel yang optimal (Manab, H, Rabiula, & Matalata, 2022). Berikut ini **Gambar 2.1** diagram alir yang menggambarkan alur penelitian yang adakan dilaksanakan.



Gambar 2.1 *a.* Diagram Alir Penelitian; *b.* Diagram Alir Perancangan PVsys

3. HASIL DAN PEMBAHASAN

3.1. Estimasi Kebutuhan Listrik Operasional

Pada penelitian ini, telah diperoleh data berupa estimasi kebutuhan listrik untuk mendukung operasional Gedung F ITERA. Data yang telah didapatkan tersebut akan digunakan untuk membuat perkiraan analisis teknis pada pembangunan PLTS *Off-Grid*. Rata-rata kebutuhan daya sebuah gedung kampus termasuk dalam golongan B-2/TR atau B-3/TR, dengan kapasitas daya berkisar antara 6.600 VA – 200 kVA atau di atas 200 kVA. Adapun tarif listrik yang berlaku untuk golongan ini adalah sekitar Rp 1.444,70 hingga Rp 1.444,74 per kWh. Berdasarkan data estimasi kebutuhan listrik pada Gedung F ITERA, diketahui bahwa beban listrik yang diperlukan untuk setiap ruangan adalah 4.235 watt, dengan total kapasitas beban seluruh ruangan di gedung mencapai 321.860 watt. Perhitungan yang disajikan pada **Tabel 3.1** dan **Tabel 3.2** menunjukkan estimasi kebutuhan listrik untuk setiap ruangan di Gedung F ITERA.

Tabel 3.1 Estimasi Kebutuhan Listrik Operasional Ruangan Gedung

Ruangan pada Gedung F ITERA (76 Ruangan)				
No	**Jenis Kebutuhan**	**Jumlah**	**Daya (*Watt*)**	**Total (*Watt*)**
1	*AC* 2 *PK*	2	1800	3600
2	Lampu Daya Rendah	4	20	80
3	*LED Troffer*	6	70	420
4	Kipas Angin	2	55	110
5	*CCTV* (*Closed-Circuit Television*)	1	25	25
			Total	4.235
		Total Kebutuhan (76 Ruangan)		321.860

Pada Gedung F ITERA memiliki area pendukung publik parkiran kendaraan bermotor. Beban listrik yang didapatkan pada area publik dan pendukung Gedung F ITERA adalah sebesar 18.580 *watt*, yang dapat dilihat pada **Tabel 3.2**. Beban puncak listrik pada Gedung F ITERA tercatat sebesar 340.440 W atau sekitar 340,4 kW. Data ini sangat penting karena digunakan sebagai dasar dalam penyusunan profil beban listrik (*Load Profile*), yang menggambarkan pola konsumsi energi listrik di gedung tersebut. Profil ini mencakup jenis perangkat yang digunakan, daya masing-masing perangkat, serta durasi operasionalnya setiap hari. Dengan mengetahui total kebutuhan energi harian, perancang sistem dapat menentukan jumlah panel surya yang diperlukan untuk memenuhi kebutuhan listrik secara optimal.

Tabel 3.2 Estimasi Kebutuhan Area Publik dan Pendukung

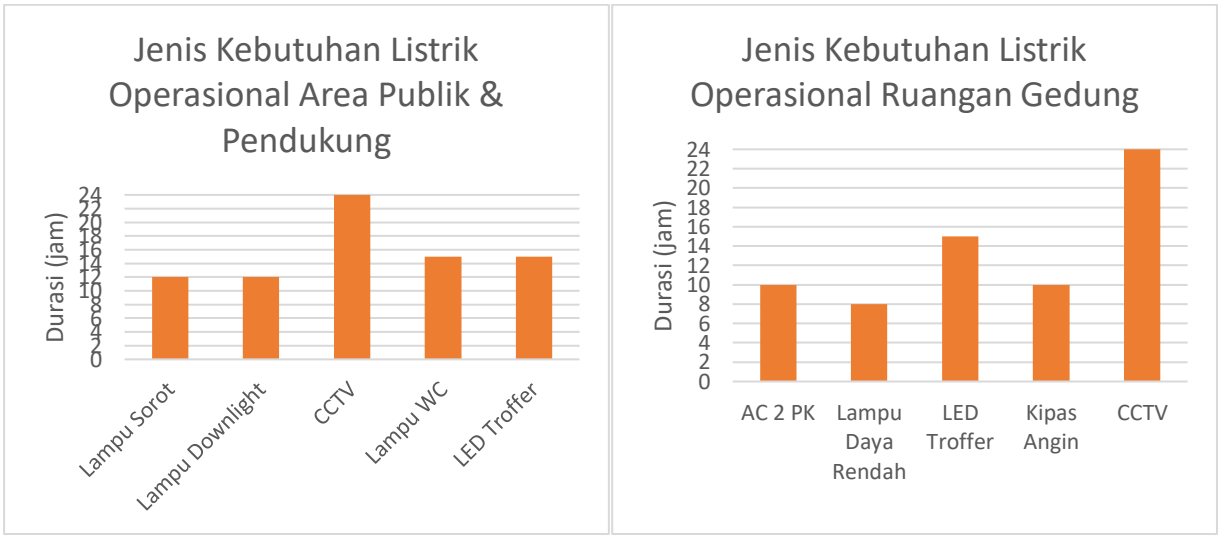
Area Publik dan Pendukung				
No	**Jenis Kebutuhan**	**Jumlah**	**Daya (*Watt*)**	**Total (*Watt*)**
1	Lampu Sorot Parkiran	8	85	680
2	Lampu Daya Rendah	10	20	200
3	*CCTV* (*Closed Circuit Television*)	20	25	500
4	Lampu *WC* (*Water Closet*)	80	12	960
5	*LED Troffer*	232	70	16.240
			Total Area Publik & Pendukung	18.580

Total estimasi kebutuhan listrik Gedung F ITERA, yang mencakup ruangan, area publik, dan fasilitas pendukung, adalah 340.440 watt.

3.2 *Load Profile*

Load profile atau profil beban adalah pola atau karakteristik penggunaan energi listrik yang menggambarkan seberapa besar daya atau energi yang digunakan oleh sistem beban dalam periode waktu tertentu, misalnya per jam, per hari, atau per bulan (Guna & Umar, 2021). Dalam perancangan sistem Pembangkit Listrik Tenaga Surya (PLTS) *Off-Grid*, memahami *load profile* sangat penting karena akan menjadi dasar untuk menentukan kapasitas komponen utama seperti panel surya, baterai, dan inverter (Aryanto, Jaya, & Darmawan, 2022). Pada penelitian kali ini *load profile* digunakan untuk mendapatkan kebutuhan energi listrik yang akan digunakan selama aktifitas di Gedung F ITERA berlangsung. Pada *load profile*, diperlukan data durasi pemakaian energi listrik untuk setiap jenis kebutuhan di Gedung F ITERA, yang diperoleh melalui survei langsung di lapangan.

Durasi pemakaian listrik dapat dilihat pada **Gambar 3.1.a**. Berdasarkan dari data survei langsung yang dilakukan pada lokasi penelitian. Pada hasil survei ditunjukkan durasi pemakaian listrik paling lama terdapat pada *CCTV* (*Closed-Circuit Television*) dengan durasi penggunaan sekitar 24 jam pemakaian dan durasi penggunaan dengan durasi terendah terdapat pada lampu daya rendah dengan waktu pemakaian sekitar 8 jam pemakaian.



(a) (b)

Gambar 3.1. a) Durasi Kebutuhan Listrik Operasional Gedung F ITERA; b) Durasi Kebutuhan Listrik Operasional Area Publik & Pendukung

Selanjutnya pada area publik dan pendukung pada Gedung F ITERA dengan pemaikain listrik tertigi terdapat pada *CCTV* (*Closed-Circuit Television*) dengan durasi pemakaian selama 24 jam, sedangkan durasi konsumsi energi listrik terendah terjadi

pada lampu sorot parkiran dan lampu daya rendah dengan waktu penggunaan selama 12 jam dalam satu hari. Data hasil survei tersebut tersebut dapat dilihat pada **Gambar 3.1.b**.

Untuk menentukan nilai *load profile*, diperlukan analisis terhadap durasi pemakaian energi listrik dalam operasional Gedung F ITERA, yang mencakup berbagai perangkat elektronik serta kebutuhan listrik di setiap ruangan dan area pendukung. Proses ini dilakukan guna memperoleh data yang akurat mengenai total konsumsi listrik harian serta pola penggunaan energi di gedung tersebut. Selain itu, agar pengolahan dan penyajian data lebih efisien, akurat, dan mudah dianalisis, digunakan bantuan perangkat lunak Microsoft Excel dalam melakukan perhitungan serta penentuan lama waktu penggunaan setiap alat elektronik. Melalui pendekatan ini, perhitungan kebutuhan energi listrik dapat dilakukan secara lebih sistematis, sehingga dapat menjadi dasar yang kuat dalam perancangan sistem PLTS *Off-Grid* yang optimal dan sesuai dengan kebutuhan Gedung F ITERA. Data yang ditampilkan berasal dari perhitungan estimasi kebutuhan harian dan beban kerja perangkat. Hasil analisis yang dilakukan dapat dilihat pada **Tabel 3.3**, dimana tabel tersebut menyajikan data *electric load* yang telah dihasilkan sesuai dengan waktu penggunaan setiap fasilitas. Setiap ruangan yang terdapat pada Gedung F ITERA memiliki kebutuhan energi listrik sebesar 44,64 kWh dengan jumlah keseluruhan ruangan yang ada adalah 76 ruangan. Adapun perhitungan pada **Tabel 3.3** & **Tabel 3.4** menggunakan persamaan 1 berikut (Duffie & Beckman, 2013).

$$E_{total} = \sum_{i=1}^{n} (P_i \times t_1) \quad \textbf{(1)}$$

Keterangan:

E_{total} = Total konsumsi energi listrik harian (kWh)
P_i = Daya listrik perangkat ke- i (W)
$t\ i$ = Waktu penggunaan perangkat ke- i dalam sehari (jam)
n = Jumlah perangkat listrik yang digunakan

Jumlah secara menyeluruh untuk satu gedung membutuhkan energi listrik sebesar 3.392,64 kWh berdasarkan data lama pemakaian yang telah ditentukan. Pada area publik dan pendukung didapatkan *electric load* sebesar 284,6 kWh, dapat dilihat pada **Tabel 3.4**. Pada jumlah *load profile* dari 2 area bangunan tersebut dapat dijumlahkan *electric load* total pada kawasan Gedung F ITERA berjumlah 3.677,24 kWh

dalam perhari. Kebutuhan listrik yang akan dihasilkan sistem PLTS *Off-Grid* sebesar 100% untuk satu jenis kebutuhan dengan penggunaan yang rutin pada Gedung F, yaitu lampu daya rendah pada 76 ruangan yang ada.

Tabel 3.3 *Load Profile* Ruangan pada Gedung F ITERA

Ruangan pada Gedung F ITERA (76 Ruangan)					
No	**Jenis Kebutuhan**	**Jumlah**	**Daya (*Watt*)**	**Durasi (Jam)**	***Electric Load* (kWh)**
1	*AC* 2 *PK*	2	1800	10	36
2	Lampu Daya Rendah	4	20	8	0,64
3	*LED Troffer*	6	70	15	6,3
4	Kipas Angin	2	55	10	1,1
5	*CCTV* (*Closed Circuit Television*)	1	25	24	0,6
				Total	44,64
		Total Kebutuhan (76 Ruangan)			3.392,64

Tabel 3.4 *Load Profile* Area Publik dan Pendukung

Area Publik dan Pendukung					
No	**Jenis Kebutuhan**	**Jumlah**	**Daya (*Watt*)**	**Durasi (Jam)**	***Electric Load* (kWh)**
1	Lampu Sorot	8	85	12	8,16
2	Lampu Daya Rendah	10	20	12	2,4
3	CCTV (*Closed-Circuit Television*)	20	25	24	12
4	Lampu *WC* (*Water Closet)*	80	12	15	14,4
5	*LED Troffer*	232	70	15	243,6
				Total	284,6

Adapun nilai total estimasi untuk profil beban pada Gedung F ITERA yang terdiri dari ruangan dan area publik dan pendukung sebesar 3.677,24 kWh.

3.3 Analisis Teknis

Merujuk pada hasil perhitungan pada *load profile* pada yang dipaparkan pada **Tabel 4.3** dan **Tabel 4.4**, permintaan energi listrik yang dibutuhkan pada kawasan Gedung F ITERA adalah sebesar 3.677,24 kWh dalam satu hari. Analisis teknis ini

digunakan dalam merancang Pembangkit Listrik Tenaga Surya (PLTS) antara lain untuk dapat menentukan PV area, kapasitas PLTS, kapasitas inverter, kapasitas baterai. Berdasarkan analisis teknis dari aspek kebutuhan lahan yang di butuhkan untuk membangun PLTS *Off-Grid* di Gedung F ITERA, luas lahan yang dibutuhkan ada sekitar 1,7 *hektare*. Berdasarkan fakta dilapangan yang mana ketersediaan lahan yang tidak terlalu memadai dan terbilang terlalu memakan banyak area untuk kebutuhan 1 gedung saja. Oleh karena itu kebutuhan listrik yang akan dihasilkan oleh sistem PLTS *Off-Grid* adalah sebesar 100% hanya untuk salah satu jenis kebutuhan saja yaitu lampu daya rendah pada ruangan yang ada di Gedung F ITERA. Adapun perhitungan analisis teknis PLTS *Off-Grid* adalah sebagai berikut:

A. *PV Area*

Dalam perkiraan untuk menentukan luas area modul surya, didapatkan bahwa area yang diperlukan untuk membangun PLTS *Off-Grid* seluas sekitar 52 m^2 dengan luas area yang tersedia adalah 930 m^2. Jenis modul surya (panel surya) yang digunakan adalah modul dengan besaran kapasitas 450 Wp tiap modulnya. Pada perhitungan kali ini, nilai *global horizontal irradiation* yang diserap dalam rata-rata per hari yaitu sebesar 4,616 kWh/m^2. Perhitungan untuk mencari nilai PV *area* menggunakan persamaan (2) (Duffie & Beckman, 2013).

$$PV\ Area = \frac{Eb}{GSR \times TCF \times \eta PV \times \eta ef} \quad \textbf{(2)}$$

B. Kapasitas PLTS

Pada analisis perhitungan kapasitas PLTS *Off-Grid*, didapatkan luas area modul surya yang digunakan adalah seluas 52 m^2. nilai efisiensi dari modul surya yang dipilih sebesar 20,7%. Adapun nilai *Peak Sun Intensity* (PSI) yang dapat diterima oleh modul adalah 1000 W/m^2. Dari data tersebut jumlah kapasitas total yang dihasilkan adalah 10.764 Wp, dikonversi menjadi 10.8 kWp berdasarkan hasil perhitungan dari persamaan (6). Hal ini diperlukan untuk memastikan bahwa sistem dapat berjalan dengan bagus dalam berbagai keadaan. Dalam penerapannya, jumlah modul surya yang digunakan adalah sebanyak 24 modul dengan masing-masing kapasitas tiap modul adalah 450 Wp yang didapatkan menggunakan persamaan (3) dan persamaan (4) (Duffie & Beckman, 2013).

$$E_{day} = n \times \frac{watt}{kebutuhan} \quad \textbf{(3)}$$

$$PWP = PV\ area \times PSI \times \eta PV \quad \textbf{(4)}$$

C. Kapasitas Inverter

Dalam pertimbangan inverter yang akan digunakan untuk sistem PLTS *Off-Grid* pada Gedung F ITERA, didapatkan total kapasitas inverter yang digunakan sebesar 13.455 Wp atau dikonversi menjadi 13,5 kWp yang didapatkan

berdasarkan hasil perhitungan dari persamaan (5). Pada perancangan sistem ini dibutuhkan inverter dengan jumlah 1 unit dengan kapasitas 15 kW (Duffie & Beckman, 2013).

$$Clv = Dw \times Sf \quad \textbf{(5)}$$

D. Kapasitas Baterai

Dalam analisis kapasitas baterai untuk sistem PLTS *Off-Grid* di Gedung F ITERA, ditetapkan yaitu hari otonomi (*autonomy days*) yang diinginkan adalah 2 hari kerja dengan *Depth of Discharge* (DoD) baterai sebesar 90% dan nilai *Net Efficiency Factor* (nef) sebesar lebih dari 97%. Dengan kebutuhan beban listrik yang dibutuhkan sejumlah 50 kWp, maka kapasitas baterai yang dibutuhkan sebesar 1.477,4 Ah berdasarkan hasil perhitungan menggunakan persamaan (6) (Duffie & Beckman, 2013).

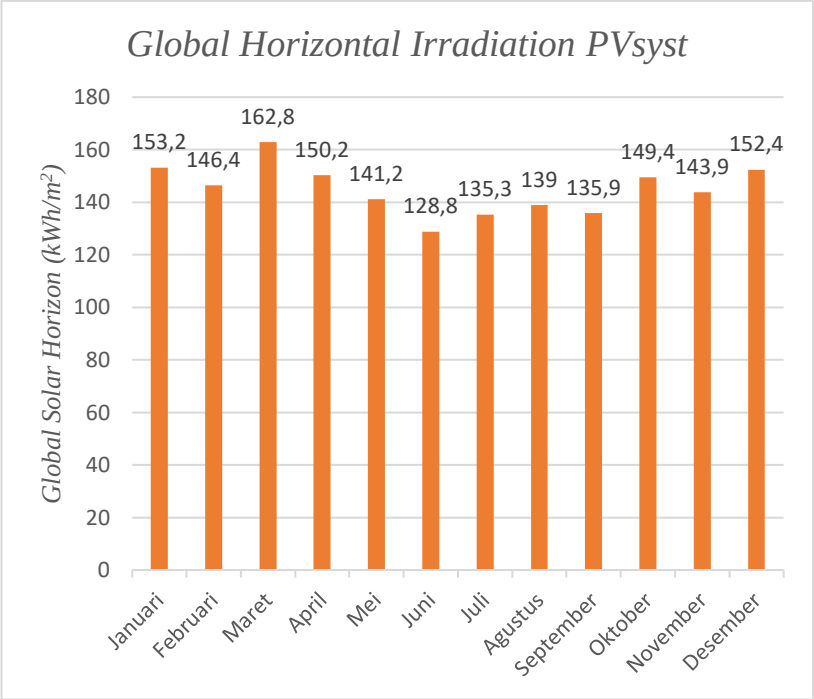
$$C = \frac{D_N \times E_{day}}{V_s \times DOD \times nef} \quad \textbf{(6)}$$

3.4 Hasil Simulasi *Software*

Pada penelitian kali ini didapatkan hasil simulasi sistem PLTS *Off-Grid* ini memiliki tujuan untuk menganalisa kelayakan dari teknis yang telah dirancang. Dalam pemodelan PLTS *Off-Grid* di Gedung F Institut Teknologi Sumatera, terdapat beberapa faktor yang dianalisis dan dievaluasi mencakup *Performance Ratio* (rasio kerja), *Shading* (efek bayangan), produksi energi dan nilai *Losses* (kerugian) dari skema yang dirancang.

A. Global Solar Horizon

Nilai *Global Solar Horizon* (GHI) yang dijadikan acuan dalam simulasi diperoleh dari *software Pvsyst* disajikan pada **Gambar 4.12**. Pada simulasi dengan *software Pvsyst*, *datasheet* cuaca yang digunakan adalah Metronom 8.2 dari tahun 2000-2021.

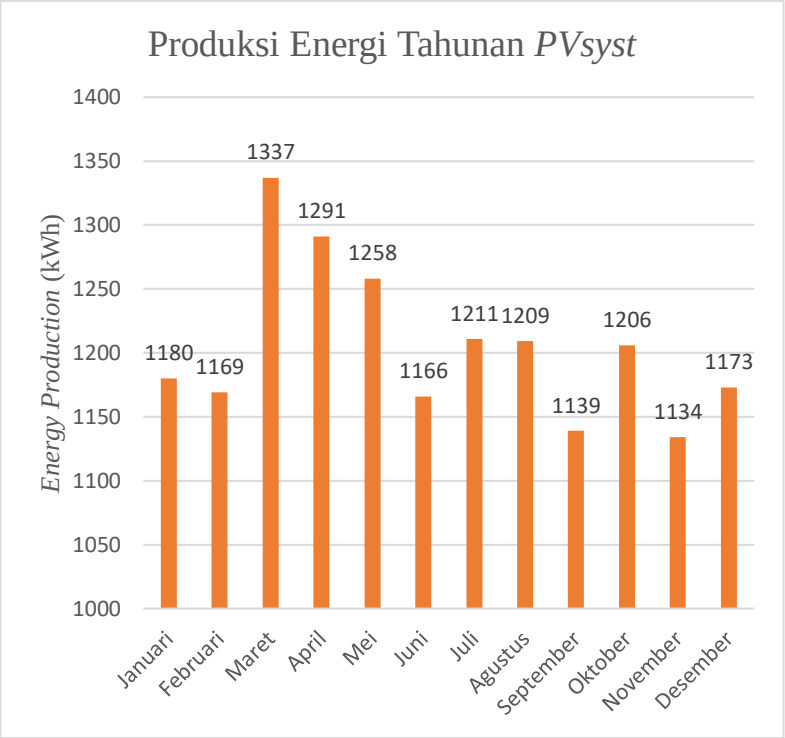


Gambar 4.11 *Global Horizontal Irradiation PVsyst*

Hasil *Global Horizontal Irradiation* yang didapatkan dari simulasi *software PVsyst* terdapat variasi yang mana nilai tertinggi dihasilkan pada bulan maret dimana jumlah total energi radiasi matahari yang diterima oleh permukaan panel dengan nilai sebesar 162,8 kWh/m^2 dengan total produksi selama satu periode dalam 1 tahun dalah sebesar 1.738,5 kWh/m^2. Hasil ini dipengaruhi oleh orientasi matahari pada bulan Maret karena memiliki sudut ketinggian tertinggi.

B. Produksi Energi

Berdasarkan hasil simulasi permodelan PLTS yang dirancang menggunakan bantuan *software PVsyst*, didapatkan nilai produksi energi (*Energy Production*) tiap bulan selama periode satu tahun dari *software* tersebut. Berikut pada **Gambar 4.13** dapat dilihat hasil *Energy Production*. Hasil *Energy Production* (Produksi Energi) yang didapatkan pada simulasi *software PVsyst* terdapat variasi yang mana nilai tertinggi dihasilkan pada bulan maret dengan nilai sebesar 1.337 kWh dengan total produksi selama satu periode dalam 1 tahun dalah sebesar 14.475 kWh. Hasil ini dipengaruhi oleh orientasi matahari pada bulan Maret karena memiliki sudut ketinggian tertinggi.



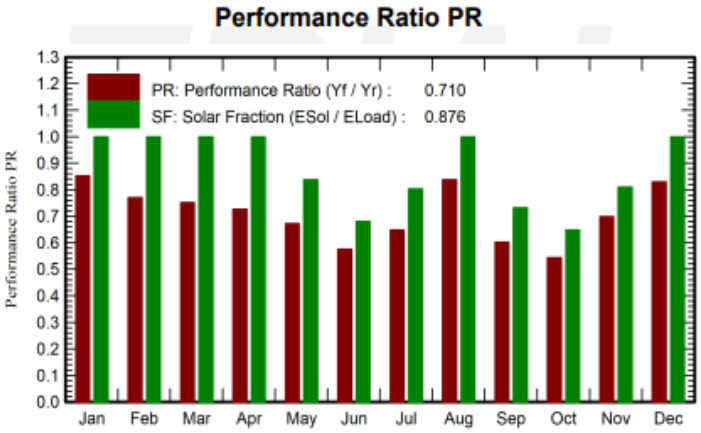
Gambar 4.12 Produksi Energi Tahunan

C. *Performance Ratio* (PR)

Pada hasil simulasi yang dilakukan menggunakan *software PVsyst* , dihasilkan nilai *performance ratio* sebesar 73,01%. Beberapa faktor dapat mempengaruhi tingkat *performance ratio* (PR) seperti cahaya, lokasi pembangunan, kondisi cuaca, ukuran kapasitas PLTS dan kualitas yang dipilih untuk sistem PLTS tersebut. Pada perhitungan berikut menggunakan persamaan (7) yang digunakan untuk mencari nilai *performance ratio* (Duffie & Beckman, 2013).

$$PR = \frac{E_{AC}}{E_G} \quad \textbf{(7)}$$

Dilihat pada **Gambar 4.14** dari nilai *performance ratio* yang dihasilkan oleh *software PVsyst*, kinerja sistem PLTS atap *Off-Grid* yang direncanakan termasuk dalam kategori diatas standar kelayakan dan layak untuk diimplementasikan untuk dibangun. Nilai minimal *performance ratio* untuk sistem PLTS agar dinyatakan layak untuk direalisasikan adalah sebesar 70% (DEVELOPMENT, SOLAR ENERGY;, 2024). berdasarkan *performance* ratio pada sistem PLTS, dapat dikatakan layak dikarenakan sistem dianggap cukup efisien dalam mengkonversi energi matahari menjadi energi listrik yang akan digunakan.



Gambar 4.13 Grafik *Performance Ratio* (PR)

4. KESIMPULAN

Pada penelitian kali ini yang telah dilaksanakan dan didapatkan kesimpulan sebagai berikut:

1. Pada perencanaan kali ini, didapatkan potensi energi di lokasi Gedung F Institut Teknologi Sumatera yang telah dianalisis menggunakan data sekunder dari *website Global Solar Atlas*. Lokasi penelitian berada di wilayah Kabupaten Lampung Selatan, Provinsi Lampung Selatan, memperlihatkan nilai iradiasi global senilai 1.684,9 kWh/m²/tahun. Berdasarkan analisis dari *website Global Solar Atlas*, bahwa kawasan Gedung F ITERA memiliki *Global Horizontal Irradiation* sebesar 4.616 kWh/m²/hari dan didapatkan sudut optimal pemasangan panel surya (Modul PV) di Gedung F ITERA adalah 8º. Proses iradiasi matahari yang paling optimal terjadi pada pukul 09.00 WIB hingga pukul 15.00 WIB, dengan puncak penghasilan energi terbesar terdapat pada pukul 11.00 WIB hingga pukul 13.00 WIB, mencapai 513,903 kWh pada sudut kemiringan modul surya 8º.
2. Pada hasil penelitian kali ini menunjukkan perancangan sistem PLTS *Off-Grid* pada Gedung F ITERA layak untuk direalisasikan berdasarkan aspek-aspek secara teknis yang telah terpenuhi. Luas area untuk pembangunan panel surya ini membutuhkan area sebesar 52 m² dengan menggunakan 24 buah modul PV tipe AESOLAR MC-144 450 Wp, dengan total kapasitas PLTS terpasang sebesar 10,8 kWp. Sistem ini juga dilengkapi oleh 1 unit inverter *Off-Grid* dengan tipe *Victron Quattro* 48/15000 (15 kW), dengan baterai untuk penyimpanan energi jenis Huawei LUNA2000-15-S0 yang direncanakan untuk menopang operasi mandiri (*Autonomy Days*) selama 2 hari. Baterai ini disusun secara paralel dengan total unit sebanyak 114 buah yang mempunyai kapasitas 15 kW pada masing-masing baterai. Pada hasil simulasi yang dilakukan menggunakan *software PVsyst*,

dihasilkan nilai *performance ratio* sebesar 73,01%. Nilai minimal *performance ratio* untuk sistem PLTS agar dinyatakan layak untuk direalisasikan adalah sebesar 70%. Beberapa faktor dapat mempengaruhi tingkat *performance ratio* (PR) seperti cahaya, lokasi pembangunan, kondisi cuaca, ukuran kapasitas PLTS dan kualitas yang dipilih untuk sistem PLTS tersebut.

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Research Article

Performance evaluation of off-grid solar systems for critical medical instruments in remote regions

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Abstract In areas with limited access to electricity or during power outages, ensuring continuous and reliable use of grid-powered electrical instruments is challenging, especially in remote emergency centers. A stable source of electricity is crucial to prevent disruptions in power supply, as they can lead to severe medical complications, jeopardize patient well-being, and even result in fatal incidents. To address this issue, integrating renewable electricity sources such as off-grid solar systems into existing power supply infrastructure can be a viable solution. Recent studies suggest that off-grid solar systems can be reliable and sustainable options for powering medical facilities, particularly in areas lacking uninterrupted grid connectivity. Therefore, this research aims to evaluate the feasibility, benefits, and challenges of integrating off-grid power to support critical medical instruments. Based on an extensive literature review, interviews with experts, and surveys among relevant users, this study finds that the system has the capability to maintain a consistent, dependable power supply, even during adverse weather conditions. Cost and feasibility are highlighted as paramount considerations, based on surveys and focus group results. The study concludes that off-grid solar systems offer an economical, low-maintenance, and environmentally sustainable alternative for remote medical facilities. Finally, this study proposes recommendations to optimize critical device performance during power outages and improve overall system functionality and efficiency.

Keywords: Off-grid solar systems, Renewable energy, Remote areas, Critical medical equipment, Photovoltaics

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1. Introduction

Continuous access to electricity is critical for essential medical instruments in healthcare facilities, including ventilators, oxygen concentrators, and defibrillators, which play a vital role in saving lives. These instruments rely on a consistent power supply to function effectively and deliver accurate results. Interruptions in electricity can have severe consequences, potentially harming patients and causing critical delays in medical procedures. Ensuring a continuous and reliable power source is crucial to maintaining the functionality of these instruments, especially in remote areas with limited grid connectivity. Renewable energy technologies, such as off-grid solar systems, provide potentially sustainable and dependable solutions for operating critical medical instruments, prioritizing patient well-being, even in challenging environments.

Renewable energy has gained popularity due to its clean and natural sources, making it environmentally friendly compared to fossil fuels. These sources are considered infinite and produce no harm to the environment, offering cost-effectiveness and emitting no harmful greenhouse emissions. Solar systems, utilizing solar panels to generate electricity from sunlight, particularly Off-Grid Photovoltaics (PV), present a practical application in areas lacking reliable grid power supply. These systems store solar-generated power in batteries for later use and convert it into the required electricity type using an inverter (Burns *et al.* 2012). Unlike diesel generators, off-grid solar systems are self-sufficient, clean, and sustainable energy sources, producing no harmful emissions and potentially being more cost-effective in the long run due to their independence from constant fuel supply (Baurzhan *et al.* 2016).

These systems show significant potential as energy sources for healthcare facilities in rural zones, ensuring a continuous and steady energy supply for critical medical equipment. When combined with grid-connected systems during the daytime, off-grid solar systems can effectively reduce energy demands in hospitals. They prove valuable, particularly in developing countries with unreliable electricity, enhancing patient health outcomes and saving lives. Proper performance evaluations are crucial to ensure the dependability and effectiveness of off-grid solar systems. Applying project management principles to these evaluations helps ensure organized and efficient processes, with monitoring and control playing crucial roles in optimizing system operations, identifying potential issues, and enhancing performance and profitability (Dauenhauer *et al.* 2020). Therefore, this study focuses on evaluating the performance of off-grid solar systems for critical medical instruments in remote and rural areas. The aim is to enhance essential healthcare outcomes, preserve non-renewable resources, and safeguard the environment. The objectives include assessing feasibility, addressing environmental and social challenges, exploring advantages over other power sources, reducing implementation costs and time, and implementing error-reduction measures. By evaluating key performance indicators and costs, ensuring workforce

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efficiency, and extending the reach to developing nations, this study aims to enhance the availability and functionality of critical medical instruments in underserved areas.

The study follows a structured approach, beginning with a comprehensive literature review, analyzing academic research on off-grid solar systems and their application in medical facilities. The methodology section outlines the research's purpose, methods, data analysis, and discussions. The results and discussion section presents the findings of the survey and their comparison with relevant literature. Based on the analysis, the study provides recommendations for engineering managers on the suitability of off-grid solar panels for powering critical medical instruments and identifies potential challenges. A concise conclusion summarizes the significant findings and links them to the project objectives, acknowledging any limitations and suggesting future research directions.

2. Literature Review

To ensure uninterrupted and efficient healthcare services in remote regions, it is essential to evaluate the performance of off-grid solar systems designed specifically for critical medical instrument applications. Limited research has been conducted in this area, and this section aims to provide a comprehensive examination of existing literature on the performance evaluation of off-grid solar systems tailored for medical instrument applications (Baurzhan *et al.* 2016).

2.1 Off-grid solar system

Solar power is recognised as a promising solution to global energy challenges, although its current contribution to the global power supply remains relatively low due to the high costs of photovoltaic (PV) panels. Studies comparing grid-connected, and off-grid solar PV installations highlight their effectiveness, dependability, and cost-effectiveness, aiding policymakers and decision-makers in tailored decision-making. Off-grid solar systems provide a decentralized and reliable source of electricity, especially in underserved regions where grid access is limited or non-existent. These systems operate independently from the main electrical grid, utilizing solar panels to generate electricity that is stored in batteries for use when sunlight is not available. Solar energy offers benefits such as income generation and improved living standards, particularly in off-grid communities in less developed remote nations. Despite challenges like high initial costs and storage expenses, ongoing advancements in technology are making solar power increasingly affordable and practical for both homes and businesses. Additionally, solar energy's sustainability and lack of adverse side effects make it an attractive alternative for those concerned about environmental impact. Leveraging renewable energy sources and adopting localised solutions can expand access to electricity, promote sustainable development, and eradicate energy poverty worldwide. Overall, solar energy proves to be a viable and practical solution for meeting the growing energy needs of remote areas while contributing to a more sustainable future (Mohtasham 2015).

2.2 Off-grid solar systems for healthcare centers

Off-grid solar power systems offer a sustainable and cost-effective solution for powering critical medical instruments in resource-limited settings, thereby improving healthcare outcomes, reducing costs, and enhancing access to quality services in health clinics facing challenges due to unreliable or inadequate electricity supply.

Two case studies conducted by Lunze & Hamer (2018) investigated the implementation of off-grid solar systems in healthcare settings. Lunze & Hamer's study focused on health clinics in southern Malawi and demonstrated the success of these solar systems in meeting the clinics' energy needs, including powering medical equipment, lighting, and refrigeration. The use of off-grid solar systems resulted in cost savings and reduced carbon emissions by reducing reliance on diesel generators. These studies emphasized the importance of involving local communities and stakeholders in the design and implementation of these systems for long-term sustainability. On the other hand, the research explored the feasibility of using off-grid solar systems to power critical medical devices in rural health centers in Uganda. Their findings indicated that solar systems could supply sufficient power to medical devices, and the initial investment could be recovered in five to seven years due to savings on fuel and maintenance costs. Both studies demonstrated the potential of off-grid solar power in healthcare facilities, providing reliable and sustainable energy solutions in remote settings (Lunze *et al.* 2019).

Worku et al. (2021) described the implementation of a solar-powered off-grid medical clinic in rural Ethiopia, addressing challenges stemming from unreliable electricity supply. They highlighted the reliability, cost savings, and environmental sustainability of off-grid solar power systems compared to traditional diesel generators, emphasizing their noiseless operation, minimal maintenance requirements, and absence of fuel costs. Similarly, Lazardis et al. (2019) developed a solar-powered water pumping and purification system for rural health centers in Ethiopia, aiming to alleviate water supply issues and reduce reliance on fossil fuels. This system effectively reduced water-borne diseases while contributing to ecological sustainability. This study conducted a systematic review, confirming the benefits of off-grid solar systems in improving electricity access, reliability, and cost-effectiveness in healthcare settings, despite challenges related to installation costs and maintenance. Additionally, Ouedraogo et al. (2022) evaluated an off-grid solar system in a hospital in Burkina Faso, demonstrating its reliability and cost-saving potential compared to diesel generators (Worku *et al.* 2021, Lazardis *et al.* 2019, Oueradogo *et al.* 2022).

Moreover, Yadav et al. (2019) demonstrated the feasibility and reliability of off-grid solar systems in a distant Indian village. Their study showed that a 1kW solar power system connected to a battery bank successfully powered medical devices, with an estimated payback period of five years and a Return on Investment (ROI) of approximately 20% (Yadav *et al.* 2019).

Collectively, the outcomes of reviewed studies underscore the promising potential of off-grid solar power systems in addressing energy challenges in healthcare settings. Case studies in Malawi and Uganda demonstrated their effectiveness in meeting energy needs and powering medical devices. Implementation of solar-powered clinics in rural Ethiopia showcased their reliability, cost-effectiveness, and environmental benefits compared to traditional diesel generators. Additionally, solar-powered water systems in Ethiopia aimed to mitigate water supply challenges and reduce reliance on fossil fuels, thus alleviating water-borne diseases. Systematic reviews provided insights into improved access to electricity and reduced energy costs in healthcare facilities. Evaluations

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in Burkina Faso and India further supported the reliability and cost-saving potential of off-grid solar systems. Overall, these findings highlight the promising role of off-grid solar power in enhancing healthcare delivery, advocating for collaboration, community engagement, and continued research to ensure successful implementation and long-term sustainability.

Implementing off-grid solar power systems in healthcare facilities can significantly improve access to quality healthcare services, diminish operating expenses, and contribute to a more sustainable future (Ouedraogo *et al.* 2022). These systems present a sustainable and cost-effective solution for powering critical medical instruments in resource-limited settings, demonstrating their potential to improve healthcare outcomes, reduce costs, and enhance access to quality healthcare services. Collaboration between stakeholders, community engagement, and ongoing research is essential for their successful implementation and long-term viability. Policymakers, healthcare providers, and technology developers can benefit from the insights provided by these studies to drive positive change in healthcare delivery in resource-limited settings. Further research and implementation efforts are needed to optimise the design and effectiveness of off-grid solar systems for healthcare applications.

2.3 Challenges of off-grid solar systems in rural healthcare settings

Recent studies have investigated the use of off-grid solar systems in rural health facilities, highlighting their potential to provide reliable power for medical devices. However, challenges related to maintenance and capacity building have been identified as significant barriers to their effective implementation.

Salaam (2023) studied the use of solar-powered systems in rural health facilities in Tanzania. While providing reliable power for medical devices, these systems faced a significant challenge identified in the study such as poor maintenance. Factors such as a lack of technical knowledge, inadequate maintenance funding, and limited spare parts availability contributed to frequent breakdowns. Battery failure was the most common cause of system breakdowns, attributed to the use of low-quality batteries and over-discharging. The study recommended adequate system maintenance and repair training for health facility staff (Salaam *et al.* 2023).

Gebreslassie et al. (2022) also assessed the reliability of off-grid solar systems in providing electricity to health centers in rural Ethiopia. The study found that solar systems could offer reliable and sustainable power to medical devices; however, their reliability was affected by weather conditions and poor maintenance. Proper training and capacity building for local staff ensured optimal system maintenance. The study also recommended incorporating backup systems or battery storage to mitigate the impact of intermittent power supply (Gebreslassie *et al.* 2022).

In conclusion, both studies emphasize the importance of maintenance and capacity building for effectively implementing off-grid solar systems in rural health facilities (Salaam, 2023; Gebreslassie et al., 2022). Poor maintenance, often due to a lack of technical knowledge and funding, leads to frequent breakdowns and affects the delivery of medical services. Proper training programs and adequate resources for maintenance are vital to ensure solar systems' reliable and sustainable functioning (Salaam *et al.* 2023, Gebreslassie *et al.* 2022). Policymakers and stakeholders in the healthcare sector are encouraged to prioritize the maintenance and sustainability of these systems to guarantee the provision of quality healthcare services in rural areas

2.4 Literature review outcomes

The literature review examined various strategies for ensuring a reliable power supply for medical instruments in remote areas, focusing particularly on renewable energy sources like solar power and battery storage systems. Solar power emerged as a promising solution due to its abundance in remote regions, low maintenance requirements, and environmental sustainability. Studies showcased the feasibility of solar-powered systems in providing continuous energy for essential medical equipment, supporting diagnosis, treatment, and patient care in remote healthcare settings. Additionally, solar power was found to align with global sustainable development goals and efforts to mitigate climate change. However, the review also identified challenges such as maintenance, technical knowledge gaps, and funding limitations that hinder the effective implementation of solar-powered systems in rural healthcare settings. Recommendations included the importance of adhering to international standards and guidelines, implementing proper training programs, and securing adequate maintenance funding to ensure the reliable and sustainable functioning of off-grid solar systems. Overall, the literature review provided valuable insights for healthcare practitioners, policymakers, and stakeholders, emphasizing the potential of solar power to improve patient care through reliable and sustainable energy access in rural zones. Further research is recommended to explore practical applications and optimize the utilization of off-grid solar systems for critical medical instruments in remote healthcare facilities.

3. Methodology

The research methodology employed in this study focused on analyzing the feasibility and effectiveness of off-grid solar systems for powering critical medical instruments in remote and underprivileged areas. The review was divided into three main components, addressing the selection of off-grid solar panels, evaluating their usage in powering medical devices, and assessing the overall effectiveness of the systems. Feasibility, reliability, safety, and cost-effectiveness were key factors considered during the rigorous evaluation processes. The data collection involved a comprehensive review of literature from reputable sources like Google Scholar and the Institute of Electrical and Electronics Engineers (IEEE), identifying gaps in existing research and providing an overview of current scholarly discourse on the topic.

The study further utilized market data and expert consultations to establish appropriate evaluation criteria. Data collection was carried out through various methods, including questionnaires, interviews, and observations. A large group of individuals, experts with extensive experience in off-grid solar panels, participated in the study. The survey, distributed through emails and online platforms, gathered insights from a diverse group, including medical professionals, energy experts, and solar energy field engineers and managers.

The comprehensive data analysis involved a meticulous examination of survey responses, which were presented in visually appealing graphs created using Excel. This approach facilitated a deeper understanding of the survey results, allowing for effective

communication of the findings. Overall, the survey results indicated a positive attitude towards the adoption of off-grid solar systems for medical instruments, emphasizing the benefits of renewable energy sources, reduced reliance on fossil fuels, and lower environmental impact.

In conclusion, the research findings strongly support the use of off-grid solar systems for powering critical medical instruments in remote or isolated areas. The study demonstrates the feasibility, reliability, and cost-effectiveness of these systems, highlighting their potential to address healthcare challenges in underserved regions. The results emphasize the positive impact of off-grid solar systems in reducing reliance on traditional systems and their suitability for emergency scenarios. These findings present compelling evidence for the adoption of off-grid solar systems in remote healthcare settings, improving access to reliable power and enhancing healthcare delivery in underserved communities.

4. Results Analysis and Discussions

4.1 Off-grid solar system

This section provides an overview of the research methodology, detailing the approach to data collection and analysis, along with supporting evidence that validates the significance of the chosen methodology. Figure 1 illustrates the key criteria to be considered when evaluating off-grid solar power for critical medical equipment. Surveyed engineers and managers, both in developed and developing countries, have expressed a preference for off-grid solutions, primarily due to the reliability of solar energy sources, which offer consistent power supply. Additionally, the capacity of energy that storage batteries can store emerges as a crucial consideration, with 67% of engineers and 83% of managers emphasizing the importance of cost-effectiveness. This suggests that participants regard the quantity of energy produced by solar panels as cost-effective for the overall system. Lastly, while approximately half of the experts considered the availability of renewable energy sources in the specific area based on weather conditions or energy demands, it is noted that this factor has less influence on decision-making.

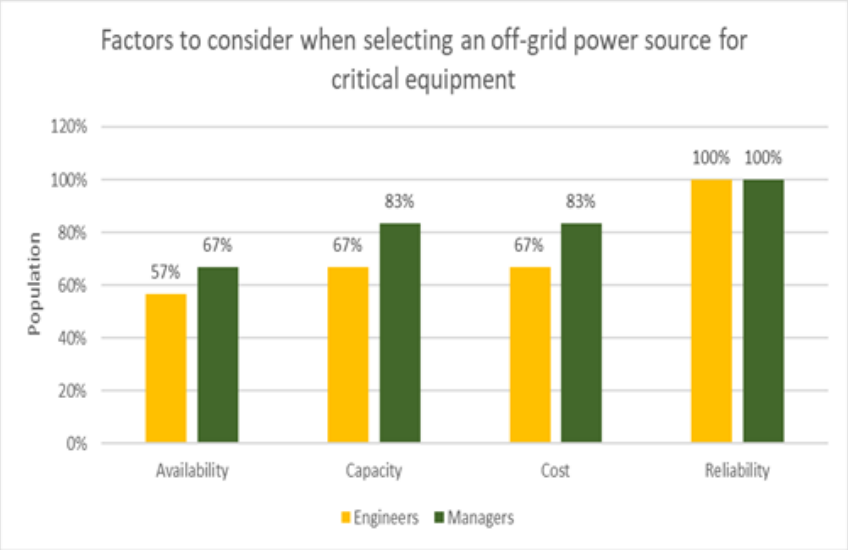


Figure 1. Important factors in selecting off-grid power source for critical equipment

The findings in Figure 2 underscore several key advantages of off-grid solar systems for powering medical instruments in remote areas. Firstly, they significantly reduce carbon dioxide and greenhouse gas emissions, aligning with global environmental sustainability goals. By harnessing solar energy, healthcare facilities can diminish their carbon footprint, promoting a cleaner environment. Additionally, transitioning away from fossil fuels eliminates associated health risks from air pollution. This shift promotes public health and well-being in the community.

Moreover, off-grid solar systems provide uninterrupted power supply, ensuring continuous operation of critical medical instruments. This reliability is crucial for maintaining timely diagnoses, treatments, and patient care in remote areas. Furthermore, these systems offer simplified installation and maintenance, reducing operational complexities and lowering overall costs. Compared to conventional power sources like diesel generators, off-grid solar solutions are easier to install and require minimal maintenance, making them more feasible for remote medical facilities. Overall, the survey emphasizes how off-grid solar systems fulfill key feasibility criteria, making them a practical and sustainable solution for powering medical instruments in remote healthcare settings.

Figure 3 data reveals that only about 30% of managers and engineers have utilized off-grid solar panels for powering scanners, such as X-Ray, MRI, and CT machines, indicating limited usage for larger, less portable equipment. Participants cited feasibility concerns, noting that solar panel installation is more practical for smaller, mobile devices like patient monitors. Similar trends were observed for other medical devices, such as syringe pumps and ventilators, where off-grid solar panel usage was more prominent for petite and portable equipment. Challenges include higher energy demands, space limitations, and cost considerations associated with larger equipment, making solar panels less feasible. This highlights the importance of tailored approaches for implementing off-grid solar systems based on the specific needs and practicalities of different medical devices.

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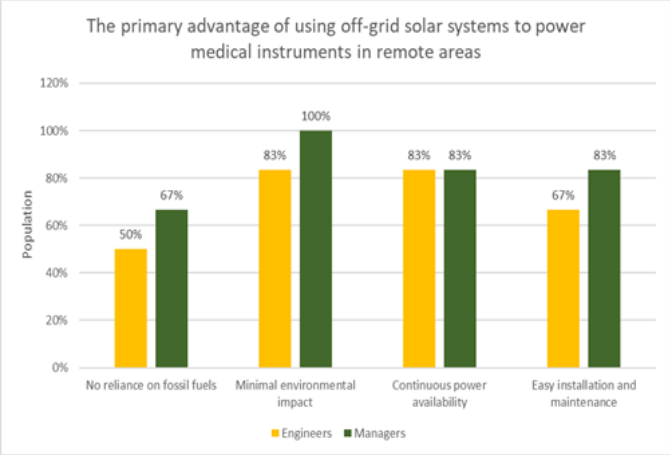


Figure 2. Benefits of using off-grid systems to power medical devices in remote areas

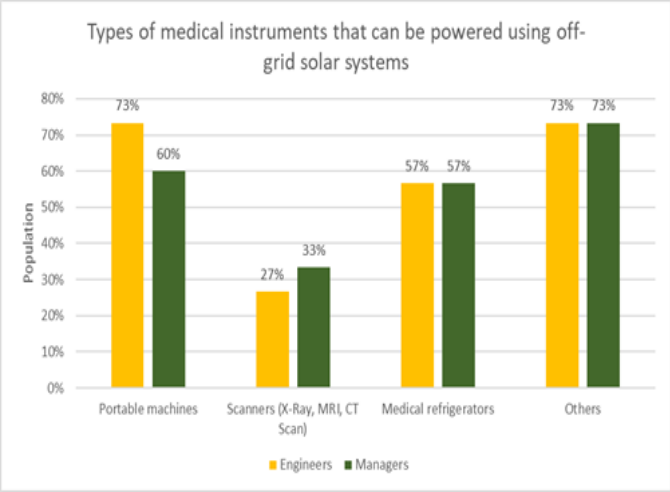


Figure 3. Medical instrument types powered using off-grid solar systems

The primary challenge identified by specialists in off-grid solar systems is the limited power supply on overcast days, as indicated by 90% of the respondents in Figure 4. This is followed by concerns regarding high installation costs and the need for qualified workers for system maintenance. However, only half of the specialists reported problems with system installation and finding maintenance experts.

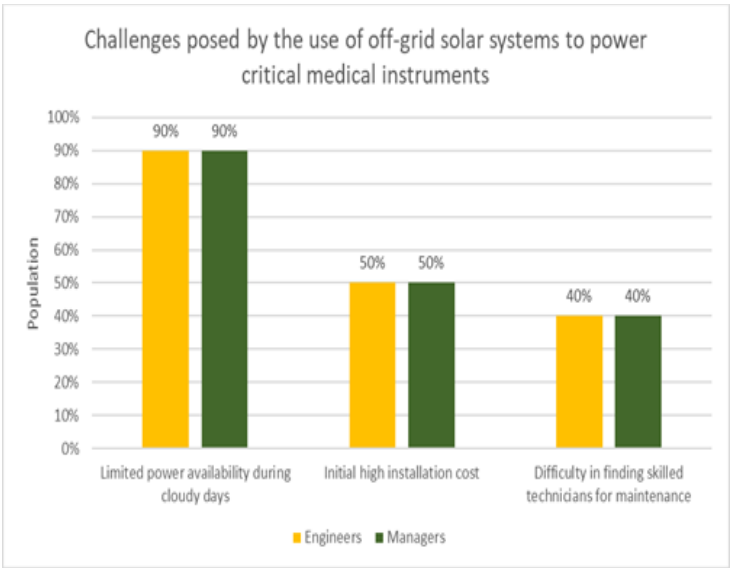


Figure 4. Challenges in using off-grid solar systems

Concerning the information presented in Figure 5, all participants acknowledged that the primary function of batteries in off-grid solar systems is to provide backup power during outages or system failures. This understanding highlights the crucial role of battery storage in ensuring the reliability of these systems for powering vital medical instruments. Furthermore, batteries play a significant role in stabilizing power output and preventing fluctuations. They also have the capacity to store excess solar energy, which can be utilized during periods of low sunlight, thereby contributing to the system's overall efficiency and effectiveness.

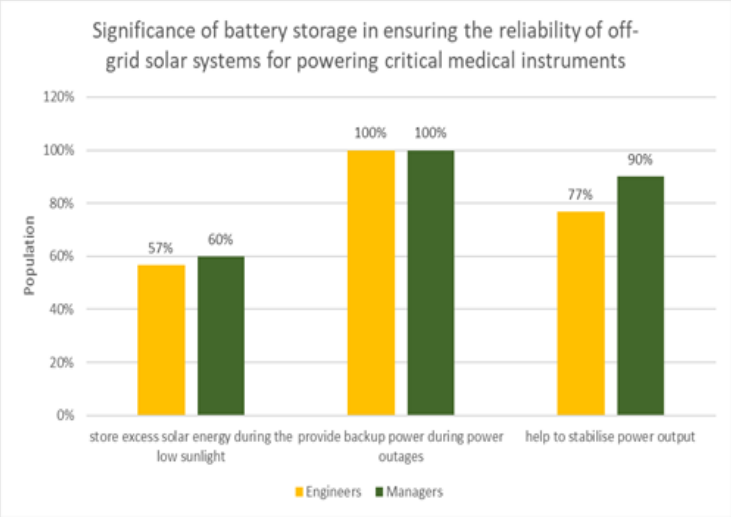


Figure 5. Battery storage's role in ensuring the reliability of off-grid solar systems

The respondents' endorsement of the system stems from its numerous advantages, including reliability, cost-effectiveness, environmental friendliness, and the ability to provide uninterrupted power supply to critical medical equipment. The system's performance in powering medical devices without any notable impact on their functionality further strengthens the case for its adoption. These findings suggest that the surveyed professionals recognize the potential of off-grid solar systems to revolutionize the way electricity is generated, particularly in the context of vital medical devices.

4.2 Findings and Discussion

The survey findings indicate that a significant proportion of the surveyed population, including engineers and managers, have previous experience and knowledge of utilising off-grid solar systems for medical equipment. The primary consideration when selecting an off-grid power source for critical equipment was reliability. Renewable energy sources were preferred due to their reliability and cost-effectiveness, while availability was considered less crucial. Cost-effectiveness was highlighted as off-grid solar systems were found to provide lower electricity costs compared to conventional systems. The lifespan of these systems was considered acceptable, as most medical devices have a lifecycle of less than ten years. Environmental benefits were also recognized, particularly in reducing carbon dioxide and greenhouse gas emissions. The challenges faced by specialists in this field included limited power supply on overcast days, high initial installation costs, and difficulties in finding qualified workers for maintenance. Storage batteries were suggested as backup power solutions. Climate change factors such as storms and cloudy days were seen as potential limitations affecting system functionality. However, the majority of participants reported no issues with the performance of off-grid solar systems.

It is worth noting that using off-grid solar panels for powering scanners like X-Ray, MRI, and CT scan machines was relatively uncommon according to the participants. Instead, they suggested that utilizing these systems for portable machines like ventilators may be more practical. Overall, the survey results showcase a favorable attitude towards the adoption of off-grid solar systems for medical instruments, pointing to a high demand for such projects. Participants emphasized the benefits of reduced reliance on fossil fuels and highlighted the lower environmental impact.

Dependability emerged as a top priority, with a majority expressing satisfaction regarding the performance of off-grid solar systems both during and after installation. In summary, the findings affirm the feasibility and viability of off-grid solar systems for powering critical medical instruments in remote or isolated areas. The combination of reliability, cost-effectiveness, and environmental benefits positions them as a dependable option. Despite existing challenges, the overall satisfaction and demand signal a positive outlook for the utilization of off-grid solar systems in healthcare settings.

5. Recommendations

Based on the study findings, the following suggestions are proposed to address challenges and enhance the efficiency of off-grid solar power system as a dependable and sustainable power solution for medical devices in electricity-deprived regions:

1) Promoting Environmental Benefits and Suitability
   a) Clarity on environmental benefits: Clearly articulating the environmental advantages of off-grid solar power is essential to garner support and understanding from stakeholders.
   b) Focus on power utilization: Emphasizing the optimization of power utilization for critical medical devices showcases a commitment to ensuring the reliability and sustainability of healthcare services.
2) Addressing Power Supply Limitations

a) Maintenance and inspections: Regular maintenance and inspections are crucial for sustaining the efficiency of solar panels over time. This proactive approach ensures longevity and consistent performance.
b) Battery storage integration: The recommendation to integrate high-efficiency battery storage systems is key for overcoming intermittent power supply challenges, providing a reliable energy source during periods of low sunlight.

3) Engaging Business Owners and Stakeholders
a) Increased attention from stakeholders: Encouraging business owners and stakeholders in health and renewable energy sectors to focus on the potential of off-grid solar panels underscores the need for collaborative efforts in addressing healthcare challenges.
b) Energy monitoring and management systems: Deploying monitoring systems reflects a commitment to ongoing improvement and efficiency, allowing for timely identification and rectification of issues.

4) Engagement with Local Stakeholders
a) Customization for medical facilities: Collaboration with local healthcare professionals and community leaders for customizing off-grid solar panel systems demonstrates an understanding of the unique needs of each medical facility.
b) Community involvement: Involving local stakeholders in the planning and implementation of solar projects ensures cultural relevance and community support.

5) Call for Further Research and Updates
a) Adaptability to local conditions: Recommending further research and updates aligns with the dynamic nature of economic and medical conditions in different regions, emphasizing the importance of tailoring solutions to local contexts.

By incorporating these recommendations and remaining adaptable to regional conditions, the objective of delivering reliable and sustainable power for critical healthcare needs in areas without electricity access can be achieved. This approach maximizes the potential of off-grid solar panels for medical devices and contributes to improved healthcare outcomes in underserved regions.

6. Conclusion

This paper underscores off-grid photovoltaics as a viable and low-maintenance power solution for critical medical instruments in resource-limited settings. It demonstrates that off-grid solar systems provide sustainable energy for essential medical devices, such as patient monitors and ventilators. The utilization of off-grid solar technology enhances healthcare delivery in remote areas, particularly in developing countries facing frequent electricity blackouts. This technology establishes a reliable energy source for critical medical instruments, ensuring healthcare provision in challenging environments and improving access in rural areas with limited fuel availability.

The implications of these findings underscore the significance of off-grid solar technology for enhancing healthcare access and delivery in resource-limited settings. By addressing challenges like limited electricity access, inadequate infrastructure, and high maintenance costs associated with conventional electricity generation methods, investing in off-grid solar systems enables healthcare facilities to improve patient outcomes and contribute to community development. Prioritizing off-grid solar power for medical devices is crucial, requiring comprehensive battery management knowledge and engagement with local stakeholders to ensure reliable power supply and successful integration, thus optimizing healthcare services sustainably. However, further study and development are necessary to optimize off-grid solar systems for specific medical instrument requirements, enhance energy storage capabilities, and address cost barriers. Collaboration between the health sector, renewable energy industry, and local communities is crucial for the effective deployment and sustainability of off-grid solar solutions. Leveraging the potential of off-grid solar technology can enable healthcare providers to establish a more resilient and sustainable healthcare infrastructure in resource-limited regions, ultimately enhancing the well-being and quality of life for underserved populations.

This study recommends two strategies to overcome power supply limitations and high installation costs. Firstly, utilizing high-efficiency battery storage systems and conducting regular maintenance can address power supply challenges. These systems store excess energy during optimal conditions, ensuring a consistent power supply for critical medical devices, even in adverse weather. Additionally, adhering to industry standards and regulations is crucial to establishing the system's validity, safety, and compatibility with medical equipment. This reinforces the system's credibility in critical healthcare settings, promoting reliable and effective operation. In summary, the evaluation of the off-grid photovoltaic system highlights its reliability and sustainability in providing power for critical medical instruments in areas without access to electricity. Adhering to the recommendations outlined in this study can achieve optimal patient care in resource-limited settings. Additionally, these measures contribute to the conservation of the environment and the reduction of pollutants, aligning with the goals of the renewable energy industry. Future studies should scrutinize critical medical devices' performance during power outages and further development of off-grid solar systems.

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PEMANFAATAN CCTV *ANALOG CAMERA* PADA SISTEM *MONITORING* KEAMANAN RUANGAN BERBASIS *MOBILE WEB*

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ABSTRAK

Semakin besar kemajemukan sebuah kota semakin besar pula ancaman terhadap keamanannya. Tingkat kasus kriminal di Kota Kupang dilaporkan sebanyak 1.472 kasus dengan resiko kejahatan sebesar 438 per 100.000 penduduk. Salah satu kasus kriminal yang tercatat adalah pencurian, yakni sebanyak 1.288 kasus. Angka ini tentunya sangat tinggi dan jika tidak ditanggulangi maka dapat menimbulkan keresahan dalam masyarakat. Kasus pencurian juga pernah dialami oleh STIKOM Uyelindo Kupang, berupa hilangnya 7 unit laptop. Semakin tingginya angka kriminalitas mendorong diperlukannya sebuah sistem keamanan berbasis teknologi yang efektif, efisien dan mudah diakses di mana saja, salah satunya adalah *Closed Circuit Television* (CCTV). CCTV adalah sebuah kamera digital yang digunakan untuk menangkap suara dan gambar bergerak, kemudian dikirim ke video *recorder* untuk direkam dan selanjutnya diteruskan ke layar monitor. Berdasarkan hasil pengujian, CCTV yang terpasang di 21 ruangan tertutup dan 3 area terbuka berjalan dengan baik dan dapat diakses di mana saja. Sebanyak 97% responden sangat setuju bahwa CCTV membantu mempermudah pemantauan kondisi ruangan dan meminimalkan tindakan pencurian. Untuk penelitian selanjutnya, perlu dilakukan peningkatan dari kamera analog ke kamera *Internet Protocol* (IP) pada CCTV yang ada.
Kata kunci: CCTV, Kamera Analog, Kamera IP, Keamanan, *Mobile Web*

ABSTRACT

The greater the diversity of a city, the greater the threat to its security. The crime rate in Kupang City was reported at 1,472 cases with a crime risk of 438 per 100,000 population. One of the most common crimes recorded was theft, with 1,288 cases. This figure is very high and if not addressed, it can cause restlessness in the society. Theft cases have also been experienced by STIKOM Uyelindo Kupang, in the form of the loss of 7 laptop units. The higher crime rate encourages the need for a technology-based security system that are effective, efficient, and easily accessible anywhere, one of which is Closed Circuit Television (CCTV). CCTV is a digital camera that used to capture sound and moving images, then sent to a video recorder to be recorded and then forwarded to the monitor screen. Based on the test results, CCTV that installed in 21 closed rooms and 3 open areas runs well and can be accessed anywhere. As many as 97% of respondents strongly agree that CCTV helps make it easier to monitor room conditions and minimize theft. For further research, it is necessary to upgrade from analog cameras to internet protocol (IP) cameras on existing CCTV.
Keywords: CCTV, Analog Camera, IP Camera, Security, Mobile Web

1. PENDAHULUAN

Kota Kupang memiliki tingkat kompleksitas yang tinggi karena semakin berkembangnya peradaban, semakin banyak kepentingan dan ragam persoalan yang muncul. Hal ini tentunya dapat memicu berbagai tindakan kejahatan atau kriminal. Badan Pusat Statistik (BPS) Provinsi Nusa Tenggara Timur melaporkan, kasus tindak kejahatan di Kota Kupang paling banyak terjadi pada tahun 2021, yakni sebanyak 1.472 kasus, dengan resiko tindak kejahatan sebesar 438 per 100.000 penduduk. Jumlah tindak pidana terhadap hak milik khususnya kasus pencurian, tercatat sebanyak 1.288 kasus [1]. Pada September 2014 kasus pencurian telah terjadi di STIKOM Uyelindo Kupang. Pencuri berhasil membobol laboratorium komputer dan berhasil mencuri 7 unit laptop yang merupakan inventaris kampus. Hal ini tentunya memberikan kerugian yang besar bagi STIKOM Uyelindo Kupang [2]. Selain kasus pencurian, juga ada kasus-kasus lain yang kerap kali terjadi yakni kasus perkelahian antar mahasiswa. Akibat peningkatan angka kriminalitas khususnya pencurian, maka diperlukan sebuah alat berbasis teknologi informasi yang dapat membantu pemantauan suatu peristiwa atau kejadian secara *real-time*, kapan dan di mana saja.

Pesatnya perkembangan teknologi informasi dan komunikasi ditunjukan dengan jumlah pengguna internet yang terus meningkat. Sebuah lembaga survei Indonesia, Asosiasi Penyelenggara Jasa Internet Indonesia (APJII) melaporkan, pada tahun 2021-2022 pengguna internet di dalam negeri berjumlah 210,03 juta atau mengalami penetrasi sebesar 77,02% [3]. BPS melaporkan, pada tahun 2020 indeks pembangunan

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teknologi informasi dan komunikasi di Indonesia adalah sebesar 5,59 pada skala 0-10. Jika dibandingkan dengan tahun 2021, maka terjadi peningkatan sebesar 5,76 [4]. Sejalan dengan perkembangan teknologi informasi dan komunikasi, sistem keamanan pun turut mengalami perkembangan, seperti hadirnya kamera CCTV. Dalam hal keamanan, telah terbukti bahwa memasang kamera CCTV dapat meningkatkan sistem keamanan dan menjadi salah satu upaya mencegah tindak kejahatan di suatu properti [5]. Ada 2 jenis kamera CCTV yakni kamera analog dan kamera IP. Kedua jenis kamera ini dapat diakses melalui jaringan internet, serta pemantauannya dapat dilakukan melalui *smartphone*, tablet dan komputer *desktop*. Kamera analog lebih terjangkau dan memiliki arsitektur yang lebih sederhana dibandingkan dengan kamera IP yang lebih mahal dan kompleks, namun pemilihan jenis kamera harus didasarkan pada kebutuhan pengguna dan kesesuaian dengan teknologi yang digunakan [6]. Sistem pemantau ruangan yang paling umum digunakan adalah melalui kamera CCTV, di mana hasil rekamannya dapat ditampilkan secara *real-time* pada komputer, *smartphone*, atau perangkat *mobile* lainnya. Hasil rekaman CCTV sangat berharga dalam melengkapi sistem keamanan konvensional dan dapat membantu mencegah tindak kejahatan atau membantu penyelidikan terhadap suatu kejadian [7].

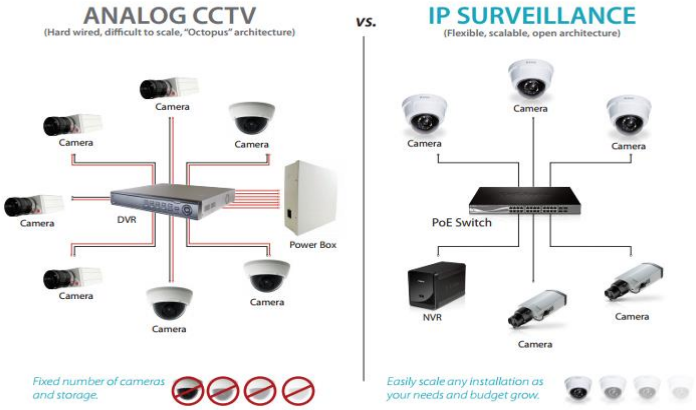
Penelitian terkait penggunaan CCTV sebagai alat pemantau keamanan telah dilakukan oleh beberapa peneliti. Pada tahun 2021, [8] merancang dan membangun sistem pemantauan ruangan dengan menggunakan CCTV Hik-*Connect* untuk memudahkan *monitoring* situasi kantor selama masa WFH (*Work From Home*). Sementara itu, [9] mengembangkan sistem *monitoring* ruangan dengan menggunakan robot CCTV yang dapat melakukan pemantauan ruangan secara otomatis dan manual untuk mempercepat dan mempermudah proses *monitoring*. Kedua penelitian ini menyimpulkan bahwa penggunaan CCTV sangat membantu dalam *monitoring* sistem keamanan ruangan.

Berdasarkan uraian permasalahan, hasil penelitian beberapa peneliti terdahulu, kesiapan teknologi informasi, dan keunggulan teknologi CCTV dalam bidang keamanan, maka dibangunlah sistem *monitoring* keamanan ruangan di STIKOM Uyelindo Kupang. Sistem ini memanfaatkan CCTV kamera analog dan berbasis *mobile* web, sehingga akses data menjadi lebih efektif dan efisien di mana saja.

2. MATERI DAN METODE

Closed Circuit Television (CCTV)

CCTV adalah sebuah perangkat keras yang digunakan sebagai sistem keamanan baik di rumah, perkantoran, atau tempat-tempat publik. Pada Gambar 1, terlihat bahwa rangkaian CCTV analog terdiri dari beberapa kamera *non*-IP yang terhubung ke *Digital Video Recorder* (DVR), sedangkan CCTV IP memerlukan *Power over Ethernet* (PoE) *switch* untuk menghubungkan kamera IP dengan *Network Video Recorder* (NVR) sebagai perangkat perekam dan penyimpanan rekaman.



Gambar 1. Perbandingan Kamera CCTV [6]

Untuk melihat hasil rekaman atau *streaming* CCTV, pengguna hanya perlu mengaksesnya melalui perangkat *mobile* yang terkoneksi internet. Dengan adanya CCTV, pemantauan kondisi suatu tempat atau lokasi dapat menjadi lebih mudah sehingga dapat meminimalisir berbagai tindakan kejahatan seperti pencurian atau perampokan. Selain itu, rekaman CCTV juga dapat digunakan sebagai bukti tindakan kejahatan yang terjadi di suatu tempat. Untuk berfungsi dengan baik, sebuah perangkat CCTV perlu dilengkapi dengan kamera (baik analog atau IP), monitor, DVR, dan peralatan jaringan komputer. CCTV memiliki cara kerja yang berbeda dari televisi konvensional, karena terdiri dari kamera digital yang

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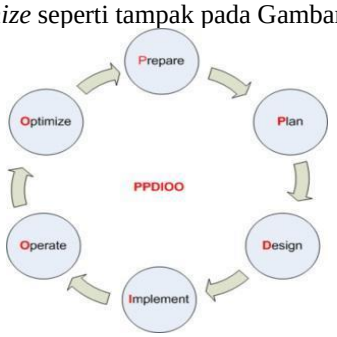
merekam video dan mengirimkannya ke monitor melalui sinyal tertutup sehingga disebut sebagai televisi sirkuit tertutup [5].

Kamera CCTV harus terhubung ke perangkat perekam NVR (untuk kamera IP) atau DVR (untuk kamera analog) melalui kabel atau *wireless*. Jika menggunakan kabel, untuk kamera analog dihubungkan dengan kabel *coaxial* sementara kamera IP dihubungkan dengan kabel *Unshield Twisted Pair* (UTP). Selanjutnya agar *streaming* CCTV dapat diakses melalui jaringan global maka perangkat perekam video harus terhubung ke jaringan *wide area network* atau jaringan internet. Sebuah perangkat CCTV yang telah terhubung internet, dapat diakses dari mana saja menggunakan berbagai perangkat bergerak seperti smartphone, tablet, laptop, komputer desktop, dan lain-lain [6]. CCTV memiliki beberapa keunggulan sebagai berikut:

a. Meningkatkan keamanan: CCTV dapat membantu pengguna untuk memantau atau me*monitoring* secara langsung kejadian atau peristiwa pada suatu lokasi tertentu sehingga jika terjadi suatu hal yang tidak diinginkan dapat segera diatasi lebih awal. CCTV dilengkapi dengan sensor infra merah yang mampu merekam dalam cahaya yang redup bahkan gelap. Hal ini tentunya akan membuat sistem keamanan menjadi lebih baik.
b. Memantau aktivitas pegawai: proses pemantauan aktivitas pegawai akan sangat mudah sehingga dapat menekan kurang produktifnya pegawai dalam mengemban tugas.
c. Menjaga barang inventaris perusahaan: sebuah perusahaan atau instansi tertentu, pasti memiliki barang-barang inventaris atau aset. Agar aset tersebut dapat terlindungi dari berbagai tindakan kejahatan seperti pencurian atau pengrusakan, maka perlu dilengkapi dengan CCTV pada setiap lokasi di mana aset tersebut diletakan.
d. Dijadikan sebagai alat bukti kejahatan: hasil rekaman CCTV secara otomatis akan tersimpan dalam *video recorder* dalam waktu lama tergantung pada kapasitas media simpan yang terpasang pada *video recorder* tersebut. Jika terjadi tindakan kejahatan di sekitar lokasi di mana CCTV berada, maka hasil rekaman CCTV dapat dijadikan sebagai barang bukti yang akurat sehingga dapat membantu pihak kepolisian untuk menyelidiki kasus kejahatan tersebut.
e. Meminimalisasi terjadinya kecelakaan: jika CCTV ditempatkan pada lokasi yang tepat seperti di tempat-tempat keramaian, rawan kecelakaan atau rawan kebakaran, dapat meminimalisasi terjadinya dampak yang lebih besar karena langsung diketahui dan segera diatasi sehingga tidak menimbulkan kerugian yang besar.
f. *Monitoring* kinerja dan loyalitas pegawai: proses pemantauan kehadiran dan kinerja pegawai akan menjadi lebih mudah dan akurat sehingga pimpinan dapat menilai kinerja dan loyalitas pegawai dengan lebih akurat. Hal ini tentunya akan membawa dampak yang baik bagi perusahaan.
g. Arsip perusahaan: *video* rekaman CCTV yang tersimpan pada *video recorder* dapat diunduh dan disimpan sebagai arsip perusahaan. Jika dibutuhkan informasi terkait rekaman peristiwa pada suatu lokasi tertentu maka dapat diunduh dan diputar kembali.

Metode *Prepare, Plan, Design, Implement, Operate, Optimize* (PPDIOO)

Dalam membangun sistem *monitoring* keamanan ruangan berbasis *mobil web* digunakan metode pengembangan perangkat lunak dengan siklus PPDIOO. Terdapat 6 siklus PPDIOO yakni: *prepare*, *plan*, *design*, *implement*, *operate* dan *optimize* seperti tampak pada Gambar 2 [10].



Gambar 2. Metode PPDIOO [10]

a. *Prepare* (mempersiapkan): melakukan studi pendahuluan dengan cara mengumpulkan data primer yang berhubungan dengan data kriminalitas, berbagai kasus yang mengganggu keamanan, serta kesiapan teknologi informasi di lingkungan STIKOM Uyelindo Kupang. Pengumpulan data dapat berupa observasi, wawancara dan studi literatur.

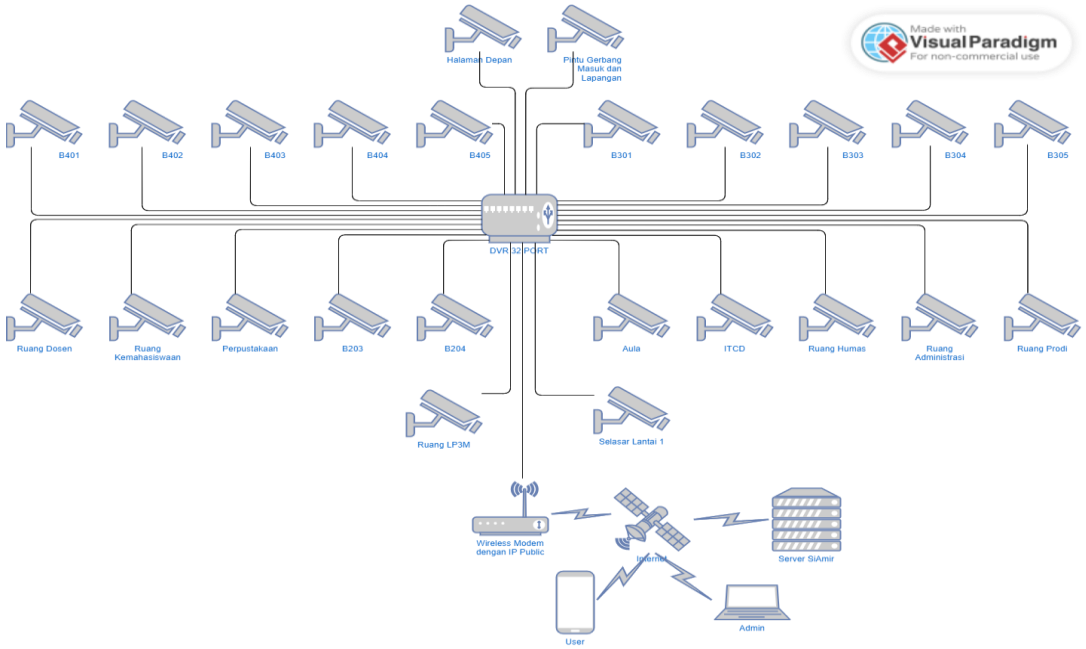
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b. *Plan* (rencana): melakukan identifikasi berbagai macam kebutuhan pengembangan sistem terkait kebutuhan aktor (mahasiswa, dosen, karyawan dan admin STIKOM Uyelindo Kupang), kebutuhan perangkat lunak, perangkat keras dan infrastruktur jaringan.
c. *Design* (desain): melakukan analisis dan perancangan sistem yang akan dibangun yang meliputi desain arsitektur perangkat lunak, *use case diagram* dan perancangan antarmuka sistem. Arsitektur perangkat lunak menggambarkan hubungan antar komponen teknologi informasi yang bekerja sama untuk melakukan proses pengolahan data. *Use case diagram* menggambarkan hubungan interaksi yang terjadi antara pengguna dengan sistem itu sendiri, sedangkan perancangan antarmuka menggambarkan tampilan *input* dan *output* sistem. Pada tahap ini, pengembang sistem memilih model perancangan yang digunakan dan mendesain arsitektur pengembangan perangkat lunak.
d. *Implement* (menerapkan): tahap implementasi dan verifikasi dimulai setelah tahap desain disetujui oleh pengguna sistem. Proses pembangunan sistem mengacu pada hasil analisis dan perancangan sistem yang telah ditetapkan atau disetujui pada tahap sebelumnya yakni pada tahap *design*.
e. *Operate* (mengoperasikan): pada tahap ini, sistem telah berhasil dibangun dan dapat dioperasikan. Selama proses operasi, dapat dilakukan pengujian sistem seperti deteksi kesalahan, perbaikan, dan pemantauan kinerja yang mana hasil pengujian dapat dijadikan sebagai acuan untuk yakni tahap optimasi.
f. *Optimize* (mengoptimalkan): berdasarkan hasil pengujian pada tahap sebelumnya, maka pada tahap ini akan dilakukan pemecahan masalah, perbaikan dan peningkatan serta menyiapkan strategi yang dilakukan untuk mengatasi permasalahan baru yang mungkin akan timbul.

3. HASIL DAN PEMBAHASAN

Arsitektur jaringan dan sistem

Gambar 3 menjelaskan arsitektur jaringan dan sistem yang terdiri dari 26 kamera analog yang terhubung ke DVR 32 *port* melalui kabel jaringan. Setelah merekam video, data video dikirim dan disimpan di DVR. Selanjutnya, video tersebut diteruskan ke *server* sistem melalui modem internet dengan IP *public*. Video yang tersimpan di *server* dapat diakses oleh pengguna melalui perangkat *mobile*.



Gambar 3. Arsitektur jaringan dan sistem

Konfigurasi CCTV

Untuk menjalankan *streaming* video CCTV, dibutuhkan sebuah protokol *streaming*. *Real-Time Streaming Protocol* (RTSP) merupakan sebuah protokol komunikasi yang digunakan pada sistem jaringan untuk mengendalikan data multimedia. Berikut adalah beberapa format RTSP:

a. rtsp://user:pass@mydomain.com:554/h264
b. rtsp://user:pass@ippublic/streaming/channels/NoChannel

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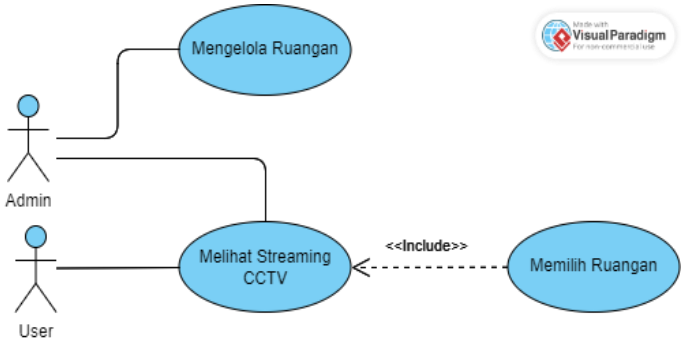
Tabel 1. Daftar nomor *channel*

No	No. CCTV	Ruangan	No. *Channel*
1	Cam1	Halaman Depan	101
2	Cam2	Pintu Gerbang Masuk dan Lapangan	102
3	Cam3	B401	103
4	Cam4	B402	104
5	Cam5	B403	105
6	Cam6	B404	106
7	Cam7	B405	107
8	Cam8	B301	108
9	Cam9	B302	109
10	Cam10	B303	110
11	Cam11	B304	111
12	Cam12	B305	112
13	Cam13	Ruangan Dosen	113
14	Cam14	Ruangan Kemahasiswaan	114
15	Cam15	Perpustakaan	115
16	Cam16	B203	116
17	Cam17	B204	117
18	Cam18	Aula	118
19	Cam19	ITCD	119
20	Cam20	Ruangan Humas	120
21	Cam21	Ruangan Administrasi	121
22	Cam22	Ruangan Prodi	122
23	Cam23	Ruangan LP3M	123
24	Cam24	Selasar Lantai 1	124

Tabel 1 memperlihatkan daftar nomor *channel* yang merupakan salah satu atribut unik RTSP yang dimiliki oleh setiap kamera. RTSP yang sudah terbentuk, selanjutnya dapat didaftarkan pada https://www.ipcamlive.com/streamtest (layanan pihak ketiga untuk menangani *live streaming* kamera CCTV), kemudian diambil *tag iframe* dan diletakan langsung pada *website* atau pada *database* dan selanjutnya ditampilkan ke halaman *website*.

Diagram *Use Case System*

Gambar 4 memperlihatkan hubungan interaksi antara aktor dan sistem. Sebelum ditampilkan ke *user*, admin melakukan pengolahan data ruangan yang meliputi menambah, mengubah, dan menghapus data. Admin memasukkan RTSP atau HTTP *stream* untuk mengakses CCTV di setiap ruangan. Selanjutnya, *user*, seperti mahasiswa, karyawan, dan dosen dapat melihat video *streaming* CCTV dengan memilih ruangan yang ingin ditampilkan terlebih dahulu.

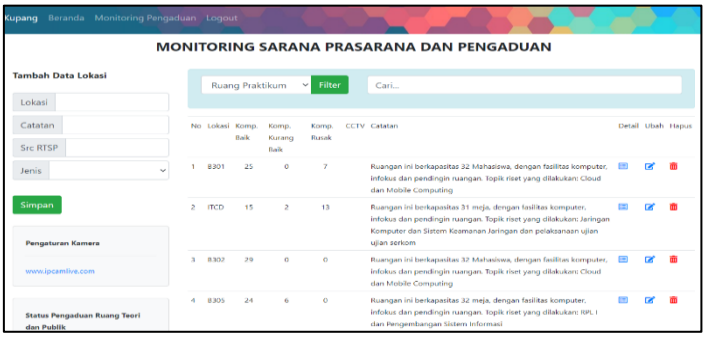


Gambar 4. Diagram *Use case system*

Antarmuka sistem

a. Antarmuka kelola ruangan oleh admin

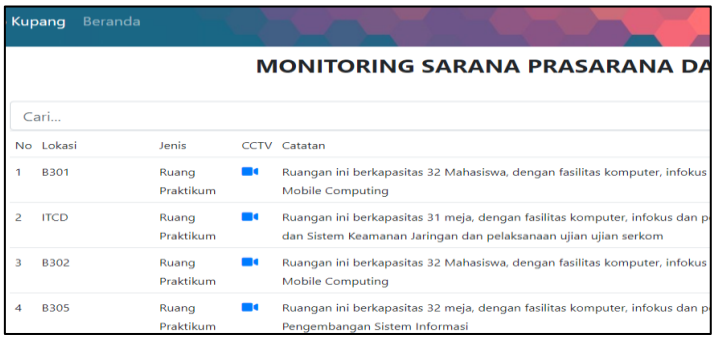
Laman ini digunakan oleh admin untuk mengelola data ruangan. Terdapat tiga ruangan di STIKOM Uyelindo Kupang yakni ruangan teori, praktikum dan publik. Setiap ruangan memiliki atribut yang harus diisi oleh admin yaitu: nama ruangan atau lokasi, catatan, *source* RTSP dan memilih jenis ruangan. Tampilan antarmuka kelola ruangan dapat dilihat pada Gambar 5:



Gambar 5. Antarmuka kelola ruang oleh admin

b. Antarmuka pilih ruangan

Pada Gambar 6, terlihat antarmuka pilihan ruangan yang digunakan oleh pengguna untuk memilih ruangan tertentu dan melihat spesifikasi ruangan, pengaduan ruangan, daftar mata kuliah yang menggunakan ruangan tersebut, serta menonton *streaming* CCTV secara *real-time*.



Gambar 6. Antarmuka pilih ruang

c. Antarmuka melihat *streaming* CCTV

Hasil rekaman CCTV dapat ditonton secara *real-time* melalui antarmuka *streaming* yang disajikan pada halaman terpisah. Antarmuka ini dilengkapi dengan fungsi kontrol yang terintegrasi langsung pada layer video. Contoh tampilan antarmuka *streaming* dapat dilihat pada Gambar 7.



Gambar 7. Antarmuka melihat *streaming* CCTV

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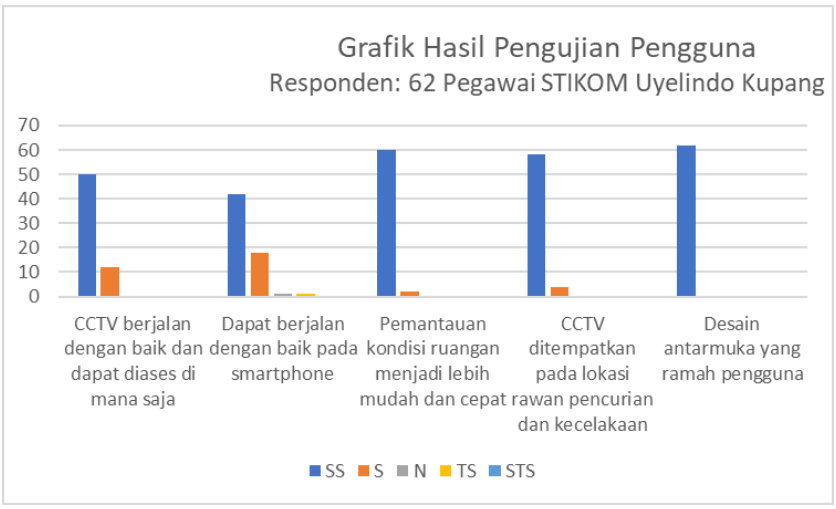
Hasil

Kamera CCTV telah berhasil dipasang di 24 titik, yakni 21 titik di ruangan tertutup dan 3 titik di area terbuka. Berdasarkan hasil pengujian, video *streaming* dapat berjalan dengan baik pada sistem *monitoring* keamanan ruangan dan dapat diakses secara publik. Tabel 2 menunjukan hasil pengujian *live streaming* CCTV dengan mengambil sampel 4 kamera CCTV.

Tabel 2. Pengujian *live streaming* CCTV

No. CCTV dan Ruangan	*Streaming*	No. CCTV dan Ruangan	*Streaming*
Cam4 B405		Cam14 Ruangan Kemahasiswaan	
Cam5 B403		Cam15 Perpustakaan	

Sistem *monitoring* keamanan ruangan yang telah berhasil dibangun kemudian diuji menggunakan metode kuesioner yang diberikan kepada 62 pegawai STIKOM Uyelindo Kupang. Hasil pengujian menunjukkan bahwa 81% responden sangat setuju bahwa CCTV dapat berjalan dengan baik dan dapat diakses dari mana saja, sementara 97% responden sangat setuju bahwa dengan adanya CCTV proses pemantauan kondisi ruangan menjadi lebih mudah dan cepat. Grafik hasil pengujian pengguna sistem direpresentasikan pada Gambar 8.



Gambar 8. Grafik hasil pengujian pengguna

4. KESIMPULAN DAN SARAN

Saat peradaban semakin berkembang, banyak kepentingan dan persoalan yang semakin beragam. Hal ini dapat memicu tindakan kriminal di masyarakat. Penggunaan CCTV untuk meningkatkan keamanan adalah pilihan yang tepat, seperti yang dilakukan oleh STIKOM Uyelindo Kupang. Berdasarkan hasil pengujian, CCTV yang terpasang di 21 ruangan tertutup dan 3 area terbuka berjalan dengan baik dan dapat diakses di mana saja. Sebanyak 97% responden sangat setuju bahwa CCTV membantu mempermudah pemantauan kondisi ruangan dan meminimalkan tindakan pencurian. Untuk penelitian selanjutnya, perlu dilakukan *upgrade* dari kamera analog ke kamera IP pada CCTV yang ada.

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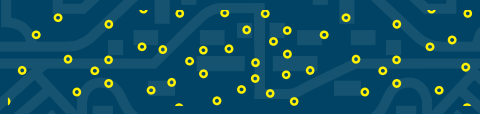
TENTH EDITION

MANAGERIAL ECONOMICS and BUSINESS STRATEGY



MICHAEL R. BAYE / JEFFREY T. PRINCE

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MANAGERIAL ECONOMICS AND BUSINESS STRATEGY

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DEDICATION

To Mom.

—Michael R. Baye

To Annie, Kate, Elise, and Henry.

—Jeffrey T. Prince

About the Authors



SOURCE: Federal Trade Commission

Michael R. Baye is the Bert Elwert Professor of Business Economics & Public Policy at Indiana University's Kelley School of Business, and currently serves as the Chairman of the U.S. Consumer Financial Protection Bureau's *Academic Research Council*. He also served as the Director of the Bureau of Economics at the Federal Trade Commission from July 2007 to December 2008. He received his BS in economics from Texas A&M University in 1980 and earned a PhD in economics from Purdue University in 1983. Prior to joining Indiana University, he taught graduate and undergraduate courses at the Pennsylvania State University, Texas A&M University, and the University of Kentucky. He has held a variety of editorial posts in economics, marketing, and business, and currently serves as a co-editor for the *Journal of Economics and Management Strategy.*

Professor Baye has won numerous awards for his outstanding teaching and research and teaches courses in managerial economics and industrial organization at the undergraduate, MBA, and PhD levels. His research has been published in the *American Economic Review*, *Journal of Political Economy*, *Econometrica*, *Review of Economic Studies*, *Economic Journal*, and *Management Science*. It has also been featured in *The Wall Street Journal*, *Forbes*, the *New York Times*, and numerous other outlets. When he is not teaching or engaged in research, Mike enjoys activities ranging from camping to shopping for electronic gadgets.



SOURCE: The Trustees of Indiana University

Jeffrey T. Prince is Professor of Business Economics & Public Policy at Indiana University's Kelley School of Business. He is also the Harold A. Poling Chair in Strategic Management and Co-Director of the Institute for Business Analytics at Kelley. From September 2019 to September 2020, he served as Chief Economist at the Federal Communications Commission. He received his BA in economics and BS in mathematics and statistics from Miami University in 1998 and earned a PhD in economics from Northwestern University in 2004. Prior to joining Indiana University, he taught graduate and undergraduate courses at Cornell University.

Professor Prince has won top teaching honors as a faculty member at both Indiana University and Cornell and as a graduate student at Northwestern. He has a broad research agenda within applied economics, having written and published on topics that include demand in technology markets, Internet diffusion, regulation in health care, risk aversion in insurance markets, and quality competition among airlines. He is one of a small number of economists to have published in both the top journal in economics (*American Economic Review*) and the top journal in management *(Academy of Management Journal*). He currently serves as a co-editor for the *Journal of Economics and Management Strategy* and is on the editorial board for *Information Economics and Policy*. In his free time, Jeff enjoys activities ranging from poker and bridge to running and racquetball.

Preface

Thanks to feedback from users around the world, *Managerial Economics and Business Strategy* remains the best-selling managerial text in the market. We are grateful to all of you for allowing us to provide this updated and improved edition. Before highlighting some of the new features of the tenth edition, we would like to stress that the fundamental goal of the book—providing students with the tools from intermediate microeconomics, game theory, and industrial organization that they need to make sound managerial decisions—has not changed. What *has* changed are the examples used to make managerial economics come to life for this generation of students, a stronger integration with data-based decision-making, and an enriched utilization of new technologies (such as *Connect*) for enhancing the teaching and learning experiences of instructors and their students.

This book begins by teaching managers the practical utility of basic economic tools such as present value analysis, supply and demand, regression, indifference curves, isoquants, production, costs, and the basic models of perfect competition, monopoly, and monopolistic competition. Adopters and reviewers also praise the book for its real-world examples and because it includes modern topics not contained in any other single managerial economics textbook: oligopoly, penetration pricing, multistage and repeated games, foreclosure, contracting, vertical and horizontal integration, networks, bargaining, predatory pricing, principal–agent problems, raising rivals' costs, adverse selection, auctions, screening and signaling, search, limit pricing, and a host of other pricing strategies for firms enjoying market power. This balanced coverage of traditional and modern microeconomic tools makes it appropriate for a wide variety of managerial economics classrooms. An increasing number of business schools are adopting this book to replace (or use alongside) managerial strategy texts laden with anecdotes but lacking the microeconomic tools needed to identify and implement the business strategies that are optimal in a given situation.

This tenth edition of *Managerial Economics and Business Strategy* has been revised to include updated examples and problems, but it retains all of the basic content that made previous editions a success. The basic structure of the textbook is largely unchanged to ensure a smooth transition to this edition.

KEY PEDAGOGICAL FEATURES

The tenth edition retains all of the class-tested features of previous editions that enhance students' learning experiences and make it easy to teach from this book.

Headlines

As in previous editions, each chapter begins with a *Headline* that is based on a real-world economic problem—a problem that students should be able to address after completing the chapter. These *Headlines* are essentially hand-picked "mini-cases" designed to motivate

students to learn the material in the chapter. Each *Headline* is answered at the end of the relevant chapter—when the student is better prepared to deal with the complications of real-world problems. Reviewers, as well as users, of previous editions praise the *Headline*s not only because they motivate students to learn the material in the chapter, but also because the answers at the end of each chapter help students learn how to use economics to make business decisions.

Learning Objectives

Each chapter includes learning objectives designed to enhance the learning experience. End-of-chapter problems are denoted with the learning objective(s) to which they relate.

Demonstration Problems

The best way to learn economics is to practice solving economic problems. Every chapter contains *Demonstration Problems* that provide students with detailed answers to help them verify that they have mastered the material. Select *Demonstration Problems* also offer a video walk-through of the problem, explaining the steps along the way. Students can click the link in their ebook or key in the URL provided to access the videos and solutions. Videos and solutions are also provided in the Connect Library, under Instructor Resource for instructors. The goal is in providing this additional guidance is to minimize time spent with students and instructors discussing answers to problems, allowing instructors more time to focus on other concepts.

Inside Business Applications

Most chapters offer *Inside Business* applications boxes to illustrate how theories explained in the text relate to a host of different business situations. As in previous editions, this feature is authored to strike a balance between applications drawn from the current economic literature and the popular press.

Calculus and Non-Calculus Alternatives

Users can easily include or exclude calculus-based material without losing content or continuity. That's because the basic principles and formulae needed to solve a particular class of economic problems (e.g., $MR = MC$) are first stated without appealing to the notation of calculus. Immediately following each stated principle or formula is a clearly marked *Calculus Alternative.* Each of these calculus alternatives states the preceding principle or formula in calculus notation and explains the relation between the calculus-based and non-calculus-based formulas. More detailed calculus derivations are relegated to chapter *Appendices*. Thus, the book is designed for use by instructors who want to integrate calculus into managerial economics and by those who do not require students to use calculus.

Variety of End-of-Chapter Problems

Three types of problems are offered. Highly structured but nonetheless challenging *Conceptual and Computational Questions* stress fundamentals. These are followed by *Problems and Applications,* which are far less structured and, like real-world decision environments, may contain more information than is actually needed to solve the problem. Many of these applied problems are based on actual business events.

Additionally, the new *Spectrum* case that follows Module Group B includes 13 problems called Memos that have a "real-world feel" and complement the text. All of these case-based problems may be assigned on a chapter-by-chapter basis as specific skills are introduced, or as part of a capstone experience.

Detailed answers to all problems can be found among the instructor resource material available via *Connect*.

Case Study

A case study in business strategy, *Spectrum—the Spawn of Time Warner Cable and Charter Communications—Navigates Challenges from Cord Cutting and Mobile Competition* follows Module Group B and was prepared especially for this text. It can be used either as a capstone case for the course or to supplement individual chapters. The case allows students to apply core elements from managerial economics to a remarkably rich business environment. Instructors can use the case as the basis for an "open-ended" discussion of business strategy, or they can assign specific "memos" (contained at the end of the case) that require students to apply specific tools from managerial economics to the case. Teaching notes, as well as solutions to all of the memos, are provided among the instructor resource material available via *Connect*.

Flexibility

Instructors of managerial economics have genuinely heterogeneous textbook needs. Reviewers and users continue to praise the book for its flexibility, and they assure us that sections or even entire chapters can be excluded without losing continuity. For instance, an instructor wishing to stress microeconomic fundamentals might choose to cover Chapters 2, 3, 4, 5, 8, 9, 10, 11, and 12. An instructor teaching a more applied course that stresses business strategy might choose to cover Chapters 1, 2, 3, 5, 6, 7, 8, 10, 11, and some or all of Module Group A. Each may choose to include additional content (for example, some or all of Module Group B or the *Time Warner Cable* case) as time permits. More generally, instructors can easily omit topics such as present value analysis, regression, indifference curves, isoquants, or reaction functions without losing continuity.

CHANGES IN THE TENTH EDITION

We have made every effort to update and improve *Managerial Economics and Business Strategy* while assuring a smooth transition to the tenth edition. Following is a summary of the pedagogical improvements, enhanced supplements, and content changes that make the tenth edition an even more powerful tool for teaching and learning managerial economics and business strategy.

- New and updated mini-cases on topics such as: Google Search, Netflix Pricing, and a range of mergers.
- New and updated end-of-chapter problems.
- New and updated *Headlines.*
- New and updated *Inside Business* applications.
- New Excel Exercises in Connect. As denoted in the text with an Excel icon, this edition offers students the ability to get more hands-on practice using Excel.
- Content from Chapters 13 and 14 in the previous edition are now placed in stand-alone modules that permit instructors to easily pick-and-choose topics to include along with their conventional materials.
- *Spectrum—the Spawn of Time Warner Cable and Charter Communications—Navigates Challenges from Cord Cutting and Mobile Competition* replaces the old *Time Warner Cable* Case.



Chapter-by-Chapter Changes

- **Chapter 1** contains a new section discussing how managers make data-driven decisions, setting the stage to incorporate the use of data to solve managerial problems throughout the remainder of the text. It also contains new and updated examples and two new end-of-chapter problems centered on the use of data analysis for managerial decision-making.
- **Chapter 2** contains two updated and one new *Inside Business* applications. The new application discusses globalization and the supply of automobiles from China.
- **Chapter 3** contains updated examples and several new elasticity tables. It also contains a new *Inside Business* about strategy in digital markets. In addition, it has a new section about data-driven demand curves and another new *Inside Business* application about the use of data to estimate demand for gamers.
- **Chapter 4** contains an updated *Inside Business* application and updated end-of-chapter problems.
- **Chapter 5** contains a new *Inside Business* application on artificial intelligence and cost minimization. It also includes new sections on data-driven production and cost functions, and there are two new end-of-chapter problems based on these new sections.
- **Chapter 6** offers a new *Headline* on vertical integration, two updated *Inside Business* applications, and a new *Inside Business* application on outsourcing.
- **Chapter 7** contains a new *Headline* on the Sprint/T-Mobile merger along with updated examples and industry data. It also provides a new *Inside Business* application on demand elasticities and a new end-of-chapter problem.
- **Chapter 8** contains an updated *Headline* and two new end-of-chapter problems.
- **Chapter 9** contains an updated *Inside Business* applications and two new end-of-chapter problems focused on data-driven decision-making.
- **Chapter 10** contains a new *Inside Business* application examining Canadian gasoline markets, as well as an updated *Inside Business* application and *Demonstration Problem*. It also contains a new end-of-chapter problem on competition between Google and Amazon in the smart home market.
- **Chapter 11** contains a new *Inside Business* application on bundling telecommunications services to reduce churn. It also includes an updated *Headline* and *Inside Business* application, as well as two new end-of-chapter problems on data-driven decision-making.
- **Chapter 12** contains an updated *Inside Business* application.
- **Module Group A (formerly Chapter 13)** has been transformed into four self-contained, concise and easy-to-navigate modules on entry prevention, lessening competition, restructuring game timing, and overcoming network effects.
- **Module Group B (formerly Chapter 14)** has been transformed into three self-contained, concise and easy-to-navigate modules on regulatory constraint on market power; regulation of markets with externalities, public goods, or incomplete information; and government policy and international markets.

Remote Proctoring & Browser-Locking Capabilities

New remote proctoring and browser-locking capabilities, hosted by Proctorio within Connect, provide control of the assessment environment by enabling security options and verifying the identity of the student.

Seamlessly integrated within Connect, these services allow instructors to control students' assessment experience by restricting browser activity, recording students' activity, and verifying students are doing their own work.

Instant and detailed reporting gives instructors an at-a-glance view of potential academic integrity concerns, thereby avoiding personal bias and supporting evidence-based claims.

ACKNOWLEDGMENTS

We thank the many users of *Managerial Economics and Business Strategy* who provided both direct and indirect feedback that has helped improve *your* book. This includes thousands of students at Indiana University's Kelley School of Business and instructors worldwide who have used this book in their own classrooms, colleagues who unselfishly gave up their own time to provide comments and suggestions, and reviewers who provided detailed suggestions to improve this and previous editions of the book. We especially thank the following professors, past and present, for enlightening us on the market's diverse needs and for providing suggestions and constructive criticisms to improve this book.

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As always, we welcome your comments and suggestions for the next edition. Please feel free to write to us directly at *mbaye@indiana.edu* or *jeffprin@indiana.edu.*

Michael R. Baye
Jeffrey T. Prince

SUPPLEMENTS

We know the content and reliability of new editions and book supplements are of utmost importance to users of our book. Because of this, and unlike most other managerial economics books, we personally are involved in crafting and accuracy checking virtually every content update and supplement for our book. Below we discuss popular features of some of the supplements that have been greatly expanded for this edition. The following ancillaries are available for quick download and convenient access via the instructor resource material available through *Connect*.

Cases

In addition to the *Spectrum* case, nearly a dozen full-length cases were updated and prepared to accompany *Managerial Economics and Business Strategy.* These cases complement the textbook by showing how real-world businesses use tools like demand elasticities, markup pricing, third-degree price discrimination, bundling, Herfindahl indices, game theory, and

predatory pricing to enhance profits or shape business strategies. The cases are based on actual decisions by companies that include Microsoft, Heinz, Visa, Staples, American Airlines, and Nasdaq. Expanded teaching notes and solutions for all of the cases—including the *Spectrum* case—are also provided.

PowerPoint Slides

Thoroughly updated and fully editable PowerPoint presentations with animated figures and graphs, make teaching and learning a snap. For instance, a simple mouse click reveals the firm's demand curve. Another click reveals the associated marginal revenue curve. Another click shows the firm's marginal cost. A few more clicks, and students see how to determine the profit-maximizing output, price, and maximum profits. Animated graphs and tables are also provided for all other relevant concepts (like Cournot and Stackelberg equilibrium, normal form and extensive form games, and the like).

Solutions Manual

We have prepared a solutions manual that provides detailed answers to all end-of-chapter problems, all of which have been class-tested for accuracy.

Test Bank

An updated test bank, offers well over 1,000 multiple-choice questions categorized by learning objectives, AACSB learning categories, Bloom's taxonomy objectives, and level of difficulty.

Computerized Test Bank

Test Builder within Connect allows you to create tests that can be printed or administered within your LMS. This cloud-based application includes a modern, streamlined interface for easy assessment creation. Content can easily be configured to match your course needs, including the ability to:

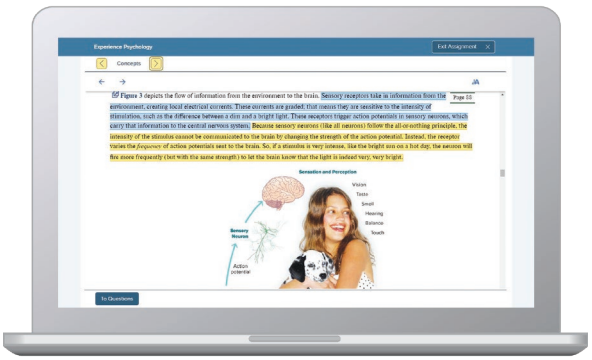
- Easily pinpoint the most relevant content through robust filtering options.
- Manipulate the order of questions.
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- Scramble questions and/or answers.
- Pin questions to a specific location within a test.
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- Add instructions.
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Solutions for your challenges

A product isn't a solution. Real solutions are affordable, reliable, and come with training and ongoing support when you need it and how you want it. Visit **www.supportateverystep.com** for videos and resources both you and your students can use throughout the semester.

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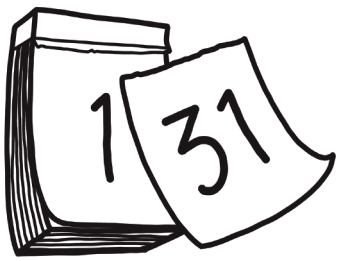
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> ***"I really liked this app—it made it easy to study when you don't have your textbook in front of you."***
>
> - Jordan Cunningham, Eastern Washington University



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Connect Economics Asset Alignment with Bloom's Taxonomy

We Take Students Higher

As a learning science company we create content that supports higher order thinking skills. Within Connect®, we tag assessments accordingly so you can filter your search, assign it, and receive reporting on it. These content asset types can be associated with one or more levels of Bloom's Taxonomy.

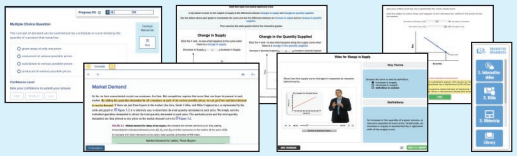
The chart below shows a few of the key assignable economics assets with *McGraw Hill Connect* aligned with Bloom's Taxonomy. Take your students higher by assigning a variety of applications, moving them from simple memorization to concept application.



* Outside of Connect.

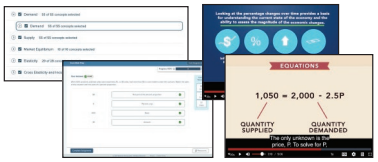
SmartBook 2.0

Adaptively aids students to study more efficiently by highlighting where in the chapter to focus, asking review questions and pointing them to passages in the text until they understand. Assignable and assessable.



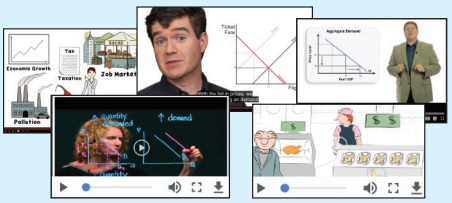
Math Preparedness

Math Preparedness assignments help students refresh important prerequisite topics necessary to be successful in economics. Tutorial videos are included to help illustrate math concepts to students visually.



Videos

Select Economic Naturalist examples have been developed into videos that show how to employ basic economic principles to understand and explain what you observe in the world around you. All videos are closed captioned and are assignable with assessment questions for improved retention.



Exercises

Exercises with algorithmic variations provide ample opportunities for students to practice and hone quantitative skills. Graphing Exercises provide opportunities for students to draw, interact with, manipulate, and analyze graphs.



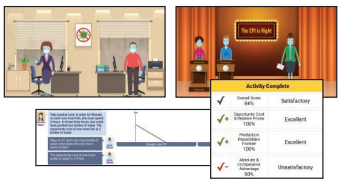
Interactive Graphs

Interactive Graphs provide visual displays of real data and economic concepts for students to manipulate. All graphs are accompanied by assignable assessment questions and feedback to guide students through the experience of learning to read and interpret graphs and data.



Application-Based Activities

Immersive real-life scenarios engage students and put them in the role of everyday economists. Students practice their economic thinking and problem-solving skills as they apply course concepts and see the implications of their decisions as they go. Each activity is designed as a 15-minute experience, unless students eagerly replay for a better outcome.



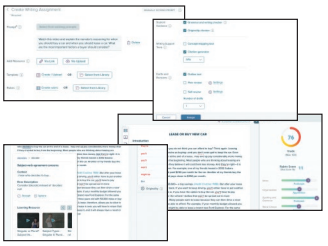
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1 The Fundamentals of Managerial Economics

LEARNING OBJECTIVES

After completing this chapter, you will be able to:

- **LO1** Summarize how goals, constraints, incentives, and market rivalry affect economic decisions.
- **LO2** Distinguish economic versus accounting profits and costs.
- **LO3** Explain the role of profits in a market economy.
- **LO4** Apply the five forces framework to analyze the sustainability of an industry's profits.
- **LO5** Apply present value analysis to make decisions and value assets.
- **LO6** Apply marginal analysis to determine the optimal level of a managerial control variable.
- **LO7** Identify and apply seven principles of effective managerial decision making.

headLINE

Amcott Loses $3.5 Million; Manager Fired

On Tuesday software giant Amcott posted a year-end operating loss of $3.5 million. Reportedly, $1.7 million of the loss stemmed from its foreign language division.

At a time when Amcott was paying First National a hefty 7 percent rate to borrow short-term funds, Amcott decided to use $20 million of its retained earnings to purchase three-year rights to Magicword, a software package that converts generic word processor files saved as French text into English. First-year sales revenue from the software was $7 million, but thereafter sales were halted pending a copyright infringement suit filed by Foreign, Inc. Amcott lost the suit and paid damages of $1.7 million. Industry insiders say that the copyright violation pertained to "a very small component of Magicword."

Ralph, the Amcott manager who was fired over the incident, was quoted as saying, "I'm a scapegoat for the attorneys [at Amcott] who didn't do their homework before buying the rights to Magicword. I projected annual sales of $7 million per year for three years. My sales forecasts were right on target."

Do you know why Ralph was fired?[1]

[1]Each chapter concludes with an answer to the question posed in that chapter's opening headline. After you read each chapter, you should attempt to solve the opening headline on your own and then compare your solution to that presented at the end of the chapter.

INTRODUCTION

Many students taking managerial economics ask, "Why should I study economics? Will it tell me what the stock market will do tomorrow? Will it tell me where to invest my money or how to get rich?" Unfortunately, managerial economics by itself is unlikely to provide definitive answers to such questions. Obtaining the answers would require an accurate crystal ball. Nevertheless, managerial economics is a valuable tool for analyzing business situations such as the ones raised in the headlines that open each chapter of this book.

In fact, if you surf the Internet, browse a business publication such as *Bloomberg Businessweek* or *The Wall Street Journal*, or read a trade publication like *National Restaurant News* or *Supermarket News*, you will find a host of stories that involve managerial economics. A recent search generated the following headlines:

"Disney to Assume Full Operational Control of Hulu in Comcast Deal"

"Walmart Ups the Delivery Game with Next Day Shipping"

"Generic Drug Companies, Executives Slapped with Price-Fixing Lawsuit"

"Is 'Never Knowingly Undersold' Killing John Lewis?"

"Brands Rethink Social Media Strategy"

"Uber and Lyft Are in 'an Arms Race in Marketing Spend Right Now'"

"U.S. Government Steps Up Challenges to Hospital Mergers"

"Amazon Is Paying Employees $10,000 and 3 Months' Salary to Quit and Start Their Own Business"

Sadly, billions of dollars are lost each year because many existing managers fail to use basic tools from managerial economics to shape pricing and output decisions, optimize the production process and input mix, choose product quality, guide horizontal and vertical merger decisions, or optimally design internal and external incentives. Happily, if you learn a few basic principles from managerial economics, you will be poised to drive the inept managers out of their jobs! You will also understand why the latest recession was great news to some firms and why some software firms spend millions on the development of applications for smartphones but permit consumers to download them for free.

Managerial economics is not only valuable to managers of *Fortune* 500 companies; it is also valuable to managers of not-for-profit organizations. It is useful to the manager of a food bank who must decide the best means for distributing food to the needy. It is valuable to the coordinator of a shelter for the homeless whose goal is to help the largest possible number of homeless, given a very tight budget. In fact, managerial economics provides useful insights into every facet of the business and nonbusiness world in which we live—including household decision making.

Why is managerial economics so valuable to such a diverse group of decision makers? The answer to this question lies in the meaning of the term *managerial economics*.

The Manager

manager
A person who directs resources to achieve a stated goal.

A **manager** is a person who directs resources to achieve a stated goal. This definition includes all individuals who (1) direct the efforts of others, including those who delegate tasks within an organization such as a firm, a family, or a club; (2) purchase inputs to be used in the production of goods and services such as the output of a firm, food for the needy, or shelter for the homeless; or (3) are in charge of making other decisions, such as product price or quality.

A manager generally has responsibility for his or her own actions as well as for the actions of individuals, machines, and other inputs under the manager's control. This control may involve responsibilities for the resources of a multinational corporation or for those of a single household. In each instance, however, a manager must direct resources and the behavior of individuals for the purpose of accomplishing some task. While much of this book assumes the manager's task is to maximize the profits of the firm that employs the manager, the underlying principles are valid for virtually any decision process.

Economics

The primary focus of this book is on the second word in *managerial economics*. **Economics** is the science of making decisions in the presence of scarce resources. *Resources* are simply anything used to produce a good or service or, more generally, to achieve a goal. Decisions are important because scarcity implies that by making one choice, you give up another. A computer firm that spends more resources on advertising has fewer resources to invest in research and development. A food bank that spends more on soup has less to spend on fruit. Economic decisions thus involve the allocation of scarce resources, and a manager's task is to allocate resources so as to best meet the manager's goals.

economics
The science of making decisions in the presence of scarce resources.

One of the best ways to comprehend the pervasive nature of scarcity is to imagine that a genie has appeared and offered to grant you three wishes. If resources were not scarce, you would tell the genie you have absolutely nothing to wish for; you already have everything you want. Surely, as you begin this course, you recognize that time is one of the scarcest resources of all. Your primary decision problem is to allocate a scarce resource—time—to achieve a goal—such as mastering the subject matter or earning an A in the course.

Managerial Economics Defined

Managerial economics, therefore, is the study of how to direct scarce resources in the way that most efficiently achieves a managerial goal. It is a very broad discipline in that it describes methods useful for directing everything from the resources of a household to maximize household welfare to the resources of a firm to maximize profits.

managerial economics
The study of how to direct scarce resources in the way that most efficiently achieves a managerial goal.

To understand the nature of decisions that confront managers of firms, imagine that you are the manager of a *Fortune* 500 company that makes computers. You must make a host of decisions to succeed as a manager: Should you purchase components such as disk drives and chips from other manufacturers or produce them within your own firm? Should you specialize in making one type of computer or produce several different types? How many computers should you produce, and at what price should you sell them? How many employees should you hire, and how should you compensate them? How can you ensure that employees work hard and produce quality products? How will the actions of rival computer firms affect your decisions?

The key to making sound decisions is to know what information is needed to make an informed decision and then to collect and process the data. If you work for a large firm, your legal department can provide data about the legal ramifications of alternative decisions; your accounting department can provide tax advice and basic cost data; your marketing department can provide you with data on the characteristics of the market for your product; and your firm's financial analysts can provide summary data for alternative methods of obtaining financial capital. Ultimately, however, the manager must integrate all of this information, process it, and arrive at a decision. The remainder of this book will show you how to perform this important managerial function by using seven principles that comprise effective management.

THE ECONOMICS OF EFFECTIVE MANAGEMENT

The nature of sound managerial decisions varies depending on the underlying goals of the manager. Since this course is designed primarily for managers of firms, this book focuses on managerial decisions as they relate to maximizing profits or, more generally, the value of the firm. Before embarking on this special use of managerial economics, we provide an overview of the basic principles that comprise effective management. In particular, an effective manager must (1) identify goals and constraints, (2) recognize the nature and importance of profits, (3) understand incentives, (4) understand markets, (5) recognize the time value of money, (6) use marginal analysis, and (7) make data-driven decisions.

Identify Goals and Constraints

The first step in making sound decisions is to have well-defined *goals* because achieving different goals entails making different decisions. If your goal is to maximize your grade in this course rather than maximize your overall grade point average, your study habits will differ accordingly. Similarly, if the goal of a food bank is to distribute food to needy people in rural areas, its decisions and optimal distribution network will differ from those it would use to distribute food to needy inner-city residents. Notice that, in both instances, the decision maker faces *constraints* that affect the ability to achieve a goal. The 24-hour day affects your ability to earn an A in this course; a budget affects the ability of the food bank to distribute food to the needy. Constraints are an artifact of scarcity.

Different units within a firm may be given different goals; those in a firm's marketing department might be instructed to use their resources to maximize sales or market share, while those in the firm's financial group might focus on earnings growth or risk-reduction strategies. Later in this book we will see how the firm's overall goal—maximizing profits—can be achieved by giving each unit within the firm an incentive to achieve potentially different goals.

Unfortunately, constraints make it difficult for managers to achieve goals such as maximizing profits or increasing market share. These constraints include such things as the available technology and the prices of inputs used in production. The goal of maximizing profits requires the manager to decide the optimal price to charge for a product, how much to produce, which technology to use, how much of each input to use, how to react to decisions made by competitors, and so on. This book provides tools for answering these types of questions.

Recognize the Nature and Importance of Profits

The overall goal of most firms is to maximize profits or the firm's value, and the remainder of this book will detail strategies managers can use to achieve this goal. Before we provide these details, let us examine the nature and importance of profits in a free-market economy.

Economic versus Accounting Profits

When most people hear the word *profit*, they think of accounting profits. **Accounting profits** are the total amount of money taken in from sales (total revenue, or price times quantity sold) minus the dollar cost of producing goods or services. Accounting profits are what show up on the firm's income statement and are typically reported to the manager by the firm's accounting department.

A more general way to define profits is in terms of what economists refer to as economic profits. **Economic profits** are the difference between the total revenue and the total opportunity cost of producing the firm's goods or services. The **opportunity cost** of using a resource includes both the *explicit* (or *accounting*) *cost* of the resource and the *implicit cost* of giving

accounting profits
The total amount of money taken in from sales (total revenue, or price times quantity sold) minus the dollar cost of producing goods or services.

economic profits
The difference between total revenue and total opportunity cost.

opportunity cost
The explicit cost of a resource plus the implicit cost of giving up its best alternative use.

up the best alternative use of the resource. The opportunity cost of producing a good or service generally is higher than accounting costs because it includes both the dollar value of costs (explicit, or accounting, costs) and any implicit costs.

Implicit costs are very hard to measure and therefore managers often overlook them. Effective managers, however, continually seek out data from other sources to identify and quantify implicit costs. Managers of large firms can use sources within the company, including the firm's finance, marketing, and/or legal departments, to obtain data about the implicit costs of decisions. In other instances, managers must collect data on their own. For example, what does it cost you to read this book? The price you paid the bookseller for this book is an explicit (or accounting) cost, while the implicit cost is the value of what you are giving up by reading the book. You could be studying some other subject or watching TV, and each of these alternatives has some value to you. The "best" of these alternatives is your implicit cost of reading this book; you are giving up this alternative to read the book. Similarly, the opportunity cost of going to school is much higher than the cost of tuition and books; it also includes the amount of money you would earn had you decided to work rather than go to school.

In the business world, the opportunity cost of opening a restaurant is the best alternative use of the resources used to establish the restaurant—say, opening a hair salon. Again, these resources include not only the explicit financial resources needed to open the business, but any implicit costs as well. Suppose you own a building in New York that you use to run a small pizzeria. Food supplies are your only accounting costs. At the end of the year, your accountant informs you that these costs were $20,000 and that your revenues were $100,000. Thus, your accounting profits are $80,000.

However, these accounting profits overstate your economic profits because the costs include only accounting costs. First, the costs do not include the time you spent running the business. Had you not run the business, you could have worked for someone else, and this fact reflects an economic cost not accounted for in accounting profits. To be concrete, suppose you could have worked for someone else for $30,000. Your opportunity cost of time would have been $30,000 for the year. Thus, $30,000 of your accounting profits are not profits at all but one of the implicit costs of running the pizzeria.

Second, accounting costs do not account for the fact that, had you not run the pizzeria, you could have rented the building to someone else. If the rental value of the building is $100,000 per year, you gave up this amount to run your own business. Thus, the costs of running the pizzeria include not only the costs of supplies ($20,000) but the $30,000 you could have earned in some other business *and* the $100,000 you could have earned in renting the building to someone else. The economic cost of running the pizzeria is $150,000—the amount you gave up to run your business. Considering the revenue of $100,000, you actually lost $50,000 by running the pizzeria; your *economic profits* were –$50,000.

Throughout this text, when we speak of costs, we mean economic costs. Economic costs are opportunity costs and include not only the explicit (accounting) costs but also the implicit costs of the resources used in production.

The Role of Profits

A common misconception is that the firm's goal of maximizing profits is necessarily bad for society. Individuals who want to maximize profits often are considered self-interested, a quality that many people view as undesirable. However, consider Adam Smith's classic line from *The Wealth of Nations*: "It is not out of the benevolence of the butcher, the brewer, or the baker, that we expect our dinner, but from their regard to their own interest."[2]

[2]Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations,* 1776.

INSIDE BUSINESS 1–1

The Goals of Firms in Our Global Economy

Recent trends in globalization have forced businesses around the world to more keenly focus on profitability. This trend is also present in Japan, where historical links between banks and businesses have traditionally blurred the goals of firms. For example, at the turn of the twenty-first century, the Japanese business engineering firm Mitsui & Co. Ltd. launched "Challenge 21," a plan directed at helping the company emerge as Japan's leading business engineering group. According to a spokesperson for the company, "[This plan permits us to] create new value and maximize profitability by taking steps such as renewing our management framework and prioritizing the allocation of our resources into strategic areas. We are committed to maximizing shareholder value through business conduct that balances the pursuit of earnings with socially responsible behavior."

Ultimately, the goal of any continuing company must be to maximize the value of the firm. This goal is often achieved by trying to hit intermediate targets, such as minimizing costs or increasing market share. If you—as a manager—do not maximize your firm's value over time, you will be in danger of either going out of business, being taken over by other owners (as in a leveraged buyout), or having stockholders elect to replace you and other managers.

SOURCE: "Mitsui & Co., Ltd. UK Regulatory Announcement: Final Results," *Business Wire*, May 13, 2004.

Smith is saying that by pursuing its self-interest—the goal of maximizing profits—a firm ultimately meets the needs of society. If you cannot make a living as a rock singer, it is probably because society does not appreciate your singing; society would more highly value your talents in some other employment. If you break five dishes each time you clean up after dinner, your talents are perhaps better suited for filing paperwork or mowing the lawn. Similarly, the profits of businesses signal where society's scarce resources are best allocated. When firms in a given industry earn economic profits, the opportunity cost to resource holders outside the industry increases. Owners of other resources soon recognize that, by continuing to operate their existing businesses, they are giving up profits. This induces new firms to enter the markets in which economic profits are available. As more firms enter the industry, the market price falls, and economic profits decline.

Thus, profits signal the owners of resources where the resources are most highly valued by society. By moving scarce resources toward the production of goods most valued by society, the total welfare of society is improved. As Adam Smith first noted, this phenomenon is due not to benevolence on the part of the firms' managers but to the self-interested goal of maximizing the firms' profits.

PRINCIPLE

Profits Are a Signal

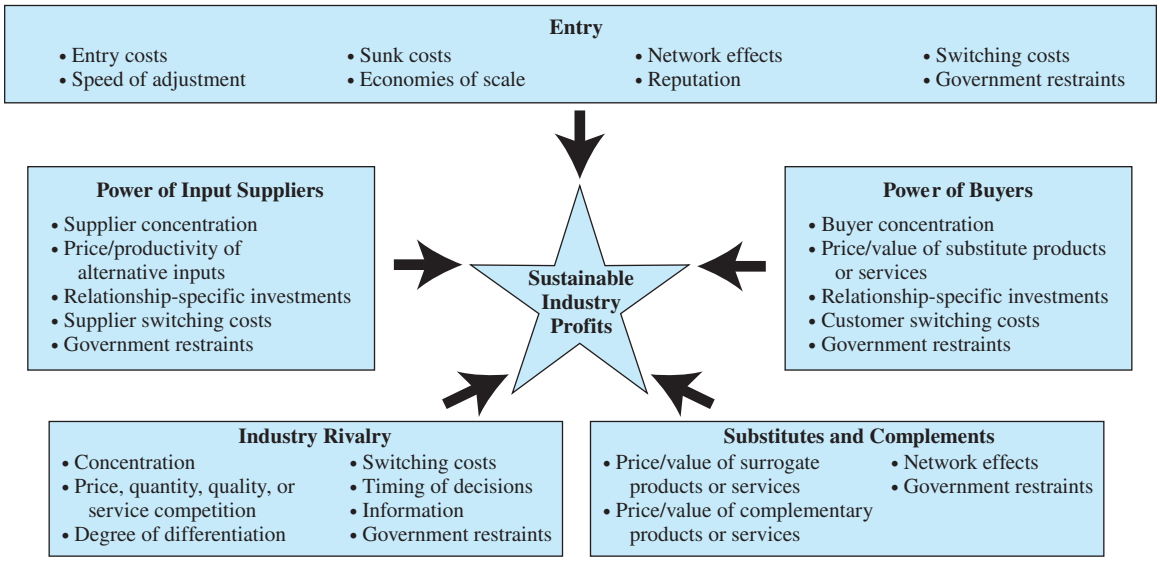
Profits signal to resource holders where resources are most highly valued by society.

The Five Forces Framework and Industry Profitability

A key theme of this textbook is that many interrelated forces and decisions influence the level, growth, and sustainability of profits. If you or other managers in the industry are clever enough to identify strategies that yield a windfall to shareholders this quarter, there is no guarantee that these profits will be sustained in the long run. You must recognize that profits are a signal—if your business earns superior profits, existing and potential competitors will do their

Figure 1–1

The Five Forces Framework



best to get a piece of the action. In the remaining chapters, we will examine a variety of business strategies designed to enhance your prospects of earning and sustaining profits. Before we do so, however, it is constructive to provide a conceptual framework for thinking about some of the factors that impact industry profitability.

Figure 1–1 illustrates the *"five forces" framework* pioneered by Michael Porter.[3] This framework organizes many complex managerial economics issues into five categories or "forces" that impact the sustainability of industry profits: (1) entry, (2) power of input suppliers, (3) power of buyers, (4) industry rivalry, and (5) substitutes and complements. The following discussion explains how these forces influence industry profitability and highlights the connections among these forces and material covered in the remaining chapters of the text.

Entry. As we will see in Chapters 2, 7, and 8, entry heightens competition and reduces the margins of existing firms in a wide variety of industry settings. For this reason, the ability of existing firms to sustain profits depends on how barriers to entry affect the ease with which other firms can enter the industry. Entry can come from a number of directions, including the formation of new companies (Wendy's entered the fast-food industry in the 1970s after its founder, Dave Thomas, left KFC), globalization strategies by foreign companies (Toyota has sold vehicles in Japan since the 1930s but waited until the middle of the last century to enter the U.S. automobile market), and the introduction of new product lines by existing firms (computer manufacturer Apple now also sells the popular iPhone).

As shown in Figure 1–1, a number of economic factors affect the ability of entrants to erode existing industry profits. In subsequent chapters, you will learn why entrants are less likely to capture market share quickly enough to justify the costs of entry in environments where there are sizable sunk costs (Chapters 5 and 9), significant economies of scale (Chapters 5 and 8), or significant network effects (Module Group A), or where existing

[3]Michael Porter, *Competitive Strategy* (New York: Free Press, 1980).

firms have invested in strong reputations for providing value to a sizable base of loyal consumers (Chapter 11) or to aggressively fight entrants (Chapter 10 and Module Group A). In addition, you will gain a better appreciation for the role that governments play in shaping entry through patents and licenses (Chapter 8), trade policies (Chapter 5 and Module Group B), and environmental legislation (Module Group B). We will also identify a variety of strategies to raise the costs to consumers of "switching" to would-be entrants, thereby lowering the threat that entrants will erode your profits.

Power of Input Suppliers. Industry profits tend to be lower when suppliers have the power to negotiate favorable terms for their inputs. Supplier power tends to be low when inputs are relatively standardized and relationship-specific investments are minimal (Chapter 6), input markets are not highly concentrated (Chapter 7), or alternative inputs are available with similar marginal productivities per dollar spent (Chapter 5). In many countries, the government constrains the prices of inputs through price ceilings and other controls (Chapter 2 and Module Group B), which limits to some extent the ability of suppliers to expropriate profits from firms in the industry.

Power of Buyers. Similar to the case of suppliers, industry profits tend to be lower when customers or buyers have the power to negotiate favorable terms for the products or services produced in the industry. In most consumer markets, buyers are fragmented and thus buyer concentration is low. Buyer concentration and hence customer power tend to be higher in industries that serve relatively few "high-volume" customers. Buyer power tends to be lower in industries where the cost to customers of switching to other products is high—as is often the case when there are relationship-specific investments and hold-up problems (Chapter 6), imperfect information that leads to costly consumer search (Chapter 12), or few close substitutes for the product (Chapters 2, 3, 4, and 11). Government regulations, such as price floors or price ceilings (Chapter 2 and Module Group B), can also impact the ability of buyers to obtain more favorable terms.

Industry Rivalry. The sustainability of industry profits also depends on the nature and intensity of rivalry among firms competing in the industry. Rivalry tends to be less intense (and hence the likelihood of sustaining profits is higher) in concentrated industries—that is, those with relatively few firms. In Chapter 7 we will take a closer look at various measures that can be used to gauge industry concentration.

The level of product differentiation and the nature of the game being played—whether firms' strategies involve prices, quantities, capacity, or quality/service attributes, for example—also impact profitability. In later chapters you will learn why rivalry tends to be more intense in industry settings where there is little product differentiation and firms compete in price (Chapters 8, 9, 10, and 11) and where consumer switching costs are low (Chapters 11 and 12). You will also learn how imperfect information and the timing of decisions affect rivalry among firms (Chapters 10 and 12 and Module Group A).

Substitutes and Complements. The level and sustainability of industry profits also depend on the price and value of interrelated products and services. Porter's original five forces framework emphasized that the presence of close substitutes erodes industry profitability. In Chapters 2, 3, 4, and 11 you will learn how to quantify the degree to which surrogate products are close substitutes by using elasticity analysis and models of consumer behavior. We will also see that government policies (such as restrictions limiting the importation of prescription

INSIDE BUSINESS 1–2

Profits and the Evolution of the Computer Industry

When profits in a given industry are higher than those in other industries, new firms will attempt to enter that industry. When losses are recorded, some firms will likely leave the industry. This sort of "evolution" has changed the global landscape of personal computer markets.

At the start of the PC era, personal computer makers enjoyed positive economic profits. These higher profits led to new entry and heightened competition. Over the past two decades, entry has led to declines in PC prices and industry profitability despite significant increases in the speed and storage capacities of PCs. Less efficient firms have been forced to exit the market.

In the early 2000s, IBM—the company that launched the PC era when it introduced the IBM PC in the early 1980s—sold its PC business to China-based Lenovo. Compaq—an early leader in the market for PCs—was acquired by Hewlett-Packard. A handful of small PC makers have enjoyed some success competing against the remaining traditional players, which include Dell and Hewlett-Packard. By the late 2000s, Dell's strategy switched from selling computers directly to consumers to entering into relationships with retailers such as Best Buy and Staples, as well as focusing on corporate customers. While only time will tell how these strategies will impact the long-run viability of traditional players, competitive pressures continue to push PC prices and industry profits downward as consumers increasingly shift toward tablets and smartphones.

drugs from Canada into the United States) can directly impact the availability of substitutes and thus industry profits.

More recent work by economists and business strategists emphasizes that complementarities also affect industry profitability.[4] For example, Microsoft's profitability in the market for operating systems is enhanced by the presence of complementary products ranging from relatively inexpensive computer hardware to a plethora of Windows-compatible application software. Analogously, Apple's profitability in the cell phone market is enhanced by the tens of thousands of complementary applications ("apps") that are compatible with its iPhone. In Chapters 3, 5, and 10, as well as Module Group A, you will learn how to quantify these complementarities or "synergies" and identify strategies to create and exploit complementarities and network effects.

Many forces that affect the level and sustainability of industry profits are interrelated. For instance, the U.S. automobile industry suffered a sharp decline in industry profitability during the 1970s as a result of sharp increases in the price of gasoline (a complement to automobiles). This change in the price of a complementary product enabled Japanese automakers to *enter* the U.S. market through a differentiation strategy of marketing their fuel-efficient cars, which sold like hotcakes compared to the gas-guzzlers American automakers produced at that time. These events, in turn, have had a profound impact on industry rivalry in the automotive industry—not just in the United States, but worldwide.

It is also important to stress that the five forces framework is primarily a tool for helping managers see the "big picture"; it is a schematic you can use to organize various industry conditions that affect industry profitability and assess the efficacy of alternative business strategies. However, it would be a mistake to view it as a comprehensive list of all factors that affect industry profitability. The five forces framework is not a substitute for understanding the economic principles that underlie sound business decisions.

[4]See, for example, Barry J. Nalebuff and Adam M. Brandenburger, *Co-Opetition* (New York: Doubleday, 1996), as well as R. Preston McAfee, *Competitive Solutions* (Princeton, NJ: Princeton University Press, 2002).

Understand Incentives

In our discussion of the role of profits, we emphasized that profits signal the holders of resources when to enter and exit particular industries. In effect, changes in profits provide an incentive to resource holders to alter their use of resources. Within a firm, *incentives* affect how resources are used and how hard workers work. To succeed as a manager, you must have a clear grasp of the role of incentives within an organization such as a firm and how to construct incentives to induce maximal effort from those you manage. Chapter 6 is devoted to this special aspect of managerial decision making, but it is useful here to provide a synopsis of how to construct proper incentives.

The first step in constructing incentives within a firm is to distinguish between the world, or the business place, as it is and the way you wish it were. Many professionals and owners of small establishments have difficulties because they do not fully comprehend the importance of the role incentives play in guiding the decisions of others.

A friend of ours—Mr. O—opened a restaurant and hired a manager to run the business so he could spend time doing the things he enjoys. Recently, we asked him how his business was doing, and he reported that he had been losing money ever since the restaurant opened. When asked whether he thought the manager was doing a good job, he said, "For the $75,000 salary I pay the manager each year, the manager *should* be doing a good job."

Mr. O believes the manager "should be doing a good job." This is the way he wishes the world was. But individuals often are motivated by self-interest. This is not to say that people never act out of kindness or charity, but rather that human nature is such that people naturally tend to look after their own self-interest. Had Mr. O taken a managerial economics course, he would know how to provide the manager with an incentive to do what is in Mr. O's best interest. The key is to design a mechanism such that if the manager does what is in *his* own interest, he will indirectly do what is best for Mr. O.

Since Mr. O is not physically present at the restaurant to watch over the manager, he has no way of knowing what the manager is up to. Indeed, his unwillingness to spend time at the restaurant is what induced him to hire the manager in the first place. What type of incentive has he created by paying the manager $75,000 per year? The manager receives $75,000 per year regardless of whether he puts in 12-hour or 2-hour days. The manager receives no reward for working hard and incurs no penalty if he fails to make sound managerial decisions. The manager receives the same $75,000, regardless of the restaurant's profitability.

Fortunately, most business owners understand the problem just described. The owners of large corporations are shareholders, and most never set foot on company ground. How do they provide incentives for chief executive officers (CEOs) to be effective managers? Very simply, they provide them with "incentive plans" in the form of bonuses. These bonuses are in direct proportion to the firm's profitability. If the firm does well, the CEO receives a large bonus. If the firm does poorly, the CEO receives no bonus and risks being fired by the stockholders. These types of incentives are also present at lower levels within firms. Some individuals earn commissions based on the revenue they generate for the firm's owner. If they put forth little effort, they receive little pay; if they put forth much effort and hence generate many sales, they receive a generous commission.

The thrust of managerial economics is to provide you with a broad array of skills that enable you to make sound economic decisions and to structure appropriate incentives within your organization. We will begin under the assumption that everyone with whom you come into contact is greedy, that is, interested only in his or her own self-interest. In such a case, understanding incentives is a must. Of course, this is a worst-case scenario; more likely, some of your business contacts will not be so selfishly inclined. If you are so lucky, your job will be all the easier.

Understand Markets

In studying microeconomics in general, and managerial economics in particular, it is important to bear in mind that there are two sides to every transaction in a market: For every buyer of a good there is a corresponding seller. The final outcome of the market process, then, depends on the relative power of buyers and sellers in the marketplace. The power, or bargaining position, of consumers and producers in the market is limited by three sources of rivalry that exist in economic transactions: consumer–producer rivalry, consumer–consumer rivalry, and producer–producer rivalry. Each form of rivalry serves as a disciplining device to guide the market process, and each affects different markets to a different extent. Thus, your ability as a manager to meet performance objectives will depend on the extent to which your product is affected by these sources of rivalry.

Consumer–Producer Rivalry

Consumer–producer rivalry occurs because of the competing interests of consumers and producers. Consumers attempt to negotiate or locate low prices, while producers attempt to negotiate high prices. In a very loose sense, consumers attempt to "rip off" producers, and producers attempt to "rip off" consumers. Of course, there are limits to the ability of these parties to achieve their goals. If a consumer offers a price that is too low, the producer will refuse to sell the product to the consumer. Similarly, if the producer asks a price that exceeds the consumer's valuation of a good, the consumer will refuse to purchase the good. These two forces provide a natural check and balance on the market process even in markets in which the product is offered by a single firm (a monopolist). An illustrative example of this type of rivalry is the common haggling over price between a potential car buyer and a salesperson.

Consumer–Consumer Rivalry

A second source of rivalry that guides the market process occurs among consumers. *Consumer–consumer rivalry* reduces the negotiating power of consumers in the marketplace. It arises because of the economic doctrine of scarcity. When limited quantities of goods are available, consumers will compete with one another for the right to purchase the available goods. Consumers who are willing to pay the highest prices for the scarce goods will outbid other consumers for the right to consume the goods. Once again, this source of rivalry is present even in markets in which a single firm is selling a product. A good example of consumer–consumer rivalry is an auction, a topic we will examine in detail in Chapter 12.

Producer–Producer Rivalry

A third source of rivalry in the marketplace is *producer–producer rivalry*. Unlike the other forms of rivalry, this disciplining device functions only when multiple sellers of a product compete in the marketplace. Given that customers are scarce, producers compete with one another for the right to service the customers available. Those firms that offer the best-quality product at the lowest price earn the right to serve the customers. For example, when two gas stations located across the street from one another compete on price, they are engaged in producer–producer rivalry.

Government and the Market

When agents on either side of the market find themselves disadvantaged in the market process, they may attempt to induce government to intervene on their behalf. For example, the market for electricity in some towns is characterized by a sole local supplier of electricity,

and thus there is no producer–producer rivalry. Consumer groups may initiate action by a public utility commission to limit the power of utilities in setting prices. Similarly, producers may lobby for government assistance to place them in a better bargaining position relative to consumers and foreign producers. Thus, in modern economies government also plays a role in disciplining the market process. Module Group B explores how government affects managerial decisions.

Recognize the Time Value of Money

The timing of many decisions involves a gap between the time when the costs of a project are borne and the time when the benefits of the project are received. In these instances it is important to recognize that $1 today is worth more than $1 received in the future. The reason is simple: The opportunity cost of receiving the $1 in the future is the forgone interest that could be earned were $1 received today. This opportunity cost reflects the **time value of money**. To properly account for the timing of receipts and expenditures, the manager must understand present value analysis.

time value of money
The fact that $1 today is worth more than $1 received in the future.

Present Value Analysis

present value (*PV*)
The amount that would have to be invested today at the prevailing interest rate to generate the given future value.

The **present value (*PV*)** of an amount received in the future is the amount that would have to be invested today at the prevailing interest rate to generate the given future value. For example, suppose someone offered you $1.10 one year from today. What is the value today (the present value) of $1.10 to be received one year from today? Notice that if you could invest $1.00 today at a guaranteed interest rate of 10 percent, one year from now $1.00 would be worth $1.00 × 1.1 = $1.10. In other words, over the course of one year, your $1.00 would earn $.10 in interest. Thus, when the interest rate is 10 percent, the present value of receiving $1.10 one year in the future is $1.00.

A more general formula follows:

Formula (Present Value). The present value (PV) of a future value (FV) received n years in the future is

$$PV = \frac{FV}{(1+i)^n} \tag{1–1}$$

where i is the rate of interest, or the opportunity cost of funds.

For example, the present value of $100.00 in 10 years if the interest rate is at 7 percent is $50.83 since

$$PV = \frac{\$100}{(1+.07)^{10}} = \frac{\$100}{1.9672} = \$50.83$$

This essentially means that if you invested $50.83 today at a 7 percent interest rate, in 10 years your investment would be worth $100.

Notice that the interest rate appears in the denominator of the expression in Equation 1–1. This means that the higher the interest rate, the lower the present value of a future amount, and conversely. The present value of a future payment reflects the difference between the *future value (FV)* and the *opportunity cost of waiting (OCW)*: $PV = FV - OCW$. Intuitively, the higher the interest rate, the higher the opportunity cost of waiting to receive a future amount and thus the lower the present value of the future amount. For example, if the interest rate is zero, the opportunity cost of waiting is zero, and the present value and the future value coincide. This is consistent with Equation 1–1 since $PV = FV$ when the interest rate is zero.

The basic idea of the present value of a future amount can be extended to a series of future payments. For example, if you are promised FV_1 one year in the future, FV_2 two years in the future, and so on for n years, the present value of this sum of future payments is

$$PV = \frac{FV_1}{(1+i)^1} + \frac{FV_2}{(1+i)^2} + \frac{FV_3}{(1+i)^3} + \cdots + \frac{FV_n}{(1+i)^n}$$

Formula (Present Value of a Stream). When the interest rate is i, the present value of a stream of future payments of $FV_1, FV_2, \ldots, FV_n$ is

$$PV = \sum_{t=1}^{n} \frac{FV_t}{(1+i)^t}$$

Given the present value of the income stream that arises from a project, one can easily compute the net present value of the project. The **net present value (*NPV*)** of a project is simply the present value (PV) of the income stream generated by the project minus the current cost (C_0) of the project: $NPV = PV - C_0$. If the net present value of a project is positive, then the project is profitable because the present value of the earnings from the project exceeds the current cost of the project. On the other hand, a manager should reject a project that has a negative net present value since the cost of such a project exceeds the present value of the income stream that project generates.

net present value (*NPV*)
The present value of the income stream generated by a project minus the current cost of the project.

Formula (Net Present Value). Suppose that by sinking C_0 dollars into a project today, a firm will generate income of FV_1 one year in the future, FV_2 two years in the future, and so on for n years. If the interest rate is i, the net present value of the project is

$$NPV = \frac{FV_1}{(1+i)^1} + \frac{FV_2}{(1+i)^2} + \frac{FV_3}{(1+i)^3} + \cdots + \frac{FV_n}{(1+i)^n} - C_0$$

DEMONSTRATION PROBLEM 1–1

The manager of Automated Products is contemplating the purchase of a new machine that will cost $300,000 and has a useful life of five years. The machine will yield (year-end) cost reductions to Automated Products of $50,000 in year 1, $60,000 in year 2, $75,000 in year 3, and $90,000 in years 4 and 5. What is the present value of the cost savings of the machine if the interest rate is 8 percent? Should the manager purchase the machine?

ANSWER:

By spending $300,000 today on a new machine, the firm will reduce costs by $365,000 over five years. However, the present value of the cost savings is only

$$PV = \frac{50{,}000}{1.08} + \frac{60{,}000}{1.08^2} + \frac{75{,}000}{1.08^3} + \frac{90{,}000}{1.08^4} + \frac{90{,}000}{1.08^5} = \$284{,}679$$

Consequently, the net present value of the new machine is

$$NPV = PV - C_0 = \$284{,}679 - \$300{,}000 = -\$15{,}321$$

Since the net present value of the machine is negative, the manager should not purchase the machine. In other words, the manager could earn more by investing the $300,000 at 8 percent than by spending the money on the cost-saving technology.

Present Value of Indefinitely Lived Assets

Some decisions generate cash flows that continue indefinitely. For instance, consider an asset that generates a cash flow of CF_0 today, CF_1 one year from today, CF_2 two years from today, and so on for an indefinite period of time. If the interest rate is i, the value of the asset is given by the present value of these cash flows:

$$PV_{Asset} = CF_0 + \frac{CF_1}{(1+i)} + \frac{CF_2}{(1+i)^2} + \frac{CF_3}{(1+i)^3} + \cdots$$

While this formula contains terms that continue indefinitely, for certain patterns of future cash flows one can readily compute the present value of the asset. For instance, suppose that the current cash flow is zero ($CF_0 = 0$) and that all future cash flows are identical ($CF_1 = CF_2 = \ldots$). In this case, the asset generates a perpetual stream of identical cash flows at the end of each period. If each of these future cash flows is CF, the value of the asset is the present value of the *perpetuity*:

$$\begin{aligned} PV_{Perpetuity} &= \frac{CF}{(1+i)} + \frac{CF}{(1+i)^2} + \frac{CF}{(1+i)^3} + \cdots \\ &= \frac{CF}{i} \end{aligned}$$

Examples of such an asset include perpetual bonds and preferred stocks. Each of these assets pays the owner a fixed amount at the end of each period, indefinitely. Based on this formula, the value of a perpetual bond that pays the owner $100 at the end of each year when the interest rate is fixed at 5 percent is given by

$$PV_{Perpetual\ bond} = \frac{CF}{i} = \frac{\$100}{.05} = \$2{,}000$$

Present value analysis is also useful in determining the value of a firm since the value of a firm is the present value of the stream of profits (cash flows) generated by the firm's physical, human, and intangible assets. In particular, if π_0 is the firm's current level of profits, π_1 is next year's profit, and so on, then the value of the firm is

$$PV_{Firm} = \pi_0 + \frac{\pi_1}{(1+i)} + \frac{\pi_2}{(1+i)^2} + \frac{\pi_3}{(1+i)^3} + \cdots$$

In other words, the value of the firm today is the present value of its current and future profits. To the extent that the firm is a "going concern" that lives on even after its founder dies, firm ownership represents a claim to assets with an indefinite profit stream.

Notice that the *value of a firm* takes into account the long-term impact of managerial decisions on profits. When economists say that the goal of the firm is to maximize profits, it should be understood to mean that the firm's goal is to maximize its value, which is the present value of current and future profits.

PRINCIPLE

Profit Maximization

Maximizing profits means maximizing the value of the firm, which is the present value of current and future profits.

While it is beyond the scope of this book to present all the tools Wall Street analysts use to estimate the value of firms, it is possible to gain insight into the issues involved by making a few simplifying assumptions. Suppose a firm's current profits are π_0 and that these profits

have not yet been paid out to stockholders as dividends. Imagine that these profits are expected to grow at a constant rate of g percent each year and that profit growth is less than the interest rate ($g < i$). In this case, profits one year from today will be $(1 + g)\pi_0$, profits two years from today will be $(1 + g)^2\pi_0$, and so on. The value of the firm, under these assumptions, is

$$\begin{aligned} PV_{Firm} &= \pi_0 + \frac{\pi_0(1+g)}{(1+i)} + \frac{\pi_0(1+g)^2}{(1+i)^2} + \frac{\pi_0(1+g)^3}{(1+i)^3} + \cdots \\ &= \pi_0\left(\frac{1+i}{i-g}\right) \end{aligned}$$

For a given interest rate and growth rate of the firm, it follows that maximizing the lifetime value of the firm (long-term profits) is equivalent to maximizing the firm's current (short-term) profits of π_0.

You may wonder how this formula changes if current profits have already been paid out as dividends. In this case, the present value of the firm is the present value of future profits (since current profits have already been paid out). The value of the firm immediately after its current profits have been paid out as dividends (called the *ex-dividend date*) may be obtained by simply subtracting π_0 from the equation:

$$PV_{Firm}^{Ex\text{-}dividend} = PV_{Firm} - \pi_0$$

This may be simplified to yield the following formula:

$$PV_{Firm}^{Ex\text{-}dividend} = \pi_0\left(\frac{1+g}{i-g}\right)$$

Thus, so long as the interest rate and growth rate are constant, the strategy of maximizing current profits also maximizes the value of the firm on the ex-dividend date.

Maximizing Short-Term Profits May Maximize Long-Term Profits

If the growth rate in profits is less than the interest rate and both are constant, maximizing current (short-term) profits is the same as maximizing long-term profits. PRINCIPLE

DEMONSTRATION PROBLEM 1–2

Suppose the interest rate is 10 percent and the firm is expected to grow at a rate of 5 percent for the foreseeable future. The firm's current profits are $100 million.

(*a*) What is the value of the firm (the present value of its current and future earnings)?

(*b*) What is the value of the firm immediately after it pays a dividend equal to its current profits?

ANSWER:

(*a*) The value of the firm is

$$\begin{aligned} PV_{Firm} &= \pi_0 + \frac{\pi_0(1+g)}{(1+i)} + \frac{\pi_0(1+g)^2}{(1+i)^2} + \frac{\pi_0(1+g)^3}{(1+i)^3} + \cdots \\ &= \pi_0\left(\frac{1+i}{i-g}\right) \\ &= \$100\left(\frac{1+.1}{.1-.05}\right) = (\$100)(22) = \$2{,}200 \text{ million} \end{aligned}$$

(*b*) The value of the firm on the ex-dividend date is this amount ($2,200 million) less the current profits paid out as dividends ($100 million), or $2,100 million. Alternatively, this may be calculated as

$$PV_{Firm}^{Ex\text{-}dividend} = \pi_0\left(\frac{1+g}{i-g}\right)$$
$$= (\$100)\left(\frac{1+.05}{.1-.05}\right) = (\$100)(21) = \$2{,}100 \text{ million}$$

INSIDE BUSINESS 1–3

Joining the Jet Set

Recently, an airline offered a standard one-year membership into its Airline Club for $450. Alternatively, one could purchase a three-month membership for $120. Many managers and executives join air clubs because they offer a quiet place to work or relax while on the road; thus, productivity is enhanced.

Let's assume you wish to join the club for one year. Should you pay the up-front $450 fee for a one-year membership or buy four three-month memberships at $120 each, for total payments of $480? For simplicity, let's suppose the airline will not change the three-month fee of $120 over the next year.

On the surface it appears that you save $30 by paying for a one-year membership in advance. But this approach ignores the time value of money. Is paying for a full year in advance profitable when you take the time value of money into account?

The present value of the cost of membership if you pay for one year in advance is $450 since all of that money is paid today. If you pay every three months, you pay $120 today, $120 in three months, $120 in six months, and $120 in nine months. Given an interest rate of 8 percent per year, which translates into a quarterly rate of 2 percent, the present value of the payments is

$$PV = \$120 + \frac{\$120}{1.02} + \frac{\$120}{(1.02)^2} + \frac{\$120}{(1.02)^3}$$

or

$$PV = 120 + 117.65 + 115.34 + 113.08$$
$$= \$466.07$$

Thus, in present value terms, you save $16.07 if you pay for an annual membership in advance. If you wish to join for one year and expect three-month fees to either remain constant or rise over the next year, it is better to pay in advance. Given the current interest rate, the airline is offering a good deal, but the present value of the savings is $16.07, not $30.

While the notion of the present value of a firm is very general, the simplified formula presented above is based on the assumption that the growth rate of the firm's profits is constant. In reality, however, the investment and marketing strategies of the firm will affect its growth rate. Moreover, the strategies used by competitors generally will affect the growth rate of the firm. In such instances, there is no substitute for using the general present value formula and understanding strategies that have different impacts on profits over time, discussed in later chapters in this book.

Use Marginal Analysis

Marginal analysis is one of the most important managerial tools—a tool we will use repeatedly throughout this text in alternative contexts. Simply put, *marginal analysis* states that optimal managerial decisions involve comparing the marginal (or incremental) benefits of a decision with the marginal (or incremental) costs. For example, the optimal amount of

studying for this course is determined by comparing (1) the improvement in your grade that will result from an additional hour of studying and (2) the additional costs of studying an additional hour. So long as the benefits of studying an additional hour exceed the costs of studying an additional hour, it is profitable to continue to study. However, once an additional hour of studying adds more to costs than it does to benefits, you should stop studying.

More generally, let $B(Q)$ denote the total benefits derived from Q units of some variable that is within the manager's control. This is a very general idea: $B(Q)$ may be the revenue a firm generates from producing Q units of output; it may be the benefits associated with distributing Q units of food to the needy; or, in the context of our previous example, it may represent the benefits derived by studying Q hours for an exam. Let $C(Q)$ represent the total costs of the corresponding level of Q. Depending on the nature of the decision problem, $C(Q)$ may be the total cost to a firm of producing Q units of output, the total cost to a food bank of providing Q units of food to the needy, or the total cost to you of studying Q hours for an exam.

Discrete Decisions

We first consider the situation where the managerial control variable is discrete. In this instance, the manager faces a situation like that summarized in columns 1 through 3 in Table 1–1. Notice that the manager cannot use fractional units of Q; only integer values are possible. This reflects the discrete nature of the problem. In the context of a production decision, Q may be the number of gallons of soft drink produced. The manager must decide how many gallons of soft drink to produce (0, 1, 2, and so on), but cannot choose to produce fractional units (e.g., one pint). Column 2 of Table 1–1 provides hypothetical data for total benefits; column 3 gives hypothetical data for total costs.

Suppose the objective of the manager is to maximize the net benefits

$$N(Q) = B(Q) - C(Q),$$

Table 1–1

Determining the Optimal Level of a Control Variable: The Discrete Case

(1) Control Variable *Q*	(2) Total Benefits *B*(*Q*)	(3) Total Costs *C*(*Q*)	(4) Net Benefits *N*(*Q*)	(5) Marginal Benefit *MB*(*Q*)	(6) Marginal Cost *MC*(*Q*)	(7) Marginal Net Benefits *MNB*(*Q*)
Given	Given	Given	(2) − (3)	Δ(2)	Δ(3)	Δ(4) or (5) − (6)
0	0	0	0	–	–	–
1	90	10	80	90	10	80
2	170	30	140	80	20	60
3	240	60	180	70	30	40
4	300	100	200	60	40	20
5	350	150	200	50	50	0
6	390	210	180	40	60	−20
7	420	280	140	30	70	−40
8	440	360	80	20	80	−60
9	450	450	0	10	90	−80
10	450	550	−100	0	100	−100

which represent the premium of total benefits over total costs of using Q units of the managerial control variable, Q. The net benefits—$N(Q)$—for our hypothetical example are given in column 4 of Table 1–1. Notice that the net benefits in column 4 are maximized when net benefits equal 200, which occurs when 5 units of Q are chosen by the manager.[5]

marginal benefit
The change in total benefits arising from a change in the managerial control variable Q.

To illustrate the importance of marginal analysis in maximizing net benefits, it is useful to define a few terms. **Marginal benefit** refers to the additional benefits that arise by using an additional unit of the managerial control variable. For example, the marginal benefit of the first unit of Q is 90 since the first unit of Q increases total benefits from 0 to 90. The marginal benefit of the second unit of Q is 80 since increasing Q from 1 to 2 increases total benefits from 90 to 170. The marginal benefit of each unit of Q—$MB(Q)$—is presented in column 5 of Table 1–1.

marginal (incremental) cost (MC)
The change in total costs arising from a change in the managerial control variable Q.

Marginal cost, on the other hand, is the additional cost incurred by using an additional unit of the managerial control variable. Marginal costs—$MC(Q)$—are given in column 6 of Table 1–1. For example, the marginal cost of the first unit of Q is 10 since the first unit of Q increases total costs from 0 to 10. Similarly, the marginal cost of the second unit of Q is 20 since increasing Q from 1 to 2 increases total costs by 20 (costs rise from 10 to 30).

Finally, the *marginal net benefits* of Q—$MNB(Q)$—are the change in net benefits that arise from a one-unit change in Q. For example, by increasing Q from 0 to 1, net benefits rise from 0 to 80 in column 4 of Table 1–1, and thus the marginal net benefit of the first unit of Q is 80. By increasing Q from 1 to 2, net benefits increase from 80 to 140, so the marginal net benefit due to the second unit of Q is 60. Column 7 of Table 1–1 presents marginal net benefits for our hypothetical example. Notice that marginal net benefits may also be obtained as the difference between marginal benefits and marginal costs:

$$MNB(Q) = MB(Q) - MC(Q)$$

Inspection of Table 1–1 reveals a remarkable pattern in the columns. Notice that by using 5 units of Q, the manager ensures that net benefits are maximized. At the net-benefit-maximizing level of Q (5 units), the marginal net benefits of Q are zero. Furthermore, at the net-benefit-maximizing level of Q (5 units), marginal benefits equal marginal costs (both are equal to 50 in this example). There is an important reason why $MB = MC$ at the level of Q that maximizes net benefits: So long as marginal benefits exceed marginal costs, an increase in Q adds more to total benefits than it does to total costs. In this instance, it is profitable for the manager to increase the use of the managerial control variable. Expressed differently, when marginal benefits exceed marginal costs, the net benefits of increasing the use of Q are positive; by using more Q, net benefits increase. For example, consider the use of 1 unit of Q in Table 1–1. By increasing Q to 2 units, total benefits increase by 80 and total costs increase by only 20. Increasing the use of Q from 1 to 2 units is profitable because it adds more to total benefits than it does to total costs.

PRINCIPLE

Marginal Principle

To maximize net benefits, the manager should increase the managerial control variable up to the point where marginal benefits equal marginal costs. This level of the managerial control variable corresponds to the level at which marginal net benefits are zero; nothing more can be gained by further changes in that variable.

[5] Actually, net benefits are equal to 200 for either 4 or 5 units of Q. This is due to the discrete nature of the data in the table, which restricts Q to be selected in one-unit increments. In the next section, we show that when Q can be selected in arbitrarily small increments (e.g., when the firm can produce fractional gallons of soft drink), net benefits are maximized at a single level of Q. At this level of Q, marginal net benefits are equal to zero, which corresponds to 5 units of Q in Table 1–1.

Notice in Table 1–1 that while 5 units of Q maximizes net benefits, it does not maximize total benefits. In fact, total benefits are maximized at 10 units of Q, where marginal benefits are zero. The reason the net-benefit-maximizing level of Q is less than the level of Q that maximizes total benefits is that there are costs associated with achieving more total benefits. The goal of maximizing net benefits takes costs into account, while the goal of maximizing total benefits does not. In the context of a firm, maximizing total benefits is equivalent to maximizing revenues without regard for costs. In the context of studying for an exam, maximizing total benefits requires studying until you maximize your grade, regardless of how much it costs you to study.

Continuous Decisions

The basic principles for making decisions when the control variable is discrete also apply to the case of a continuous control variable. The basic relationships in Table 1–1 are depicted graphically in Figure 1–2. The top panel of the figure presents the total benefits and total costs of using different levels of Q under the assumption that Q is infinitely divisible (instead of allowing the firm to produce soft drinks only in one-gallon containers as in Table 1–1, it can now produce fractional units). The middle panel presents the net benefits, $B(Q) - C(Q)$, and represents the vertical difference between B and C in the top panel. Notice that net benefits are maximized at the point where the difference between $B(Q)$ and $C(Q)$ is the greatest in the top panel. Furthermore, the slope of $B(Q)$ is $\Delta B/\Delta Q$, or marginal benefit, and the slope of $C(Q)$ is $\Delta C/\Delta Q$, or marginal cost. The slopes of the total benefits curve and the total cost curve are equal when net benefits are maximized. This is just another way of saying that when net benefits are maximized, $MB = MC$.

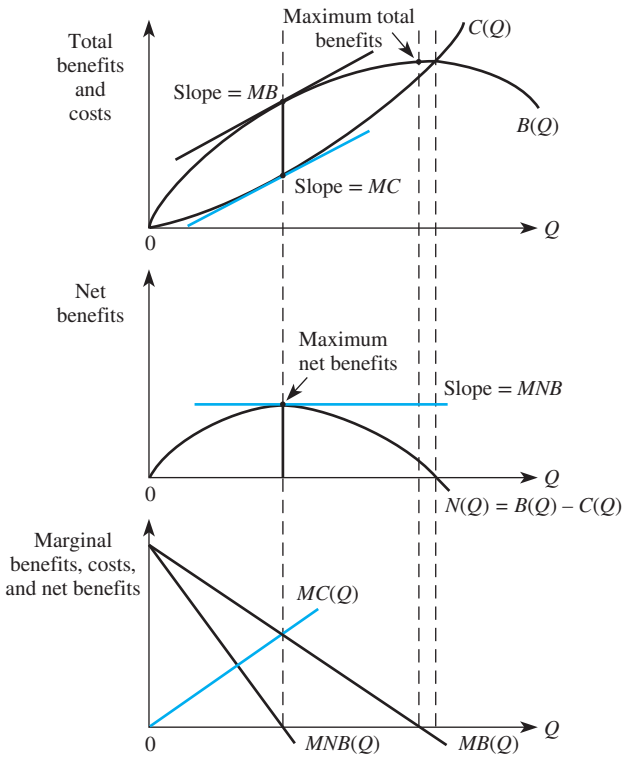


Figure 1–2
Determining the Optimal Level of a Control Variable: The Continuous Case

PRINCIPLE

Marginal Value Curves Are the Slopes of Total Value Curves

When the control variable is infinitely divisible, the slope of a total value curve at a given point is the marginal value at that point. In particular, the slope of the total benefit curve at a given Q is the marginal benefit of that level of Q. The slope of the total cost curve at a given Q is the marginal cost of that level of Q. The slope of the net benefit curve at a given Q is the marginal net benefit of that level of Q.

A CALCULUS ALTERNATIVE

Since the slope of a function is the derivative of that function, the preceding principle means that the derivative of a given function is the marginal value of that function. For example,

$$MB = \frac{dB(Q)}{dQ}$$

$$MC = \frac{dC(Q)}{dQ}$$

$$MNB = \frac{dN(Q)}{dQ}$$

The bottom panel of Figure 1–2 depicts the marginal benefits, marginal costs, and marginal net benefits. At the level of Q where the marginal benefit curve intersects the marginal cost curve, marginal net benefits are zero. That level of Q maximizes net benefits.

For a video walkthrough of this problem, visit www.mhhe.com/baye10e

DEMONSTRATION PROBLEM 1–3

An engineering firm recently conducted a study to determine its benefit and cost structure. The results of the study are as follows:

$$B(Y) = 300Y - 6Y^2$$

$$C(Y) = 4Y^2$$

so that $MB = 300 - 12Y$ and $MC = 8Y$. The manager has been asked to determine the maximum level of net benefits and the level of Y that will yield that result.

ANSWER:

Equating MB and MC yields $300 - 12Y = 8Y$. Solving this equation for Y reveals that the optimal level of Y is $Y^* = 15$. Plugging $Y^* = 15$ into the net benefit relation yields the maximum level of net benefits:

$$NB = 300(15) - (6)(15^2) - (4)(15^2) = 2{,}250$$

incremental revenues
The additional revenues that stem from a yes-or-no decision.

incremental costs
The additional costs that stem from a yes-or-no decision.

Incremental Decisions

Sometimes managers are faced with proposals that require a simple thumbs-up or thumbs-down decision. Marginal analysis is the appropriate tool to use for such decisions; the manager should adopt a project if the additional revenues that will be earned if the project is adopted exceed the additional costs required to implement the project. In the case of yes-or-no decisions, the additional revenues derived from a decision are called **incremental revenues**. The additional costs that stem from the decision are called **incremental costs**.

Table 1–2

Incremental Costs and Revenues of the New Drilling Project

	Current Situation	After New Drilling Project	Incremental Revenues and Costs	
Total revenue	$1,740,400	$1,923,600		**$183,200**
Variable cost				
Drill augers	750,000	840,000	90,000	
Temporary workers	500,000	575,000	75,000	
Total variable cost	1,250,000	1,415,000		**165,000**
Direct fixed costs				
Depreciation—equipment	120,000	120,000		
Total direct fixed cost	120,000	120,000	0	
Indirect fixed costs				
Supervisors' salaries	240,000	240,000		
Office supplies	30,000	30,000		
Total indirect fixed cost	270,000	270,000	0	
Profit	$ 100,400	$ 118,600		**$ 18,200**

To illustrate, imagine that you are the CEO of Slick Drilling Inc. and you must decide whether or not to drill for crude oil around the Twin Lakes area in Michigan. You are relatively certain there are 10,000 barrels of crude oil at this location. An accountant working for you prepared the information in Table 1–2 to help you decide whether or not to adopt the new project.

While the accountant supplied you with a lot of information in Table 1–2, the only data relevant for your decision are the incremental revenues and costs of adopting the new drilling project. In particular, notice that your direct and indirect fixed costs are the same regardless of whether you adopt the project and therefore are irrelevant to your decision. In contrast, note that your revenues increase by $183,200 if you adopt the project. This change in revenues stemming from the adoption of the project represents your incremental revenues. To earn these additional revenues, however, you must spend an additional $90,000 for drill augers and $75,000 for additional temporary workers. The sum of these costs—$165,000—represents the incremental cost of the new drilling project. Since your incremental revenues of $183,200 exceed the incremental costs of $165,000, you should give your "thumbs up" to the new project. Doing so adds $18,200 to your bottom line.

As another example, suppose the first unit of a control variable adds more to benefits than costs ($MB > MC$), but the second unit adds more to costs than benefits ($MB < MC$). In this case, the manager should give a "thumbs down" to the second unit since it adds more to costs than benefits.

Make Data-Driven Decisions

Good managers don't simply guess how their decisions will affect their organizations, they make data-driven decisions. Thanks to the digital age, most managers have vast quantities of data at their fingertips. These data greatly enhance the value of managerial economics because they permit managers to quantify managerial decisions (e.g., the optimal price for the company's smart device is $87.95) and to quantify the organizational impact (e.g., we expect 22.4 million units to be sold, adding $450.3 million to our bottom line).

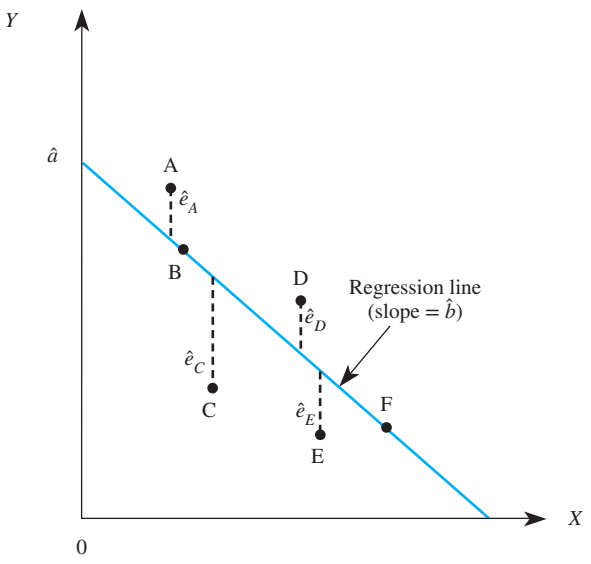
Increasingly, businesses and other organizations have personnel who use *econometrics*—the statistical analysis of economic data—to obtain quantitative estimates of how a plethora of managerial control variables impact benefits and costs. While it is beyond the scope of this text to teach you the full range of econometric models and the statistics behind them, it is possible to convey the basic ideas econometricians use to estimate equations that summarize economic relationships—thereby empowering you to make sound, quantitative managerial decisions.

As you will learn later in this text, profit maximization requires that you expand output until the revenue earned on the last unit sold equals the cost of that unit (e.g., where marginal benefit equals marginal cost). This might seem like a simple application of the marginal principle that you learned earlier in this chapter. Effective managers, however, recognize that many economic relationships and a plethora of decisions are necessary to apply this principle in the real word. For example, your production (Q) might depend on how much labor (L) and how many machines (K) you employ—and how you incentivize workers. Expressed mathematically, output is a function of how many machines and how much labor you employ: $Q = F(K, L)$. Likewise, the number of units sold (Q) might depend on the price (P) you charge consumers, according to the mathematical relationship $Q = D(P)$. Econometrics is a tool that uses real-world data to estimate equations representing the underlying mathematical relationship between these and other variables. Ultimately—if you master the material in this text—these estimates will permit you to quantify the optimal mix of labor and machines, determine profit-maximizing prices, and make a host of other optimal decisions. The primary goal of the remainder of this text is to teach you how to use data-driven estimates of demand, costs, and the competitive/strategic environment to make sound managerial decisions.

Obtaining Estimates Using Regression

We now provide you with a basic understanding of how data may be used to estimate the functional relationship between variables that are of interest to managers. Suppose there is some underlying data on the relation between a dependent variable, Y, and some explanatory variable, X. Suppose that when the values of X and Y are plotted, they appear as points A, B, C, D, E, and F in Figure 1–3. Clearly, the points do not lie on a straight line, or even a smooth curve (try alternative ways of connecting the dots if you are not convinced).

Figure 1–3
The Regression Line



The job of the econometrician is to find a smooth curve or line that does a "good" job of approximating the points. For example, suppose the econometrician believes that, on average, there is a linear relation between Y and X, but there is also some random variation in the relationship. Mathematically, this would imply that the true relationship between Y and X is

$$Y = a + bX + e$$

where a and b are unknown parameters and e is a random variable (an error term) that has a zero mean. Because the parameters that determine the expected relation between Y and X are unknown, the econometrician must find out the values of the parameters a and b.

Note that for any line drawn through the points, there will be some discrepancy between the actual points and the line. For example, consider the line in Figure 1–3, which does a reasonable job of fitting the data. If a manager used the line to approximate the true relation, there would be some discrepancy between the actual data and the line. For example, points A and D actually lie above the line, while points C and E lie below it. The deviations between the actual points and the line are given by the distance of the dashed lines in Figure 1–3, namely $\hat{e}_A$, $\hat{e}_C$, $\hat{e}_D$, and $\hat{e}_E$. Since the line represents the expected, or average, relation between Y and X, these deviations are analogous to the deviations from the mean used to calculate the variance of a random variable.

The econometrician uses a regression software package to find the values of a and b that minimize the sum of the squared deviations between the actual points and the line. In essence, the *regression line* is the line that minimizes the squared deviations between the line (the expected relation) and the actual data points. These values of a and b, which frequently are denoted $\hat{a}$ and $\hat{b}$, are called *parameter estimates*, and the corresponding line is called the **least squares regression**.

least squares regression
The line that minimizes the sum of squared deviations between the line and the actual data points.

The least squares regression line for the equation

$$Y = a + bX + e$$

is given by

$$Y = \hat{a} + \hat{b}X$$

The parameter estimates $\hat{a}$ and $\hat{b}$ represent the values of a and b that result in the smallest *sum of squared errors* between a line and the actual data.

Spreadsheet software packages, such as Excel, make it easy to use regression analysis to estimate various functions. To illustrate, suppose a television manufacturer has data on the price and quantity of TVs sold last month at 10 outlets in Pittsburgh. As we'll see throughout the book, the relationship between quantity and price is an important one to understand for your industry and can be relevant when formulating expressions for both benefits and costs. Here we use price and quantity as our explanatory and dependent variables, respectively. When the data are entered into a spreadsheet, it looks like the first 11 rows in Table 1–3. With just a few clicks, the spreadsheet calculates the average price and quantity reported in row 12. Furthermore, clicking the regression toolbar produces the regression output reported in rows 16 through 33. Cell 32-B shows that the intercept for our line relating quantity to price for TVs is 1631.47, and cell 33-B shows that the estimated coefficient of price (i.e., the slope of our line) is –2.60. Thus, the line relating quantity to price for TVs that minimizes the sum of squared errors between the actual data points and the line through the points is

$$Q = 1631.47 - 2.60P$$

Table 1–3

Using a Spreadsheet to Perform a Regression

	A	B	C	D	E	F	G
1	**Observation**	**Quantity**	**Price**				
2	1	180	475				
3	2	590	400				
4	3	430	450				
5	4	250	550				
6	5	275	575				
7	6	720	375				
8	7	660	375				
9	8	490	450				
10	9	700	400				
11	10	210	500				
12	**Average**	450.50	455.00				
13							
14							
15							
16	***Regression Statistics***						
17							
18	Multiple *R*	0.87					
19	*R*-Square	0.75					
20	Adjusted *R*-Square	0.72					
21	Standard Error	112.22					
22	Observations	10.00					
23							
24	***Analysis of Variance***						
25		***df***	***Sum of Squares***	***Mean Square***	***F***	***Significance F***	
26	Regression	1.00	301470.89	301470.89	23.94	0.0012	
27	Residual	8.00	100751.61	12593.95			
28	Total	9.00	402222.50				
29							
30		***Coefficients***	***Standard Error***	***t-Statistic***	***P-Value***	***Lower 95%***	***Upper 95%***
31							
32	Intercept	1631.47	243.97	6.69	0.0002	1068.87	2194.07
33	Price	−2.60	0.53	−4.89	0.0012	−3.82	−1.37

Notice that the spreadsheet program also produces detailed information about the regression and estimated coefficients as a by-product of the regression. Next we discuss the subset of these statistics that enables the manager to test for the statistical significance of the estimated coefficients.

Evaluating the Statistical Significance of Estimated Coefficients

Rows 30 through 33 of the regression output in Table 1–3 provide information about the precision with which the parameters of our regression of quantity on price are estimated. The coefficients reported in cells 32-B and 33-B are merely the parameter estimates—estimates of the true, unknown coefficients. Given different data generated from the same true relationship between quantity and price, different estimates of the true coefficients would be obtained. The *standard error* of each estimated coefficient is a measure of how much each estimated coefficient would vary in regressions based on the same underlying

true relationship, but with different observations. The smaller the standard error of an estimated coefficient, the smaller the variation in the estimate given data from different outlets (different samples of data).

Given a set of standard, but somewhat technical, assumptions about the regression model, data sampling, and means of the errors, the least squares estimates are unbiased estimators of the true parameters.

Confidence Intervals. Given a parameter estimate, its standard error, and the necessary technical assumptions mentioned previously, the firm manager can construct upper and lower bounds on the true value of the estimated coefficient by constructing a 95 percent *confidence interval*. A useful rule of thumb is presented in the following principle, but fortunately, regression packages compute precise confidence intervals for each coefficient estimated in a regression. For instance, cells 33-F and 33-G in Table 1–3 indicate that the upper and lower bounds of the 95 percent confidence interval for the coefficient of price are −3.82 and −1.37. The parameter estimate for the price coefficient, −2.60, lies in the middle of these bounds. Thus, we know that the best estimate of the price coefficient is −2.60, and we are 95 percent confident that the true value lies between −3.82 and −1.37.

Rule of Thumb for a 95 Percent Confidence Interval

If the parameter estimates of a regression equation are $\hat{a}$ and $\hat{b}$, the 95 percent confidence intervals for the true values of a and b can be approximated by

$$\hat{a} \pm 2\sigma_{\hat{a}}$$

and

$$\hat{b} \pm 2\sigma_{\hat{b}}$$

where $\sigma_{\hat{a}}$ and $\sigma_{\hat{b}}$ are the standard errors of $\hat{a}$ and $\hat{b}$, respectively.

PRINCIPLE

The *t*-Statistic. The ***t*-statistic** of a parameter estimate is the ratio of the value of the parameter estimate to its standard error. For example, if the parameter estimates are $\hat{a}$ and $\hat{b}$ and the corresponding standard errors are $\sigma_{\hat{a}}$ and $\sigma_{\hat{b}}$, the t-statistic for $\hat{a}$ is

***t*-statistic**
The ratio of the value of a parameter estimate to the standard error of the parameter estimate.

$$t_{\hat{a}} = \frac{\hat{a}}{\sigma_{\hat{a}}}$$

and the t-statistic for $\hat{b}$ is

$$t_{\hat{b}} = \frac{b}{\sigma_{\hat{b}}}$$

When estimating relationships between variables such as quantity and price, a natural first question is whether there's a relationship at all. When considering a regression line, this question boils down to whether certain true parameters differ from zero, and the t-statistic can help answer this question. When the t-statistic for a parameter estimate is large in absolute value, then you can be confident that the true parameter is not zero. The reason for this is that when the absolute value of the t-statistic is large, the standard error of the parameter estimate is small relative to the absolute value of the parameter estimate. Thus, one can be more confident that, given a different sample of data drawn from the true model, the new parameter estimate will be in the same ballpark.

A useful rule of thumb is that if the absolute value of a *t*-statistic is greater than or equal to 2, then the corresponding parameter estimate is statistically different from zero. Regression packages report *P-values*, which are a much more precise measure of statistical significance. For instance, in cell 33-E of Table 1–3 we see that the *P*-value for the estimated coefficient of price is .0012. This means that there is only a 12 in 10,000 chance that we'd get an estimate at least as big as –2.60 in absolute value if the true coefficient of price is actually 0 (i.e., if there is no relationship between quantity and price). Notice that the lower the *P*-value for an estimated coefficient, the more confident you are in the estimate.

Usually, *P*-values of .05 or lower are considered low enough for a researcher to be confident that the estimated coefficient is statistically significant. If the *P*-value is .05, we say that the estimated coefficient is statistically significant at the 5 percent level. Notice that the *P*-value reported in Table 1–3 for the coefficient of price implies that it is statistically significant at the .12 percent level: The estimated coefficient is highly significant.[6]

PRINCIPLE

Rule of Thumb for Using *t*-Statistics

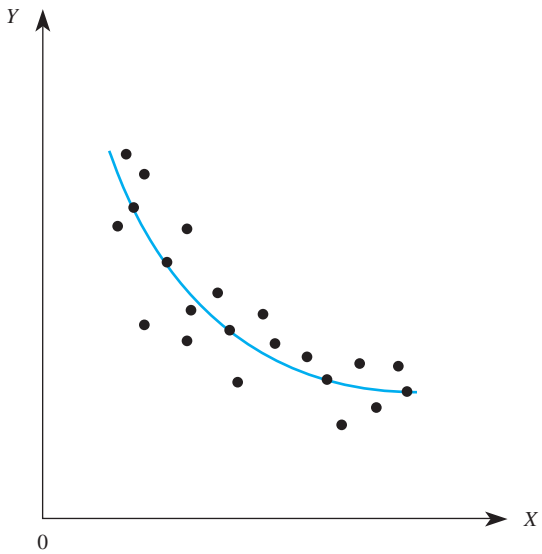
When the absolute value of the *t*-statistic is greater than 2, the manager can be 95 percent confident that the true value of the underlying parameter in the regression is not zero.

Regression for Nonlinear Functions and Multiple Regression

The techniques described to estimate a linear demand function with a single explanatory variable can also be used to estimate nonlinear functions. In addition, these same tools can be used to estimate functions in which the dependent variable (e.g., quantity) depends on several explanatory variables (e.g., price, advertising, etc.). These issues are discussed next.

Regression for Nonlinear Functions. Sometimes, a plot of the data will reveal nonlinearities in the data, as seen in Figure 1–4. Here, it appears that *Y* and *X* are not linearly related: The function is a curve instead of a line.

Figure 1–4
Log-Linear Regression Line



[6]In the Appendix, we discuss evaluating the overall fit of the regression line using the *R*-square and *F*-statistic.

To estimate a log-linear function, the econometrician takes the natural logarithm of the relevant variables (Y and X) before executing the regression routine that minimizes the sum of squared errors (e):

$$\ln Y = a + b \ln X + e$$

In other words, by using a spreadsheet to compute $Y' = \ln Y$ and $X' = \ln X$, this specification can be viewed equivalently as

$$Y' = a + bX' + e$$

which is linear in Y' and X'. Therefore, one can use procedures identical to those described earlier and regress the transformed Y' on X' to obtain parameter estimates. As we will see, estimating the parameters of a log-linear relationship between variables such as quantity and price can be particularly valuable to a manager making data-driven decisions.

Multiple Regression. In many contexts, a manager will benefit from understanding how Y depends not just on X, but on other variables as well. Regression techniques can also be used to perform *multiple regressions*—regressions of a dependent variable on multiple explanatory variables. In general, one might specify the relationship between a dependent variable, Y, and k explanatory variables as

$$Y = a + b_1X_1 + b_2X_2 + \cdots + b_kX_k + e$$

Here, a, b_1, ..., b_k are the parameters to be estimated, and e is the random error term that has a zero mean.

Note that multiple regression also includes regression using multiple versions of a single X, such as X and X^2. This situation nicely fits into the preceding general model by simply defining $X_1 = X$ and $X_2 = X^2$.

Provided the number of observations is greater than the number of parameters to be estimated, one can use standard regression packages included in spreadsheet programs to find the values of the parameters that minimize the sum of squared errors of the regression. The t-statistic and confidence intervals (and other standard statistics such as the R-square and F-statistic) for multiple regressions have the same use and interpretations for the case of a simple regression with one explanatory variable. Demonstration Problem 1–4 illustrates this fact.

DEMONSTRATION PROBLEM 1–4

FCI owns 10 apartment buildings in a college town, which it rents exclusively to students. Each apartment building contains 100 rental units, but the owner is having cash flow problems due to an average vacancy rate of nearly 50 percent. The apartments in each building have comparable floor plans, but some buildings are closer to campus than others. The owner of FCI has data from last year on the number of apartments rented, the rental price (in dollars), and the amount spent on advertising (in hundreds of dollars) at each of the 10 apartments. These data, along with the distance (in miles) from each apartment building to campus, are presented in rows 1 through 11 of Table 1–4. The owner regressed the number of apartments rented on price, advertising, and distance. The results of the regression are reported in rows 16 through 35 of Table 1–4. What is the estimated relationship between the number of apartments rented and price, advertising, and distance? If FCI lowered rents at one complex by $100, what would you expect to happen to the number of units rented? What inferences should be drawn from this analysis?

Table 1–4

Input and Output from a Multiple Regression

	A	B	C	D	E	F	G
1	**Observation**	**Quantity**	**Price**	**Advertising**	**Distance**		
2	1	28	250	11	12		
3	2	69	400	24	6		
4	3	43	450	15	5		
5	4	32	550	31	7		
6	5	42	575	34	4		
7	6	72	375	22	2		
8	7	66	375	12	5		
9	8	49	450	24	7		
10	9	70	400	22	4		
11	10	60	375	10	5		
12	**Average**	53.10	420.00	20.50	5.70		
13							
14							
15							
16	***Regression Statistics***						
17							
18	Multiple *R*	0.89					
19	*R*-Square	0.79					
20	Adjusted *R*-Square	0.69					
21	Standard Error	9.18					
22	Observations	10.00					
23							
24	***Analysis of Variance***						
25		***df***	***Sum of Squares***	***Mean Square***	***F***	***Significance F***	
26	Regression	3.00	1920.99	640.33	7.59	0.0182	
27	Residual	6.00	505.91	84.32			
28	Total	9.00	2426.90				
29							
30		***Coefficients***	***Standard Error***	***t-Statistic***	***P-Value***	***Lower 95%***	***Upper 95%***
31							
32	Intercept	135.15	20.65	6.54	0.0006	84.61	185.68
33	Price	−0.14	0.06	−2.41	0.0500	−0.29	0.00
34	Advertising	0.54	0.64	0.85	0.4296	−1.02	2.09
35	Distance	−5.78	1.26	−4.61	0.0037	−8.86	−2.71

ANSWER:

Letting Q, P, A, and D represent the number of apartments rented, price, advertising, and distance from campus, the estimated coefficients imply the following relationship:

$$Q = 135.15 - 0.14P + 0.54A - 5.78D$$

Because the coefficient of price is −0.14, a $100 decrease in price increases the number of apartments rented by 14.

Notice that all the estimated parameters are statistically significant at the 5 percent level, except for the coefficient of advertising. Thus, it does not appear that advertising has a statistically significant effect on the number of apartments rented. Distance from campus appears to have a significant impact on the number of apartments rented. The *t*-statistic for this coefficient is in excess of 4 in absolute value, and the *P*-value is .37 percent. Based on the lower and upper bounds of its confidence interval, the owner can be 95 percent confident that for every mile an apartment is away from campus, FCI loses between 2.71 and 8.86 renters.

Since FCI can't relocate its apartments closer to campus, and advertising does not have a statistically significant impact on units rented, it would appear that all FCI can do to reduce its cash flow problems is to adjust its rents, which do seem to have an impact. However, to determine how we should adjust price to improve cash flow, we'll need to understand demand analysis, covered later in the text.

A Caveat

You now know how to interpret the output of a regression and how to use the output to summarize the relationship between a dependent variable and an explanatory variable(s) in a simple equation. The functions that comprise $B(Q)$ and $C(Q)$, and ultimately shape managerial decisions, are not fictitious textbook constructs—they are equations that managers may actually obtain by using appropriate econometric techniques and data.

It is important to stress, however, that econometrics is a specialized field of economics that takes years of study to master. For the same reason it would not be prudent for you to perform LASIK eye surgery after merely reading a section called "The Eye" in your biology textbook, prudent managers rely on the expertise of "specialists" (economic experts or consultants) to obtain estimates for relevant equations. Unless you invest in the coursework required to master a host of econometric issues that are beyond the scope of any managerial economics textbook or spreadsheet program (e.g., endogeneity, sample selection, heteroskedasticity, autocorrelation, and unobserved effects), it is probably best for you to use your econometric knowledge primarily as a tool for communicating with (and interpreting the output provided by) econometric specialists.

LEARNING MANAGERIAL ECONOMICS

Before we continue our analysis of managerial economics, it is useful to provide some hints about how to study economics. Becoming proficient in economics is like learning to play music or ride a bicycle: The best way to learn economics is to practice, practice, and practice some more. Practicing managerial economics means practicing making decisions, and the best way to do this is to work and rework the problems presented in the text and at the end of each chapter. Before you can be effective at practicing, however, you must understand the language of economics.

The terminology in economics has two purposes. First, the definitions and formulas economists use are needed for precision. Economics deals with very complex issues, and much confusion can be avoided by using the language economists have designed to break down complex issues into manageable components. Second, precise terminology helps practitioners of economics communicate more efficiently. It would be difficult to communicate if, like Dr. Seuss, each of us made words mean whatever we wanted them to mean. However, the terminology is not an end in itself but simply a tool that makes it easier to communicate and analyze different economic situations.

Understanding the definitions used in economics is like knowing the difference between a whole note and a quarter note in music. Without such an understanding, it would be very difficult for anyone other than an extremely gifted musician to learn to play an instrument or to communicate to another musician how to play a new song. Given an understanding of the language of music, anyone who is willing to take the time to practice can make beautiful music. The same is true of economics: Anyone who is willing to learn the language of economics and take the time to practice making decisions can learn to be an effective manager.

ANSWERING THE headLINE

Why was Ralph fired from his managerial post at Amcott? As the manager of the foreign language division, he probably relied on his marketing department for sales forecasts and on his legal department for advice on contract and copyright law. The information he obtained about future sales was indeed accurate, but apparently his legal department did not fully anticipate all the legal ramifications of distributing Magicword. Sometimes, managers are given misinformation.

The real problem in this case, however, is that Ralph did not properly act on the information that was given him. Ralph's plan was to generate $7 million per year in sales by sinking $20 million into Magicword. Assuming there were no other costs associated with the project, the projected net present value to Amcott of purchasing Magicword was

$$NPV = \frac{\$7{,}000{,}000}{(1+.07)^1} + \frac{\$7{,}000{,}000}{(1+.07)^2} + \frac{\$7{,}000{,}000}{(1+.07)^3} - \$20{,}000{,}000$$
$$= -\$1{,}629{,}788$$

which means that Ralph should have expected Amcott to lose over $1.6 million by purchasing Magicword.

Ralph was not fired because of the mistakes of his legal department but for his managerial ineptness. The lawsuit publicized to Amcott's shareholders, among others, that Ralph was not properly processing information given to him: He did not recognize the time value of money.

KEY TERMS AND CONCEPTS

accounting cost
accounting profits
confidence interval
constraints
consumer–consumer rivalry
consumer–producer rivalry
econometrics
economic profits
economics
ex-dividend date
explicit cost
five forces framework
future value (*FV*)
goals
implicit cost
incentives
incremental cost
incremental revenue
least squares regression
manager
managerial economics
marginal analysis
marginal benefit
marginal cost
marginal net benefit
multiple regression
net present value (*NPV*)
opportunity cost
P-value
parameter estimates
perpetuity
present value (*PV*)
producer–producer rivalry
profit
regression line
resources
standard error
sum of squared errors
t-statistic
time value of money
value of a firm

CONCEPTUAL AND COMPUTATIONAL QUESTIONS

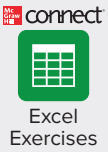


1. Southwest Airlines begins a "Bags Fly Free" campaign, charging no fees for the first and second checked bags. Does this situation best represent producer–producer rivalry, consumer–consumer rivalry, or consumer–producer rivalry? Explain. *(LO1, LO7)*

2. What is the maximum amount you would pay for an asset that generates an income of $250,000 at the end of each of five years if the opportunity cost of using funds is 8 percent? *(LO5, LO7)*
3. Suppose that the total benefit and total cost from a continuous activity are, respectively, given by the following equations: $B(Q) = 100 + 36Q - 4Q^2$ and $C(Q) = 80 + 12Q$. [*Note*: $MB(Q) = 36 - 8Q$ and $MC(Q) = 12$.] *(LO1, LO6, LO7)*
   a. Write out the equation for the net benefits.
   b. What are the net benefits when $Q = 1$? $Q = 5$?
   c. Write out the equation for the marginal net benefits.
   d. What are the marginal net benefits when $Q = 1$? $Q = 5$?
   e. What level of Q maximizes net benefits?
   f. At the value of Q that maximizes net benefits, what is the value of marginal net benefits?
4. A firm's current profits are $900,000. These profits are expected to grow indefinitely at a constant annual rate of 2 percent. If the firm's opportunity cost of funds is 4 percent, determine the value of the firm: *(LO5, LO7)*
   a. The instant before it pays out current profits as dividends.
   b. The instant after it pays out current profits as dividends.
5. What is the value of a preferred stock that pays a perpetual dividend of $120 at the end of each year when the interest rate is 3 percent? *(LO5, LO7)*
6. Complete the accompanying table and answer the accompanying questions. *(LO1, LO6, LO7)*
   a. At what level of the control variable are net benefits maximized?
   b. What is the relation between marginal benefit and marginal cost at this level of the variable?

Control Variable *Q*	Total Benefits *B(Q)*	Total Cost *C(Q)*	Net Benefits *N(Q)*	Marginal Benefit *MB(Q)*	Marginal Cost *MC(Q)*	Marginal Net Benefits *MNB(Q)*
100	1200	950		210	60	
101	1400				70	
102	1590				80	
103	1770				90	
104	1940				100	
105	2100				110	
106	2250				120	
107	2390				130	
108	2520				140	
109	2640				150	
110	2750				160	

7. It is estimated that over 100,000 students will apply to the top 30 MBA programs in the United States this year. *(LO1, LO3, LO5, LO7)*
   a. Using the concept of net present value and opportunity cost, explain when it is rational for an individual to pursue an MBA degree.
   b. What would you expect to happen to the number of applicants if the starting salaries of managers with MBA degrees remained constant but salaries of managers without such degrees decreased by 20 percent? Why?



8. Jaynet spends $30,000 per year on painting supplies and storage space. She recently received two job offers from a famous marketing firm—one offer was for $110,000 per year and the other was for $80,000. However, she turned both jobs down to continue a painting career. If Jaynet sells 25 paintings per year at a price of $8,000 each, *(LO1, LO2, LO3, LO7)*
   a. What are her accounting profits?
   b. What are her economic profits?
9. Suppose the total benefit derived from a continuous decision, Q, is $B(Q) = 20Q - 2Q^2$ and the corresponding total cost is $C(Q) = 4 + 2Q^2$, so that $MB(Q) = 20 - 4Q$ and $MC(Q) = 4Q$. *(LO1, LO6, LO7)*
   a. What is total benefit when $Q = 2$? $Q = 10$?
   b. What is marginal benefit when $Q = 2$? $Q = 10$?
   c. What level of Q maximizes total benefit?
   d. What is total cost when $Q = 2$? $Q = 10$?
   e. What is marginal cost when $Q = 2$? $Q = 10$?
   f. What level of Q minimizes total cost?
   g. What level of Q maximizes net benefits?
10. An owner can lease her building for $150,000 per year for three years. The explicit cost of maintaining the building is $50,000, and the implicit cost is $65,000. All revenues are received, and costs borne, at the end of each year. If the interest rate is 7 percent, determine the present value of the stream of: *(LO2, LO5, LO7)*
    a. Accounting profits.
    b. Economic profits.

PROBLEMS AND APPLICATIONS



11. You have recently learned that the company where you work is being sold for $500,000. The company's income statement indicates current profits of $25,000, which have yet to be paid out as dividends. Assuming the company will remain a "going concern" indefinitely and the interest rate will remain constant at 9 percent, at what constant rate does the owner believe that profits will grow? Does this seem reasonable? *(LO5, LO7)*
12. You are in the market for a new refrigerator for your company's lounge, and you have narrowed the search down to two models. The energy-efficient model sells for $1,600 and will save you $40 in electricity costs at the end of each of the next five years. The standard model has features similar to the energy-efficient model but provides no future saving in electricity costs. It is priced at only $1,350. Assuming your opportunity cost of funds is 6 percent, which refrigerator should you purchase? *(LO1, LO5, LO7)*
13. You are the human resources manager for a famous retailer and are trying to convince the president of the company to change the structure of employee compensation. Currently, the company's retail sales staff is paid a flat hourly wage of $20 per hour for each eight-hour shift worked. You propose a new pay structure whereby each salesperson in a store would be compensated $10 per hour, plus 1 percent of that store's daily profits. Assume that, when run efficiently, each store's maximum daily profits are $25,000. Outline the arguments that support your proposed plan. *(LO1, LO7)*
14. Jamie is considering leaving her current job, which pays $75,000 per year, to start a new company that develops applications for smartphones. Based on market research, she can sell about 50,000 units during the first year at a price of $4 per unit. With annual overhead costs and operating expenses amounting to $145,000, Jamie expects a profit

margin of 20 percent. This margin is 5 percent larger than that of her largest competitor, Apps Inc. *(LO2, LO3, LO7)*

a. If Jamie decides to embark on her new venture, what will her accounting costs be during the first year of operation? Her implicit costs? Her opportunity costs?

b. Suppose that Jamie's estimated selling price is lower than originally projected during the first year. How much revenue would she need in order to earn positive accounting profits? Positive economic profits?

15. Approximately 14 million Americans are addicted to drugs and alcohol. The federal government estimates that these addicts cost the U.S. economy $300 billion in medical expenses and lost productivity. Despite the enormous potential market, many biotech companies have shied away from funding research and development (R&D) initiatives to find a cure for drug and alcohol addiction. Your firm—Drug Abuse Sciences (DAS)—is a notable exception. It has spent $200 million to date working on a cure but is now at a crossroads. It can either abandon its program or invest another $60 million today. Unfortunately, the firm's opportunity cost of funds is 5 percent, and it will take another five years before final approval from the Food and Drug Administration is achieved and the product is actually sold. Expected (year-end) profits from selling the drug are presented in the accompanying table. Should DAS continue with its plan to bring the drug to market, or should it abandon the project? Explain. *(LO1, LO5, LO6, LO7)*

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
$0	$0	$0	$0	$12,000,000	$13,400,000	$17,200,000	$20,700,000	$22,450,000

16. As a marketing manager for one of the world's largest automakers, you are responsible for the advertising campaign for a new energy-efficient sports utility vehicle. Your support team has prepared the accompanying table, which summarizes the (year-end) profitability, estimated number of vehicles sold, and average estimated selling price for alternative levels of advertising. The accounting department projects that the best alternative use for the funds used in the advertising campaign is an investment returning 9 percent. In light of the staggering cost of advertising (which accounts for the lower projected profits in years 1 and 2 for the high and moderate advertising intensities), the team leader recommends a low advertising intensity in order to maximize the value of the firm. Do you agree? Explain. *(LO1, LO5, LO6, LO7)*

Profitability by Advertising Intensity

	Profits (in millions)			*Units Sold (in thousands)*			*Average Selling Price*		
	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
Advertising Intensity									
High	$20	$ 80	$300	10	60	120	$35,000	$36,500	$38,000
Moderate	40	80	135	5	12.5	25	35,800	36,100	36,300
Low	75	110	118	4	6	7.2	35,900	36,250	36,000

17. The head of the accounting department at a major software manufacturer has asked you to put together a pro forma statement of the company's value under several possible growth scenarios and the assumption that the company's many divisions will remain a

single entity forever. The manager is concerned that, despite the fact that the firm's competitors are comparatively small, collectively their annual revenue growth has exceeded 50 percent over each of the last five years. She has requested that the value projections be based on the firm's current profits of $3.2 billion (which have yet to be paid out to stockholders) and the average interest rate over the past 20 years (6 percent) in each of the following profit growth scenarios: *(LO5, LO7)*

a. Profits grow at an annual rate of 9 percent. (This one is tricky.)
b. Profits grow at an annual rate of 2 percent.
c. Profits grow at an annual rate of 0 percent.
d. Profits decline at an annual rate of 4 percent.

18. Suppose one of your clients is four years away from retirement and has only $2,500 in pretax income to devote to either a Roth or traditional IRA. The traditional IRA permits investors to contribute the full $2,500 since contributions to these accounts are tax-deductible, but they must pay taxes on all future distributions. In contrast, contributions to a Roth IRA are not tax-deductible. For example, if a person's tax rate is 25 percent, an investor is able to contribute only $1,875 after taxes; however, the earnings of a Roth IRA grow tax-free. Your company has decided to waive the one-time set-up fee of $50 to open a Roth IRA; however, investors opening a traditional IRA must pay the $50 setup fee. Assuming that your client anticipates that her tax rate will remain at 19 percent in retirement and she will earn a stable 7 percent return on her investments, will she prefer a traditional or Roth IRA? *(LO1, LO5, LO7)*

19. You are the manager in charge of global operations at BankGlobal—a large commercial bank that operates in a number of countries around the world. You must decide whether or not to launch a new advertising campaign in the U.S. market. Your accounting department has provided the accompanying statement, which summarizes the financial impact of the advertising campaign on U.S. operations. In addition, you recently received a call from a colleague in charge of foreign operations, and she indicated that her unit would lose $8 million if the U.S. advertising campaign were launched. Your goal is to maximize BankGlobal's value. Should you launch the new campaign? Explain. *(LO1, LO6, LO7)*

Financial Impact on U.S. Operations

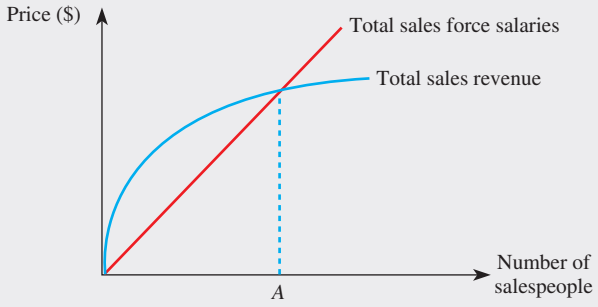
	Pre–Advertising Campaign	Post–Advertising Campaign
Total Revenues	$18,610,900	$31,980,200
Variable Cost		
TV Airtime	5,750,350	8,610,400
Ad development labor	1,960,580	3,102,450
Total variable costs	7,710,930	11,712,850
Direct Fixed Cost		
Depreciation—computer equipment	1,500,000	1,500,000
Total direct fixed cost	1,500,000	1,500,000
Indirect Fixed Cost		
Managerial salaries	8,458,100	8,458,100
Office supplies	2,003,500	2,003,500
Total indirect fixed cost	$10,461,600	$10,461,600

20. According to *The Wall Street Journal*, merger and acquisition activity in the first quarter rose to $5.3 billion. Approximately three-fourths of the 78 first-quarter deals occurred between information technology (IT) companies. The largest IT transaction of the

quarter was EMC's $625 million acquisition of VMWare. The VMWare acquisition broadened EMC's core data storage device business to include software technology enabling multiple operating systems—such as Microsoft's Windows, Linux, and OS X—to simultaneously and independently run on the same Intel-based server or workstation. Suppose that at the time of the acquisition a weak economy led many analysts to project that VMWare's profits would grow at a constant rate of 2 percent for the foreseeable future, and that the company's annual net income was $39.60 million. If EMC's estimated opportunity cost of funds is 9 percent, as an analyst, how would you view the acquisition? Would your conclusion change if you knew that EMC had credible information that the economy was on the verge of an expansion period that would boost VMWare's projected annual growth rate to 4 percent for the foreseeable future? Explain. *(LO1, LO5, LO6, LO7)*

21. Recently, European Union (EU) governments approved a five-year EU trade protection against grain-oriented electrical steel (GOES) from Russia, Japan, China, South Korea, and the United States. The protection would consist of minimum import prices on shipments of GOES from any of the five listed countries. This measure was enacted as a punishment for exporters in these countries for allegedly dumping their product (i.e., selling below cost) on the European market. The European Steel Association lauded the plan, noting it would help protect an important subdivision of the steel industry. However, transformer manufacturers, who use GOES as an input to their production, have protested the minimum prices. They argue minimum prices will result in prices for GOES that are too high and lead some of these manufacturers to downsize or move production facilities outside the EU. Describe the various rivalries depicted in this scenario, and then use the five forces framework to analyze the industry. *(LO1, LO3, LO4, LO7)*
22. You are the manager of Local Electronics Shop (LES), a small brick-and-mortar retail camera and electronics store. One of your employees proposed a new online strategy whereby LES lists its products at Pricesearch.com—a price comparison website that allows consumers to view the prices of dozens of retailers selling the same items. Would you expect this strategy to enable LES to achieve sustainable economic profits? Explain. *(LO1, LO4, LO7)*
23. Two months ago, the owner of a car dealership (and a current football star) significantly changed his sales manager's compensation plan. Under the old plan, the manager was paid a salary of $6,000 per month; under the new plan, she receives 2 percent of the sales price of each car sold. During the past two months, the number of cars sold increased by 40 percent, but the dealership's margins (and profits) significantly declined. According to the sales manager, "Consumers are driving harder bargains and I have had to authorize significantly lower prices to remain competitive." What advice would you give the owner of the dealership? *(LO1, LO7)*
24. Last year, MedSupplies—a national supplier of medical devices—posted its first loss in six years. The loss was a surprise to investors because the industry as a whole has been growing. Analysts have reached a consensus that at least part of the blame for the loss falls on Heidi Stevens, the national sales manager for MedSupplies. Ms. Stevens is responsible for determining the size of the firm's sales force, and over the past year, she engaged in a significant expansion. In this industry, it is well understood that revenues generally increase as the sales force grows. However, each new hire generally adds less new revenue than the last, as the best sales opportunities already have been exhausted. At the same time, the salaries for medical device salespeople essentially have been constant. Analysts summarize the problem in the accompanying figure. They note that Ms. Stevens appears to have expanded her sales force to point *A* and argue that her sales force is too big. When approached for comment, Ms. Stevens replied, "Of course I would choose point *A* in that graph! Anything less means the

company underperforms." Both the analysts and Ms. Stevens agree that she has chosen point *A* in the graph as the size of her sales force but disagree on the wisdom of this decision. Who is right? *(LO6, LO7)*



25. Analysts at a digital marketing firm collected data on the firm's extent of website analysis (X), along with the cost per customer (C), and the ad revenue per customer (R). Using regression analysis, the analysts produced the following two outputs:

C regressed on X^2

	Coefficients	Standard Error	*t*-Statistic	*P*-Value	Lower 95%	Upper 95%
Intercept	0.739	2.498	0.296	0.768	–4.208	5.686
X^2	0.103	0.008	12.958	1.7E-24	0.088	0.119

R regressed on X and X^2

	Coefficients	Standard Error	*t*-Statistic	*P*-Value	Lower 95%	Upper 95%
Intercept	24.598	9.092	2.706	0.008	6.594	42.602
X	11.092	1.323	8.384	1.3E-13	8.472	13.712
X^2	–0.100	0.044	–2.274	0.025	–0.188	–0.013

a. Write out the equation for revenue per customer as a function of website analysis. Are X and X^2 statistically significant? Explain.
b. Assuming the firm's number of customers is independent of X, these results imply the marginal revenue, or marginal benefit, of website analysis is $MB(X) = 11.092 - 0.2X$ and the marginal cost of website analysis is $MC(X) = 0.206X$. Under this assumption, what level of website analysis will maximize net benefits?
c. Write out the equation for cost per customer as a function of website analysis. Is X^2 statistically significant? Explain.

connect Excel Exercises

26. As the manager of a focus group company, you are interested in optimizing the number of participants you include in focus groups for your clients. Over the past year, you ran a field experiment, varying the number of participants you provided for each focus group. You collected data on the number of participants (X), focus group costs (C), and revenues (R) from clients in *Q01–26.xls*.
a. Estimate revenues as a function of focus group size, using both X and X^2 in the regression. Write out the equation for revenue as a function of focus group size based on your regression. Are all variables statistically significant?

b. Estimate costs as a function of focus group size, using both X and X^2 in the regression. Write out the equation for cost as a function of focus group size based on your regression. Are all variables statistically significant?

c. Note that these results imply the marginal revenue, or marginal benefit, of focus group size is $MB(X) = 71.77 - 0.24X$ and the marginal cost of focus group size is $MC(X) = 49.17 + 0.22X$. What size of focus group will maximize net benefits?

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APPENDIX A
THE CALCULUS OF MAXIMIZING NET BENEFITS

This appendix provides a calculus-based derivation of the important rule that to maximize net benefits, a manager must equate marginal benefits and marginal costs.

Let $B(Q)$ denote the benefits of using Q units of the managerial control variable, and let $C(Q)$ denote the corresponding costs. The net benefits are $N(Q) = B(Q) - C(Q)$. The objective is to choose Q so as to maximize

$$N(Q) = B(Q) - C(Q)$$

The first-order condition for a maximum is

$$\frac{dN}{dQ} = \frac{dB}{dQ} - \frac{dC}{dQ} = 0$$

But

$$\frac{dB}{dQ} = MB$$

is nothing more than marginal benefits, while

$$\frac{dC}{dQ} = MC$$

is simply marginal costs. Thus, the first-order condition for a maximum implies that

$$\frac{dB}{dQ} = \frac{dC}{dQ}$$

or $MB = MC$.

The second-order condition requires that the function $N(Q)$ be concave in Q or, in mathematical terms, that the second derivative of the net benefit function be negative:

$$\frac{d^2N}{dQ^2} = \frac{d^2B}{dQ^2} - \frac{d^2C}{dQ^2} < 0$$

Notice that $d^2B/dQ^2 = d(MB)/dQ$, while $d^2C/dQ^2 = d(MC)/dQ$. Thus, the second-order condition may be rewritten as

$$\frac{d^2N}{dQ^2} = \frac{d(MB)}{dQ} - \frac{d(MC)}{dQ} < 0$$

In other words, the slope of the marginal benefit curve must be less than the slope of the marginal cost curve.

DEMONSTRATION PROBLEM 1–5

Suppose $B(Q) = 10Q - 2Q^2$ and $C(Q) = 2 + Q^2$. What value of the managerial control variable, Q, maximizes net benefits?

ANSWER:

Net benefits are

$$N(Q) = B(Q) - C(Q) = 10Q - 2Q^2 - 2 - Q^2$$

Taking the derivative of $N(Q)$ and setting it equal to zero gives

$$\frac{dN}{dQ} = 10 - 4Q - 2Q = 0$$

Solving for Q gives $Q = 10/6$. To verify that this is indeed a maximum, we must check that the second derivative of $N(Q)$ is negative:

$$\frac{d^2N}{dQ^2} = -4 - 2 = -6 < 0$$

Therefore, $Q = 10/6$ indeed maximizes net benefits.

APPENDIX B
EVALUATING THE OVERALL FIT OF THE REGRESSION LINE

In addition to evaluating the statistical significance of one or more coefficients, one can also measure the precision with which the overall regression line fits the data. Two yardsticks frequently used to measure the overall fit of the regression line are the *R*-square and the *F*-statistic. It is important to note that while these statistics can be of general interest, they are seldom the focal points of an econometric analysis; careful, proper estimates of the coefficients are typically the focus.

THE *R*-SQUARE

Revisiting Table 1–3, rows 18 through 20 provide diagnostics that indicate how well the regression line explains the sample of observations of the dependent variable (in the example, quantity is the dependent variable and price is the explanatory variable). The *R-square* (also called the *coefficient of determination*) tells the fraction of the total variation in the dependent variable that is explained by the regression. It is computed as the ratio of the sum of squared errors from the regression ($SS_{Regression}$) to the total sum of squared errors (SS_{Total}):

$$R^2 = \frac{Explained\ variation}{Total\ variation} = \frac{SS_{Regression}}{SS_{Total}}$$

For instance, in cell 26-C of Table 1–3 we see that the sum of squared errors from the regression is 301470.89, while cell 28-C reveals that the total sum of squared errors is 402222.50. Thus, the *R*-square is .75 (= 301470.89/402222.50). This means that the estimated equation relating quantity to price (the regression line) explains 75 percent of the total variation in TV sales across the sample of 10 outlets. Most spreadsheet regression packages automatically calculate the *R*-square, as seen in cell 19-B of Table 1–3.[7]

The value of an *R*-square ranges from 0 to 1:

$$0 \le R^2 \le 1$$

The closer the *R*-square is to 1, the "better" the overall fit of the estimated regression equation to the actual data. Unfortunately, there is no simple cutoff that can be used to determine whether an *R*-square is close enough to 1 to indicate a "good" fit. With time series data, *R*-squares are often in excess of .9; with cross-sectional data, *R*-squares below .2 are not uncommon. Thus, a major drawback of the *R*-square is that it is a subjective measure of goodness of fit.

Another problem with the *R*-square is that it cannot decrease when additional explanatory variables are included in the regression. Thus, if we included income, advertising, and other explanatory variables in our regression, but

[7]The square root of the *R*-square, called the Multiple *R*, is also reported by most spreadsheet regression programs. It is given in cell 18-B of Table 3-8.

held other things constant, we would almost surely get a higher *R*-square. Eventually, when the number of estimated coefficients increased to the number of observations, we would end up with an *R*-square of 1. Sometimes, the *R*-square is very close to 1 merely because the number of observations is small relative to the number of estimated parameters. This situation is undesirable from a statistical viewpoint because it can provide a very misleading indicator of the goodness of fit of the regression line. For this reason, many researchers use the adjusted *R*-square reported in cell 20-B of Table 1–3 as a measure of goodness of fit.

The *adjusted R-square* is given by

$$\overline{R^2} = 1 - (1 - R^2)\frac{(n-1)}{(n-k)}$$

where n is the total number of observations and k is the number of estimated coefficients. In performing a regression, the number of parameters to be estimated cannot exceed the number of observations. The difference $(n - k)$ represents the *residual degrees of freedom* after conducting the regression. Notice that the adjusted *R*-square "penalizes" the researcher for performing a regression with only a few degrees of freedom (that is, estimating numerous coefficients from relatively few observations). In fact, the penalty can be so high that, in some instances, the adjusted *R*-square is actually negative.

In our example, cell 22-B in Table 1–3 shows us that $n = 10$. Cells 32-B and 33-B indicate that we estimated 2 parameters, so $k = 2$. With 8 residual degrees of freedom, the adjusted *R*-square of our regression is $1 - (1 - .75)(9/8) = .72$. This number is reported in cell 20-B. For these data, there is little difference between the *R*-square and the adjusted *R*-square, so it does not appear that the "high" *R*-square is a result of an excessive number of estimated coefficients relative to the sample size.

THE *F*-STATISTIC

While the *R*-square and adjusted *R*-square of a regression both provide a gauge of the overall fit of a regression, we note that there is no universal rule for determining how "high" they must be to indicate a good fit. An alternative measure of goodness of fit, called the *F-statistic*, does not suffer from this shortcoming. The *F*-statistic provides a measure of the total variation explained by the regression relative to the total unexplained variation. The greater the *F*-statistic, the better the overall fit of the regression line through the actual data. In our example, the *F*-statistic is reported as 23.94 in cell 26-E of Table 1–3.

The primary advantage of the *F*-statistic stems from the fact that its statistical properties are known. Thus, one can objectively determine the statistical significance of any reported *F* value. The significance value for our regression, .0012, is reported in cell 26-F of Table 1–3. This low number means that there is only a .12 percent chance that the estimated regression model fit the data purely by accident.

As with *P*-values, the lower the significance value of the *F*-statistic, the more confident you can be of the overall fit of the regression equation. Regressions that have *F*-statistics with significance values of 5 percent or less are generally considered significant. Based on the significance value reported in cell 26-F of Table 1–3, our regression is significant at the .12 percent level. The regression is therefore highly significant.

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2 Market Forces: Demand and Supply

LEARNING OBJECTIVES

After completing this chapter, you will be able to:

- **LO1** Explain the laws of demand and supply, and identify factors that cause demand and supply to shift.
- **LO2** Calculate consumer surplus and producer surplus, and describe what they mean.
- **LO3** Explain price determination in a competitive market, and show how equilibrium changes in response to changes in determinants of demand and supply.
- **LO4** Explain and illustrate how excise taxes, *ad valorem* taxes, price floors, and price ceilings impact the functioning of a market.
- **LO5** Apply supply and demand analysis as a qualitative forecasting tool to see the "big picture" in competitive markets.

headLINE

Samsung and Hynix Semiconductor to Cut Chip Production

Sam Robbins, owner and CEO of PC Solutions, arrived at the office and glanced at the front page of *The Wall Street Journal* waiting on his desk. One of the articles contained statements from executives of two of South Korea's largest semiconductor manufacturers—Samsung Electronic Company and Hynix Semiconductor—indicating that they would suspend all their memory chip production for one week. The article went on to say that another large semiconductor manufacturer was likely to follow suit. Collectively, these three chip manufacturers produce about 30 percent of the world's basic semiconductor chips.

PC Solutions is a small but growing company that assembles PCs and sells them in the highly competitive market for "clones." PC Solutions experienced 100 percent growth last year and is in the process of interviewing recent graduates in an attempt to double its workforce.

After reading the article, Sam picked up the phone and called a few of his business contacts to verify for himself the information contained in the *Journal.* Satisfied that the information was correct, he called the director of personnel, Jane Remak.

What do you think Sam and Jane discussed?

INTRODUCTION

This chapter describes *supply* and *demand*, which are the driving forces behind the market economies that exist in the United States and around the globe. As suggested in this chapter's opening headline, supply and demand analysis is a tool that managers can use to visualize the "big picture." Many companies fail because their managers get bogged down in the day-to-day decisions of the business without having a clear picture of market trends and changes that are on the horizon.

To illustrate, imagine that you manage a small retail outlet that sells PCs. A magic genie appears and says, "Over the next month, the market price of PCs will decline and consumers will purchase fewer PCs." The genie revealed the big picture: PC prices and sales will decline. If you worry about the *details* of your business without knowledge of these future trends in prices and sales, you will be at a significant competitive disadvantage. Absent a view of the big picture, you are likely to negotiate the wrong prices with suppliers and customers, carry too much inventory, hire too many employees, and—if your business spends money on informative advertising—purchase ads in which your prices are no longer competitive by the time they reach print.

Supply and demand analysis is a qualitative tool that, like the genie, empowers managers by enabling them to see the "big picture." It is a qualitative forecasting tool you can use to predict trends in competitive markets, including changes in the prices of your firm's products, related products (both substitutes and complements), and the prices of inputs (such as labor services) that are necessary for your operations. As we will see in subsequent chapters, after you use supply and demand analysis to see the big picture, additional tools are available to assist with details—determining *how much* the price will change, *how much* sales and revenues will change, and so on.

For those of you who have taken a principles-level course in economics, some parts of this chapter will be a review. However, make sure you have complete mastery of the tools of supply and demand. The rest of this text will assume you have a thorough working knowledge of the material in this chapter.

DEMAND

Suppose a clothing manufacturer desires information about the impact of its pricing decisions on the demand for its jeans in a small foreign market. To obtain this information, it might engage in market research to determine how many pairs of jeans consumers would purchase each year at alternative prices per unit. The numbers from such a market survey would look something like those in Table 2–1. The market research reveals that if jeans were priced at $10 per pair, 60,000 pairs of jeans would be sold per year; at $30 per pair, 20,000 pairs of jeans would be sold annually.

When there is no ambiguity, it is sometimes convenient to say simply "price" rather than "price per pair" or "price per unit." For instance, if one of your classmates says gasoline is priced at $3.99 in Indianapolis, you understand that she means $3.99 per gallon. Looking at the rows in Table 2–1, notice that the only difference in the entries is the price of jeans and the quantity of jeans sold. Everything else that might influence buyer decisions, such as consumer income, advertising, and the prices of other goods such as shirts, is held constant. In effect, the market survey does not ask consumers how much they would buy at alternative levels of income or advertising; it simply seeks to determine how much would be purchased at alternative prices. The market research reveals that, holding all other things constant, the quantity of jeans consumers are willing and able to purchase goes down as the price rises. This fundamental economic principle is known as the **law of demand**: Price and quantity demanded are

law of demand
As the price of a good rises (falls) and all other things remain constant, the quantity demanded of the good falls (rises).

Table 2–1

The Demand Schedule for Jeans in a Small Foreign Market

Price of Jeans	Quantity of Jeans Sold	Average Consumer Income	Advertising Expenditure	Average Price of Shirts
$ 0	80,000	$25,000	$50,000	$20
5	70,000	25,000	50,000	20
10	60,000	25,000	50,000	20
15	50,000	25,000	50,000	20
20	40,000	25,000	50,000	20
25	30,000	25,000	50,000	20
30	20,000	25,000	50,000	20
35	10,000	25,000	50,000	20
40	0	25,000	50,000	20

inversely related. That is, as the price of a good rises (falls) and all other things remain constant, the quantity demanded of the good falls (rises).

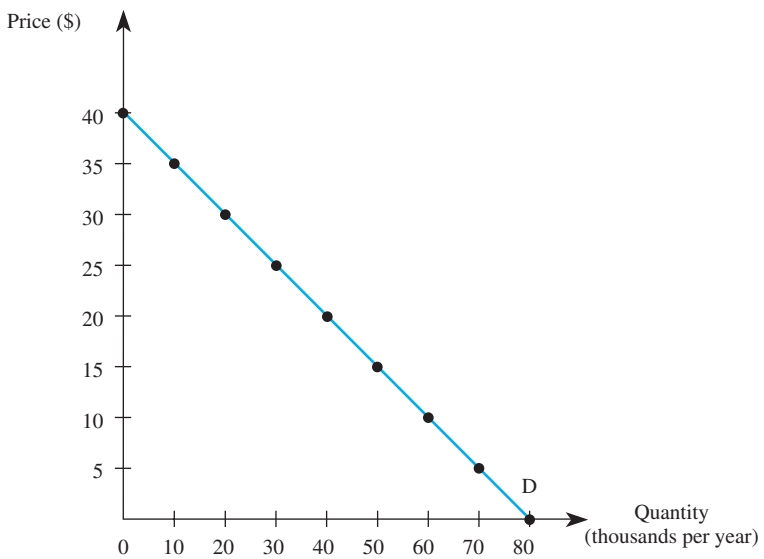
Figure 2–1 plots the data in Table 2–1. The straight line connecting those points, called the **market demand curve**, interpolates the quantities consumers would be willing and able to purchase at prices not explicitly dealt with in the market research. For example, using this market demand curve, we conclude that consumers would be willing and able to purchase 35,000 pairs of jeans when the price is $22.50 (and all other variables stay the same). Notice that the line is downward sloping, which reflects the law of demand, and that all other factors that influence demand are held constant at each point on the line.

market demand curve
A curve indicating the total quantity of a good all consumers are willing and able to purchase at each possible price, holding the prices of related goods, income, advertising, and other variables constant.

Demand Shifters

Economists recognize that variables other than the price of a good influence demand. For example, the number of pairs of jeans individuals are willing and financially able to buy also

Figure 2–1
The Demand Curve



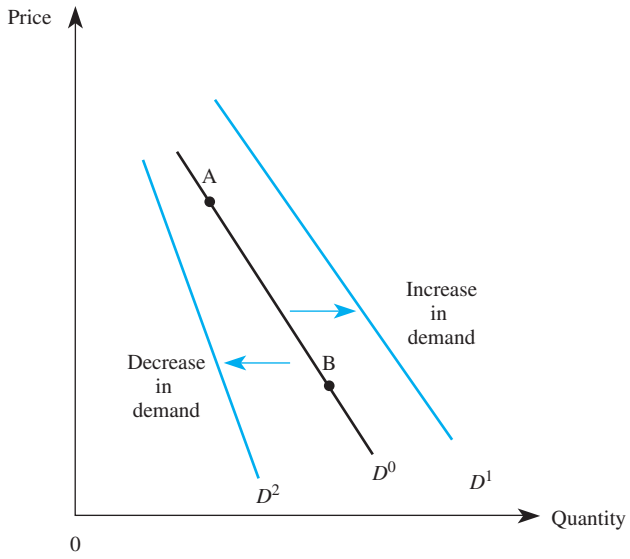


Figure 2–2
Changes in Demand

depends on the price of shirts, consumer income, advertising expenditures, and so on. Variables other than the price of a good that influence demand are known as *demand shifters*.

When we graph the demand curve for good X, we hold everything but the price of X constant. A representative demand curve is given by D^0 in Figure 2–2. The movement along a demand curve, such as the movement from A to B, is called a **change in quantity demanded**. Whenever advertising, income, or the price of related goods changes, it leads to a **change in demand**; the position of the entire demand curve shifts. A rightward shift in the demand curve is called an *increase in demand*, since more of the good is demanded at each price. A leftward shift in the demand curve is called a *decrease in demand.*

Now that we understand the general distinction between a shift in a demand curve and a movement along a demand curve, it is useful to explain how five demand shifters—consumer income, prices of related goods, advertising and consumer tastes, population, and consumer expectations—affect demand.

change in quantity demanded
Changes in the price of a good lead to a change in the quantity demanded of that good. This corresponds to a movement along a given demand curve.

change in demand
Changes in variables other than the price of a good, such as income or the price of another good, lead to a change in demand. This corresponds to a shift of the entire demand curve.

Income

Because income affects the ability of consumers to purchase a good, changes in income affect how much consumers will buy at any price. In graphical terms, a change in income shifts the entire demand curve. Whether an increase in income shifts the demand curve to the right or to the left depends on the nature of consumer consumption patterns. Accordingly, economists distinguish between two types of goods: normal and inferior goods.

A good whose demand increases (shifts to the right) when consumer incomes rise is called a **normal good**. Normal goods may include goods such as steak, airline travel, and designer jeans: As income goes up, consumers typically buy more of these goods at any given price. Conversely, when consumers suffer a decline in income, the demand for a normal good will decrease (shift to the left).

normal good
A good for which an increase (decrease) in income leads to an increase (decrease) in the demand for that good.

Changes in income tend to have profound effects on the demand for durable goods, and these effects are typically amplified in developing countries and rural areas. In 2004, for instance, farmers in India enjoyed higher incomes thanks to the impact on crops of beneficial monsoons. As a result, the demand in rural areas of India for tractors and motorcycles surged,

INSIDE BUSINESS 2–1

Asahi Breweries Ltd. and the Asian Recession

During a recent recession, Japan saw many business failures. Even businesses that traditionally do well during economic downturns, such as the beer brewing industry, were hit hard. Analysts blame the downturn in the beer market on two factors: (1) Japanese incomes (GDP) declined significantly as a result of the recession and (2) Japan's government imposed a beer tax in an effort to raise revenue.

As a result of these events, top Japanese breweries such as Kirin Brewery Company, Ltd., and Sapporo Breweries Ltd. experienced a sharp decline in domestic beer sales. Meanwhile, their competitor—Asahi Breweries—touted double-digit growth and increased its market share. Asahi attributes its growth in sales to its superior sales network and strong marketing campaign for its best-selling beer, *Asahi Super Dry*.

While part of Asahi's growth and success is attributable to the company's sales force and marketing activities—both create greater consumer awareness—this does not fully explain why Asahi has done especially well during the recent Asian recession. One possibility is that Asahi beer is an inferior good. This does not mean that Asahi beer is "skunky" or of low quality; indeed, its *Super Dry* is the beer of choice for many Japanese beer drinkers. The term *inferior good* simply means that when Japanese incomes decline due to a recession, the demand for Asahi beer increases.

SOURCES: Annual Reports for Asahi Breweries Ltd., Sapporo Breweries Ltd., and Kirin Brewery Company, Ltd.

almost tripling the level of demand in the previous year. By 2009, this surge in demand reversed due to significant reductions in consumer incomes stemming from a global economic recession. The demand for durables in developed countries also declined dramatically, and automakers were especially hard hit.

inferior good
A good for which an increase (decrease) in income leads to a decrease (increase) in the demand for that good.

In some instances, an increase in income reduces the demand for a good. Economists refer to such a good as an **inferior good**. Bologna, bus travel, and "generic" jeans are possible examples of inferior goods. As income goes up, consumers typically consume less of these goods at each price. It is important to point out that by calling such goods *inferior*, we do not imply that they are of poor quality; we use this term simply to define products that consumers purchase less of when their incomes rise and purchase more of when their incomes fall.

Prices of Related Goods

Changes in the prices of related goods generally shift the demand curve for a good. For example, if the price of a Coke increases, most consumers will begin to substitute Pepsi because the relative price of Coke is higher than before. As more and more consumers substitute Pepsi for Coke, the quantity of Pepsi demanded at each price will tend to increase. In effect, an increase in the price of Coke increases the demand for Pepsi. This is illustrated by a shift in the demand for Pepsi to the right. Goods that interact in this way are known as **substitutes**.

substitutes
Goods for which an increase (decrease) in the price of one good leads to an increase (decrease) in the demand for the other good.

complements
Goods for which an increase (decrease) in the price of one good leads to a decrease (increase) in the demand for the other good.

Many pairs of goods readily come to mind when we think of substitutes: chicken and beef, cars and trucks, raincoats and umbrellas. Such pairs of goods are substitutes for most consumers. However, substitutes need not serve the same function. For example, televisions and patio furniture could be substitutes; as the price of televisions increases, you may choose to purchase additional patio furniture rather than an additional television. Goods are substitutes when an increase in the price of one good increases the demand for the other good.

Not all goods are substitutes; in fact, an increase in the price of a good such as computer software may lead consumers to purchase fewer computers at each price. Goods that interact in this manner are called **complements**. Beer and pretzels are another example of

complementary goods. If the price of beer increased, most beer drinkers would decrease their consumption of pretzels. Notice that when good *X* is a complement to good *Y*, a reduction in the price of *Y* actually increases (shifts to the right) the demand for good *X*. More of good *X* is purchased at each price due to the reduction in the price of the complement, good *Y*.

Advertising and Consumer Tastes

Another variable that is held constant when drawing a given demand curve is the level of advertising. An increase in advertising shifts the demand curve to the right, from D^1 to D^2, as in Figure 2–3. Notice that the impact of advertising on demand can be interpreted in two ways. Under the initial demand curve, D^1, consumers would buy 50,000 units of high-style clothing per month when the price is $40. After the advertising, the demand curve shifts to D^2, and consumers will now buy 60,000 units of the good when the price is $40. Alternatively, when demand is D^1, consumers will pay a price of $40 when 50,000 units are available. Advertising shifts the demand curve to D^2, so consumers will pay a higher price—$50—for 50,000 units.

Why does advertising shift demand to the right? Advertising often provides consumers with information about the existence or quality of a product, which in turn induces more consumers to buy the product. These types of advertising messages are known as *informative advertising*.

Advertising can also influence demand by altering the underlying tastes of consumers. For example, advertising that promotes the latest fad in clothing may increase the demand for a specific fashion item by making consumers perceive it as "the" thing to buy. These types of advertising messages are known as *persuasive advertising*.

Population

The demand for a product is also influenced by changes in the size and composition of the population. Generally, as the population rises, more and more individuals wish to buy a given product, and this has the effect of shifting the demand curve to the right. Over the twentieth century, the demand curve for food products shifted to the right considerably with the increasing population.

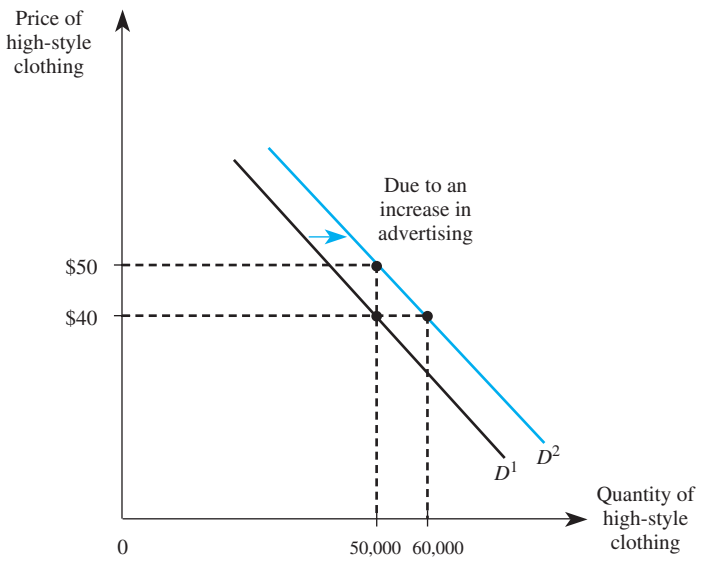


Figure 2–3
Advertising and the Demand for Clothing

It is important to note that changes in the composition of the population can also affect the demand for a product. To the extent that middle-aged consumers desire different types of products than retirees, an increase in the number of consumers in the 30- to 40-year-old age bracket will increase the demand for products like real estate. Similarly, as a greater proportion of the population ages, the demand for medical services will tend to increase.

Consumer Expectations

Changes in *consumer expectations* also can change the position of the demand curve for a product. For example, if consumers suddenly expect the price of automobiles to be significantly higher next year, the demand for automobiles today will increase. In effect, buying a car today is a substitute for buying a car next year. If consumers expect future prices to be higher, they will substitute current purchases for future purchases. This type of consumer behavior often is referred to as *stockpiling* and generally occurs when products are durable in nature. We often see this behavior for less expensive durables, too; consumers may stockpile laundry detergent in response to temporary sales at grocery stores. The current demand for a perishable product such as bananas generally is not affected by expectations of higher future prices.

Other Factors

In concluding our list of demand shifters, we simply note that any variable that affects the willingness or ability of consumers to purchase a particular good is a potential demand shifter. Health scares affect the demand for cigarettes. The birth of a baby affects the demand for diapers.

The Demand Function

By now you should understand the factors that affect demand and how to use graphs to illustrate those influences. The final step in our analysis of the demand side of the market is to show that all the factors that influence demand may be summarized in what economists refer to as a **demand function**.

demand function
A function that describes how much of a good will be purchased at alternative prices of that good and related goods, alternative income levels, and alternative values of other variables affecting demand.

The demand function for good X describes how much X will be purchased at alternative prices of X and related goods, alternative levels of income, and alternative values of other variables that affect demand. Formally, let Q_x^d represent the quantity demanded of good X; P_x the price of good X; P_y the price of a related good; M income; and H the value of any other variable that affects demand, such as the level of advertising, the size of the population, or consumer expectations. Then the demand function for good X may be written as

$$Q_x^d = f(P_x, P_y, M, H)$$

Thus, the demand function explicitly recognizes that the quantity of a good consumed depends on its price and on demand shifters. Different products will have demand functions of different forms. One very simple but useful form is the linear representation of the demand function: Demand is *linear* if Q_x^d is a linear function of prices, income, and other variables that influence demand. The following equation is an example of a **linear demand function**:

linear demand function
A representation of the demand function in which the demand for a given good is a linear function of prices, income levels, and other variables influencing demand.

$$Q_x^d = \alpha_0 + \alpha_x P_x + \alpha_y P_y + \alpha_M M + \alpha_H H$$

The α_is are fixed numbers that the firm's research department or an economic consultant typically estimates using market data and then provides to the manager. Using the basic framework discussed in Chapter 1, we illustrate how to obtain these numbers within demand estimation in Chapter 3.

By the law of demand, an increase in P_x leads to a decrease in the quantity demanded of good X. This means that $\alpha_x < 0$. The sign of α_y will be positive or negative, depending on whether goods X and Y are substitutes or complements. If α_y is a positive number, an increase in the price of good Y will lead to an increase in the consumption of good X; therefore, good X is a substitute for good Y. If α_y is a negative number, an increase in the price of good Y will lead to a decrease in the consumption of good X; hence, good X is a complement to good Y. The sign of α_M also can be positive or negative depending on whether X is a normal or an inferior good. If α_M is a positive number, an increase in income (M) will lead to an increase in the consumption of good X, and good X is a normal good. If α_M is a negative number, an increase in income will lead to a decrease in the consumption of good X, and good X is an inferior good.

DEMONSTRATION PROBLEM 2–1

Using a large collection of market data, an economic consultant for X Corp. recently provided the firm's marketing manager with this estimate of the demand function for the firm's product:

$$Q_x^d = 12{,}000 - 3P_x + 4P_y - 1M + 2A_x$$

where Q_x^d represents the amount consumed of good X, P_x is the price of good X, P_y is the price of good Y, M is income, and A_x represents the amount of advertising spent on good X. Suppose good X sells for \$200 per unit, good Y sells for \$15 per unit, the company utilizes 2,000 units of advertising, and consumer income is \$10,000. How much of good X do consumers purchase? Are goods X and Y substitutes or complements? Is good X a normal or an inferior good?

ANSWER:

To find out how much of good X consumers will purchase, we substitute the given values of prices, income, and advertising into the linear demand equation to get

$$Q_x^d = 12{,}000 - 3(200) + 4(15) - 1(10{,}000) + 2(2{,}000)$$

Adding up the numbers, we find that the total consumption of X is 5,460 units. Since the coefficient of P_y in the demand equation is $4 > 0$, we know that a \$1 increase in the price of good Y will increase the consumption of good X by 4 units. Thus, goods X and Y are substitutes. Since the coefficient of M in the demand equation is $-1 < 0$, we know that a \$1 increase in income will decrease the consumption of good X by 1 unit. Thus, good X is an inferior good.

The information summarized in a demand function can be used to graph a demand curve. Since a demand curve is the relation between price and quantity, a representative demand curve holds everything but price constant. This means one may obtain the formula for a demand curve by inserting given values of the demand shifters into the demand function, but leaving P_x in the equation to allow for various values. If we do this for the demand function in Demonstration Problem 2–1 (where $P_y = \$15$, $M = \$10{,}000$, and $A_x = 2{,}000$), we get

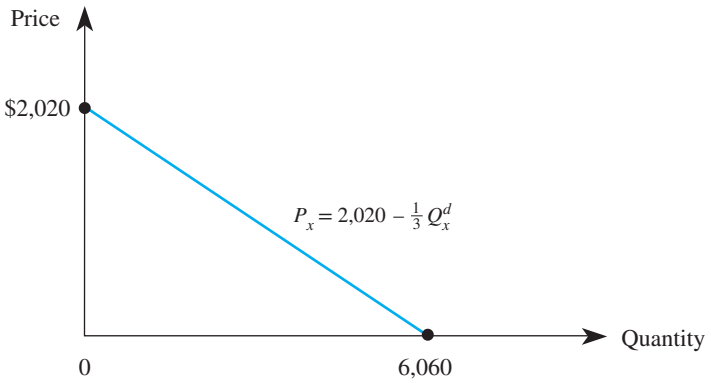
$$Q_x^d = 12{,}000 - 3P_x + 4(15) - 1(10{,}000) + 2(2{,}000)$$

which simplifies to

$$Q_x^d = 6{,}060 - 3P_x \qquad (2-1)$$

Because we usually graph this relation with the price of the good on the vertical axis, it is useful to represent Equation 2–1 with price on the left-hand side and everything else on the

Figure 2–4
Graphing the Inverse Demand Function



right-hand side. This relation is called an *inverse demand function*. For this example, the inverse demand function is

$$P_x = 2{,}020 - \frac{1}{3}Q_x^d$$

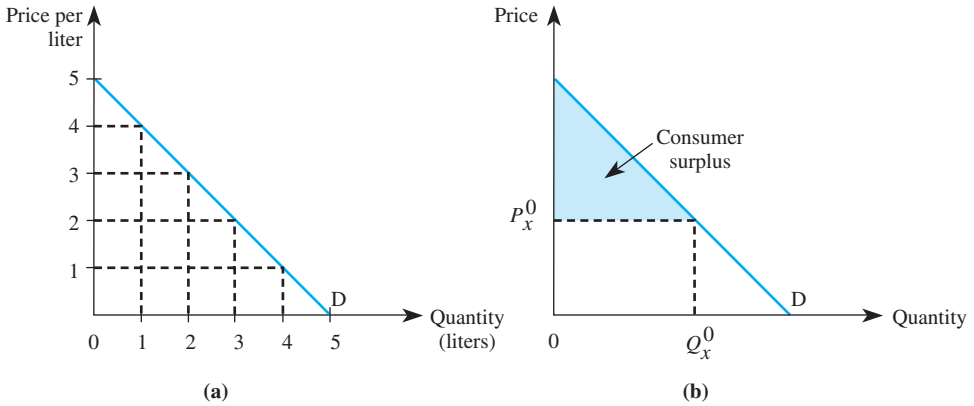
It reveals how much consumers are willing and able to pay for each additional unit of good *X*. This demand curve is graphed in Figure 2–4.

Consumer Surplus

We now show how a manager can use the demand curve to ascertain the value a consumer or group of consumers receives from a product. The concepts developed in this section are particularly useful in marketing and other disciplines that emphasize strategies such as *value pricing* and *price discrimination*.

By the law of demand, the amount a consumer is willing to pay for an additional unit of a good falls as more of the good is consumed. For instance, imagine that the demand curve in Figure 2–5(a) represents your demand for water immediately after participating in a 10K run. Initially, you are willing to pay a very high price—in this case, $5 per liter—for the first drop of water. As you consume more water, the amount you are willing to pay for an additional drop declines from $5.00 to $4.99 and so on as you move down the demand curve. Notice that after you have consumed an entire liter of water, you are willing to pay only $4 per liter for another drop. Once you have enjoyed 2 liters of water, you are willing to pay only $3 per liter for another drop.

Figure 2–5
Consumer Surplus



To find your total value (or benefit) of 2 liters of water, we simply add up the maximum amount you were willing to pay for each of these drops of water between 0 and 2 liters. This amount corresponds to the area underneath the demand curve in Figure 2–5(a) up to the quantity of 2 liters. Since the area of this region is $8, the total value you receive from 2 liters of water is $8.

Fortunately, you don't have to pay different prices for the different drops of water you consume. Instead, you face a per-unit price of, say, $3 per liter and get to buy as many drops (or even liters) as you want at that price. Given the demand curve in Figure 2–5(a), when the price is $3 you will choose to purchase 2 liters of water. In this case, your total out-of-pocket expense for the 2 liters of water is $6. Since you value 2 liters of water at $8 and only have to pay $6 for it, you are getting $2 in value over and above the amount you have to pay for water. This "extra" value is known as **consumer surplus**—the value consumers get from a good but do not have to pay for. This concept is important to managers because it tells how much extra money consumers would be willing to pay for a given amount of a purchased product.

consumer surplus
The value consumers get from a good but do not have to pay for.

More generally, consumer surplus is the area above the price paid for a good but below the demand curve. For instance, the shaded triangle in Figure 2–5(b) illustrates the consumer surplus of a consumer who buys Q_x^0 units at a price of P_x^0. To see why, recall that each point on the demand curve indicates the value to the consumer of another unit of the good. The difference between each price on the demand curve and the price P_x^0 paid represents surplus (the value the consumer receives but does not have to pay for). When we add up the "surpluses" received for each unit between 0 and Q_x^0 (this sum equals the shaded region), we obtain the consumer surplus associated with purchasing Q_x^0 units at a price of P_x^0 each.

Managers can use the notion of consumer surplus to determine the total amount consumers would be willing to pay for multiunit packages. While this will be discussed in detail in Chapter 11 where we examine pricing strategies, we illustrate the basic idea in the following problem.

DEMONSTRATION PROBLEM 2–2

A typical consumer's demand for the Happy Beverage Company's product looks like that in Figure 2–5(a). If the firm charges a price of $2 per liter, how much revenue will the firm earn and how much consumer surplus will the typical consumer enjoy? What is the most a consumer would be willing to pay for a bottle containing exactly 3 liters of the firm's beverage?

ANSWER:

At a price of $2 per liter, a typical consumer will purchase 3 liters of the beverage. Thus, the firm's revenue is $6 and the consumer surplus is $4.50 [the area of the consumer surplus triangle is one-half the base times the height, or .5(3)($5 − $2) = $4.50]. The total value of 3 liters of the firm's beverage to a typical consumer is thus $6 + $4.50, or $10.50. This is also the maximum amount a consumer would be willing to pay for a bottle containing exactly 3 liters of the firm's beverage. Expressed differently, if the firm sold the product in 3-liter bottles rather than in smaller units, it could sell each bottle for $10.50 to earn higher revenues and extract all consumer surplus.

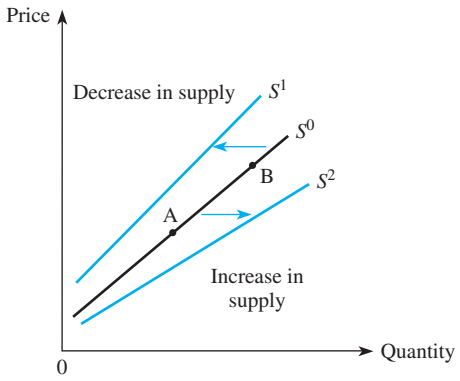
SUPPLY

In the previous section we focused on demand, which represents half of the forces that determine the price in a market. The other determinant is market supply. In a competitive market there are many producers, each producing a similar product. The **market supply curve** summarizes the total quantity all producers are willing and able to produce at alternative prices, holding other factors that affect supply constant.

market supply curve
A curve indicating the total quantity of a good that all producers in a competitive market would produce at each price, holding input prices, technology, and other variables affecting supply constant.

Figure 2–6

Changes in Supply



While the market supply of a good generally depends on many things, when we graph a supply curve, we hold everything but the price of the good constant. The movement along a supply curve, such as the one from A to B in Figure 2–6, is called a **change in quantity supplied**. The fact that the market supply curve slopes upward reflects the inverse **law of supply**: As the price of a good rises (falls) and other things remain constant, the quantity supplied of the good rises (falls). Producers are willing to produce more output when the price is high than when it is low.

change in quantity supplied
Changes in the price of a good lead to a change in the quantity supplied of that good. This corresponds to a movement along a given supply curve.

law of supply
As the price of a good rises (falls) and other things remain constant, the quantity supplied of the good rises (falls).

change in supply
Changes in variables other than the price of a good, such as input prices or technological advances, lead to a change in supply. This corresponds to a shift of the entire supply curve.

Supply Shifters

Variables that affect the position of the supply curve are called *supply shifters*, and they include the prices of inputs, the level of technology, the number of firms in the market, taxes, and producer expectations. Whenever one or more of these variables change, the position of the entire supply curve shifts. Such a shift is known as a **change in supply**. The shift from S^0 to S^2 in Figure 2–6 is called an *increase in supply* since producers sell more output at each given price. The shift from S^0 to S^1 in Figure 2–6 represents a *decrease in supply* since producers sell less of the product at each price.

Input Prices

The supply curve reveals how much producers are willing to produce at alternative prices. As production costs change, the willingness of producers to produce output at a given price changes. In particular, as the price of an input rises, producers are willing to produce less output at each given price. This decrease in supply is depicted as a leftward shift in the supply curve.

Technology or Government Regulations

Technological changes and changes in government regulations also can affect the position of the supply curve. Changes that make it possible to produce a given output at a lower cost, such as the ones highlighted in Inside Business 2–2, have the effect of increasing supply. Conversely, natural disasters that destroy existing technology and government regulations, such as emissions standards that have an adverse effect on businesses, shift the supply curve to the left.

Number of Firms

The number of firms in an industry affects the position of the supply curve. As additional firms enter an industry, more and more output are available at each given price. This is reflected by a rightward shift in the supply curve. Similarly, as firms leave an industry, fewer units are sold at each price, and the supply decreases (shifts to the left).

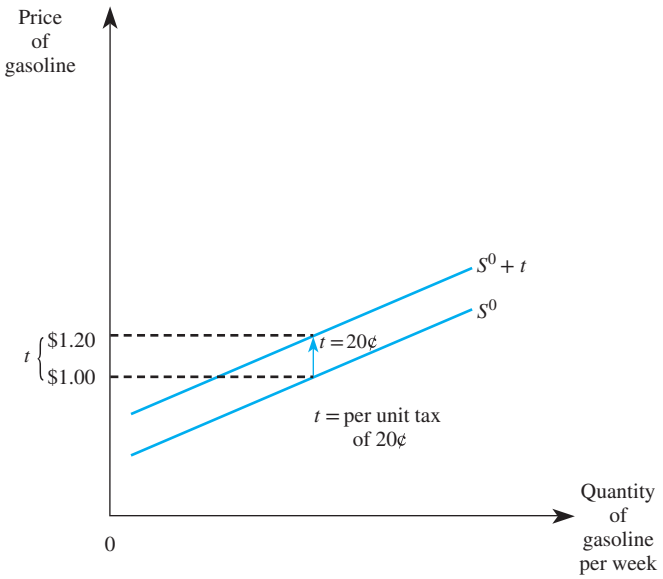


Figure 2–7
A Per-Unit (Excise) Tax

Substitutes in Production

Many firms have technologies that are readily adaptable to several different products. For example, automakers can convert a truck assembly plant into a car assembly plant by altering its production facilities. When the price of cars rises, these firms can convert some of their truck assembly lines to car assembly lines to increase the quantity of cars supplied. This has the effect of shifting the truck supply curve to the left.

Taxes

The position of the supply curve is also affected by taxes. An *excise tax* is a tax on each unit of output sold, where the tax revenue is collected from the supplier. For example, suppose the government levies a tax of $.20 per gallon on gasoline. Since each supplier must now pay the government $.20 per gallon for each gallon of gasoline sold, each must receive an additional $.20 per gallon to be willing to supply the same quantity of gasoline as before the tax. An excise tax shifts the supply curve up by the amount of the tax, as in Figure 2–7. Note that at any given price, producers are willing to sell less gasoline after the tax than before. Thus, an excise tax has the effect of decreasing the supply of a good.

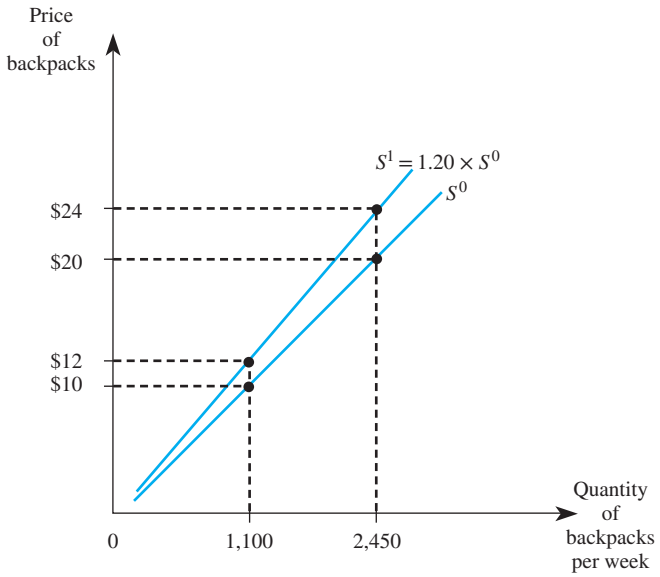
Another form of tax often used by a government agency is an ad valorem tax. *Ad valorem* literally means "according to the value." An *ad valorem tax* is a percentage tax; the sales tax is a well-known example. If the price of a good is $1 and a 10 percent ad valorem tax is attached to that good, the price after the tax is $1.10. Because an ad valorem tax is a percentage tax, it will be higher for high-priced items.

In Figure 2–8, S^0 represents the supply curve for backpacks before the inception of a 20 percent ad valorem tax. Notice that 1,100 backpacks are offered for sale when the price of a backpack is $10 and 2,450 backpacks are offered when the price is $20.

Once the 20 percent tax is implemented, the price required to produce each unit goes up by 20 percent at any output level. Therefore, price will go up by $2 at a quantity of 1,100 and by $4 at a quantity of 2,450. An ad valorem tax will rotate the supply curve counterclockwise, and the new curve will shift farther away from the original curve as the price increases. This explains why S^1 is steeper than S^0 in Figure 2–8.

Figure 2–8

An Ad Valorem Tax



INSIDE BUSINESS 2–2

International Trade Agreements and the Supply Curve

Over the past two decades, presidents from both political parties have signed trade agreements and laws that include provisions designed to reduce the cost of producing goods at home and abroad. These cost reductions translate into increases in the supply of goods and services available to U.S. consumers.

The North American Free Trade Agreement (NAFTA) among the United States, Canada, and Mexico was signed into law by Bill Clinton and contained provisions to eliminate or phase out tariffs and other barriers in industrial products (such as textiles and apparel) and agricultural products. NAFTA also included provisions designed to reduce barriers to investment in Mexican petrochemicals and financial service sectors.

The Trade Act of 2002 was enacted under George W. Bush and gives the president the ability to negotiate additional international agreements (subject to an up-or-down vote by Congress).

During his campaign and at various points in his presidency, Barack Obama pledged to renegotiate NAFTA. However, the deep recession during that time caused him to postpone that effort. Obama did negotiate the Trans-Pacific Partnership, an agreement designed to lower the tariffs of 12 Pacific Rim countries, toward the end of his presidency. However, amid concerns from both parties—centered on the possibility of job losses—his successor, Donald Trump, abandoned the deal.

Early in his presidency, Trump vowed to renegotiate NAFTA and a range of other trade agreements, including those with European nations and China, and threatened increased tariffs on countries that won't come to the table. Among other outcomes, this approach led to the signing of the United States–Mexico–Canada Agreement (USMCA) to replace NAFTA, which includes substantially more rules concerning intellectual property and data, along with labor and environmental protections. Only time will tell whether the current and future administrations will continue on the course set by Presidents Clinton and Bush.

SOURCES: "The USMCA Is Finally Done. Here's What Is in It," *Washington Post*, December 10, 2019; "It's Not Just China: Trump's Trade War Is Raging on Several Fronts," *CNBC*, May 13, 2019; "What Is TPP? Behind the Trade Deal that Died," *The New York Times*, January 23, 2107; "NAFTA Renegotiation Must Wait, Obama Says," *Washington Post*, February 20, 2009; *Economic Report of the President*, Washington, DC: U.S. Government Printing Office, February 2007, p. 60; *Economic Report of the President*, Washington, DC: U.S. Government Printing Office, February 2006, p. 153; *Economic Report of the President*, Washington, DC: U.S. Government Printing Office, February 1995, pp. 220–21.

Producer Expectations

Producer expectations about future prices also affect the position of the supply curve. In effect, selling a unit of output today and selling a unit of output tomorrow are substitutes in production. If firms suddenly expect prices to be higher in the future and the product is not perishable, producers can hold back output today and sell it later at a higher price. This has the effect of shifting the current supply curve to the left.

The Supply Function

You should now understand the difference between supply and quantity supplied and recognize the factors that influence the position of the supply curve. The final step in our analysis of supply is to show that all the factors that influence the supply of a good can be summarized in a supply function.

The **supply function** of a good describes how much of the good will be produced at alternative prices of the good, alternative prices of inputs, and alternative values of other variables that affect supply. Formally, let Q_x^s represent the quantity supplied of a good, P_x the price of the good, W the price of an input (such as the wage rate on labor), P_r the price of technologically related goods, and H the value of some other variable that affects supply (such as the existing technology, the number of firms in the market, taxes, or producer expectations). Then the supply function for good X may be written as

supply function
A function that describes how much of a good will be produced at alternative prices of that good, alternative input prices, and alternative values of other variables affecting supply.

$$Q_x^s = f(P_x, P_r, W, H)$$

Thus, the supply function explicitly recognizes that the quantity produced in a market depends not only on the price of the good but also on all the factors that are potential supply shifters. While there are many different functional forms for different types of products, a particularly useful representation of a supply function is the linear relationship. Supply is linear if Q_x^s is a linear function of the variables that influence supply. The following equation is representative of a **linear supply function**:

linear supply function
A representation of the supply function in which the supply of a given good is a linear function of prices and other variables affecting supply.

$$Q_x^s = \beta_0 + \beta_x P_x + \beta_r P_r + \beta_w W + \beta_H H$$

The coefficients (the β_is) represent given numbers that have been estimated by the firm's research department or an economic consultant.

DEMONSTRATION PROBLEM 2–3

Using a large collection of market data, your research department estimates that the supply function for high definition televisions (HDTVs) is given by

$$Q_x^s = 2{,}000 + 3P_x - 4P_t - P_w$$

where P_x is the price of HDTVs, P_t represents the price of a tablet, and P_w is the price of an input used to make HDTVs. Suppose HDTVs are sold for $400 per unit, tablets are sold for $250 per unit, and the price of an input is $1,400. How many HDTVs are produced?

ANSWER:

To find out how many television sets are produced, we insert the given values of prices into the supply function to get

$$Q_x^s = 2{,}000 + 3(400) - 4(250) - 1(1{,}400)$$

Adding up the numbers, we find that the total quantity of HDTVs produced is 800.

The information summarized in a supply function can be used to graph a supply curve. Since a supply curve is the relationship between price and quantity, a representative supply curve holds everything but price constant. This means one may obtain the formula for a supply curve by inserting given values of the supply shifters into the supply function, but leaving P_x in the equation to allow for various values. If we do this for the supply function in Demonstration Problem 2–3 (where $P_t = \$250$ and $P_w = 1{,}400$), we get

$$Q_x^s = 2{,}000 + 3P_x - 4(250) - 1(1{,}400)$$

which simplifies to

$$Q_x^s = 3P_x - 400 \tag{2–2}$$

Since we usually graph this relation with the price of the good on the vertical axis, it is useful to represent Equation 2–2 with price on the left-hand side and everything else on the right-hand side. This is known as an *inverse supply function*. For this example, the inverse supply function is

$$P_x = \frac{400}{3} + \frac{1}{3}Q_x^s$$

which is the equation for the supply curve graphed in Figure 2–9. This curve reveals how much producers must receive to be willing to produce each additional unit of good *X*.

Producer Surplus

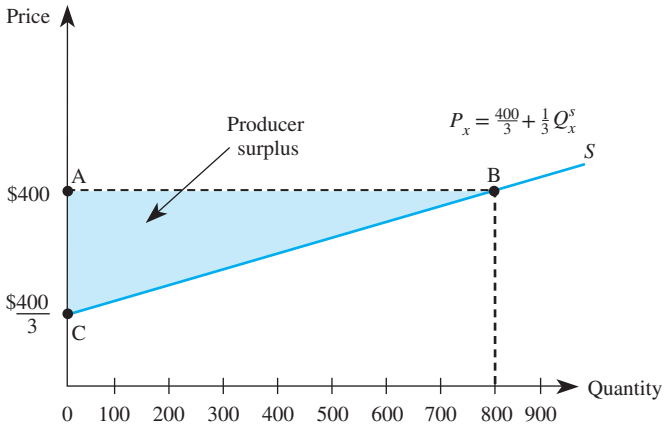
Just as consumers want price to be as low as possible, producers want price to be as high as possible. The supply curve reveals the amount producers will be willing to produce at a given price. Alternatively, it indicates the price firms would have to receive to be willing to produce an additional unit of a good. For example, the supply curve in Figure 2–9 indicates that a total of 800 units will be produced when the price is $400. Alternatively, if 800 units are produced, producers will have to receive $400 to be induced to produce another unit of the good.

producer surplus
The amount producers receive in excess of the amount necessary to induce them to produce the good.

Producer surplus is the producer analogue to consumer surplus. It is the amount of money producers receive in excess of the amount necessary to induce them to produce the good. More specifically, note that producers are willing to sell each unit of output below 800 units at a price less than $400. But if the price is $400, producers receive an amount equal to $400 for each unit of output below 800, even though they would be willing to sell those individual units for a lower price.

Geometrically, producer surplus is the area above the supply curve but below the market price of the good. Thus, the shaded area in Figure 2–9 represents the surplus producers

Figure 2–9
Producer Surplus



receive by selling 800 units at a price of $400—an amount above what would be required to produce each unit of the good. The shaded area, ABC, is the producer surplus when the price is $400. Mathematically, this area is one-half of 800 times $266.67, or $106,668.

Producer surplus can be a powerful tool for managers. For instance, suppose the manager of a major fast-food restaurant currently purchases 10,000 pounds of ground beef each week from a supplier at a price of $1.25 per pound. The producer surplus the meat supplier earns by selling 10,000 pounds at $1.25 per pound tells the restaurant manager the dollar amount that the supplier is receiving over and above what it would be willing to accept for meat. In other words, the meat supplier's producer surplus is the maximum amount the restaurant could save in meat costs by bargaining with the supplier over a package deal for 10,000 pounds of meat. Chapters 6 and 10 will provide details about how managers can negotiate such a bargain.

MARKET EQUILIBRIUM

The equilibrium price in a competitive market is determined by the interactions of all buyers and sellers in the market. The concepts of market supply and market demand make this notion of interaction more precise: The price of a good in a competitive market is determined by the interaction of market supply and market demand for the good.

Since we will focus on the market for a single good, it is convenient to drop subscripts at this point and let P denote the price of this good and Q the quantity of the good. Figure 2–10 depicts the market supply and demand curves for such a good. To see how the competitive price is determined, let the price of the good be P^L. This price corresponds to point B on the market demand curve; consumers wish to purchase Q^1 units of the good. Similarly, the price of P^L corresponds to point A on the market supply curve; producers are willing to produce only Q^0 units at this price. Thus, when the price is P^L, there is a *shortage* of the good; that is, there is not enough of the good to satisfy all consumers willing to purchase it at that price.

In situations where a shortage exists, there is a natural tendency for the price to rise; consumers unable to buy the good may offer producers a higher price in an attempt to get the product. As the price rises from P^L to P^e in Figure 2–10, producers have an incentive to expand output from Q^0 to Q^e. Similarly, as the price rises, consumers are willing to purchase less of the good. When the price rises to P^e, the quantity demanded is Q^e. At this price, just

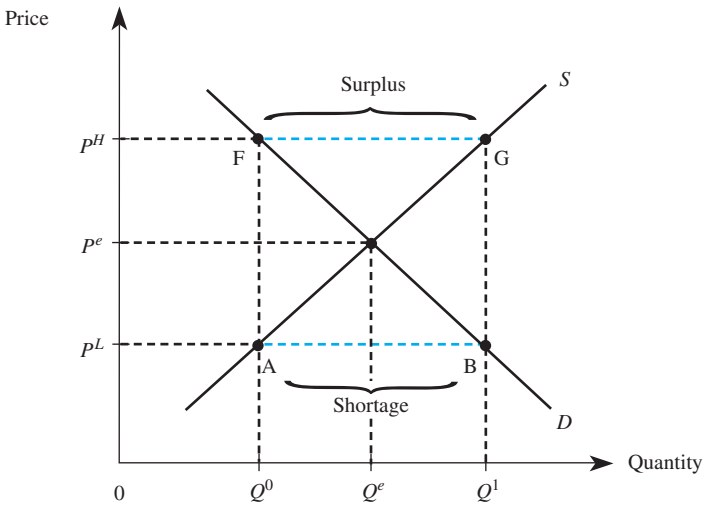


Figure 2–10
Market Equilibrium

enough of the good is produced to satisfy all consumers willing and able to purchase at that price; quantity demanded equals quantity supplied.

Suppose the price is at a higher level—say, P^H. This price corresponds to point F on the market demand curve, indicating that consumers wish to purchase Q^0 units of the good. The price P^H corresponds to point G on the market supply curve; producers are willing to produce Q^1 units at this price. Thus, when the price is P^H, there is a *surplus* of the good; firms are producing more than they can sell at a price of P^H.

Whenever a surplus exists, there is a natural tendency for the price to fall to equate quantity supplied with quantity demanded; producers unable to sell their products may ask for a lower price in an attempt to reduce their unsold inventories. As the price falls from P^H to P^e, producers have an incentive to reduce quantity supplied to Q^e. Similarly, as the price falls, consumers are willing to purchase more of the good. When the price falls to P^e, the quantity demanded is Q^e; quantity demanded equals quantity supplied.

Thus, the interaction of supply and demand ultimately determines a competitive price, P^e, such that there is neither a shortage nor a surplus of the good. This price is called the *equilibrium price* and the corresponding quantity, Q^e, is called the *equilibrium quantity* for the competitive market. Once this price and quantity are realized, the market forces of supply and demand are balanced; there is no tendency for prices either to rise or to fall.

PRINCIPLE

Competitive Market Equilibrium

Equilibrium in a competitive market is determined by the intersection of the market demand and supply curves. The equilibrium price is the price that equates quantity demanded with quantity supplied. Mathematically, if $Q^d(P)$ and $Q^s(P)$ represent the quantity demanded and supplied when the price is P, the equilibrium price, P^e, is the price such that

$$Q^d(P^e) = Q^s(P^e)$$

The equilibrium quantity is simply $Q^d(P^e)$ or, equivalently, $Q^s(P^e)$.

INSIDE BUSINESS 2–3

Unpopular Equilibrium Prices

For a recent college graduation, each graduating student was directed to pick up three free tickets any time between April 9 and April 20. After April 20, remaining tickets were given to those desiring additional tickets, on a first-come, first-served basis. Once the free tickets were fully distributed, any trades between ticket holders and ticket demanders were left to market forces—which led to a very unpopular equilibrium price.

With several concurrent events competing for students' attention during this time, many students did not claim their three free tickets by the deadline. As graduation approached, students who did not claim their tickets were willing to pay large sums of money to purchase tickets for visiting family members and friends. Since the demand for tickets was great and only a limited number of tickets were available, some sellers were asking as much as $400 for a ticket!

Several students expressed outrage over the high prices. However, the high prices are merely a symptom of the high value many students placed on graduation tickets coupled with the limited supply. Had graduating seniors without tickets better forecasted this market outcome, they would have picked up their free tickets on time.

SOURCE: "$400? Ticket Scalpers Cash in on IU Kelley's Commencement," *The Herald-Times*, May 3, 2012.

DEMONSTRATION PROBLEM 2–4

According to an article in *China Daily*, China recently accelerated its plan to privatize tens of thousands of state-owned firms. Imagine that you are an aide to a senator on the Foreign Relations Committee of the U.S. Senate, and you have been asked to help the committee determine the price and quantity that will prevail when competitive forces are allowed to equilibrate the market. The best estimates of the market demand and supply for the good (in U.S. dollar equivalent prices) are given by $Q^d = 10 - 2P$ and $Q^s = 2 + 2P$, respectively. Determine the competitive equilibrium price and quantity.

ANSWER:

Competitive equilibrium is determined by the intersection of the market demand and supply curves. Mathematically, this simply means that $Q^d = Q^s$. Equating demand and supply yields

$$10 - 2P = 2 + 2P$$

or

$$8 = 4P$$

Solving this equation for P yields the equilibrium price $P^e = 2$. To determine the equilibrium quantity, we simply plug this price into either the demand or the supply function (since, in equilibrium, quantity supplied equals quantity demanded). For example, using the supply function, we find that

$$Q^e = 2 + 2(2) = 6$$

PRICE RESTRICTIONS AND MARKET EQUILIBRIUM

The previous section showed how prices and quantities are determined in a free market. In some instances, government places limits on how much prices are allowed to rise or fall, and these restrictions can affect the market equilibrium. In this section, we examine the impact of price ceilings and price floors on market allocations.

Price Ceilings

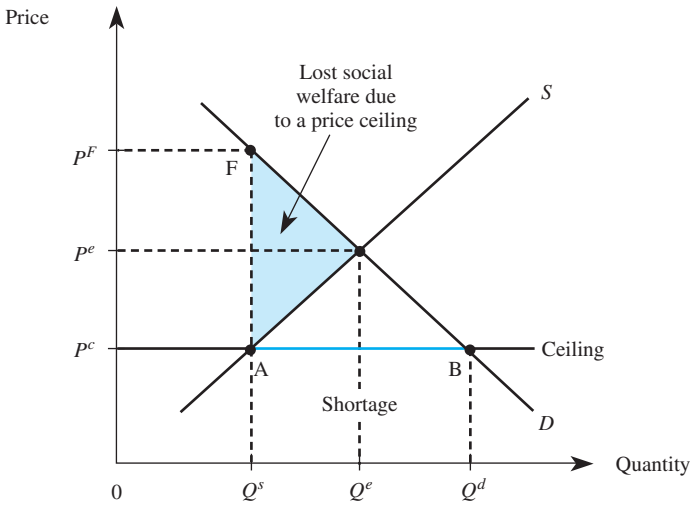
One basic implication of the economic doctrine of scarcity is that there are not enough goods to satisfy the desires of all consumers at a price of zero. As a consequence, some method must be used to determine who gets to consume goods and who does not. People who do not get to consume goods are essentially discriminated against. One way to determine who gets a good and who does not is to allocate the goods based on hair color: If you have red hair, you get the good; if you don't have red hair, you don't get the good.

The price system uses price to determine who gets a good and who does not. The price system allocates goods to consumers who are willing and able to pay the most for the goods. If the competitive equilibrium price of a pair of jeans is $40, consumers willing and able to pay $40 will purchase the good; consumers unwilling or unable to pay that much for a pair of jeans will not buy the good.

It is important to keep in mind that it is not the price system that is "unfair" if one cannot afford to pay the market price for a good; rather, it is unfair that we live in a world of scarcity. Any method of allocating goods will seem unfair to someone because there are not enough resources to satisfy everyone's wants. For example, if jeans were allocated to people on the basis of hair color instead of the price system, you would think this allocation rule was unfair unless you were born with the "right" hair color.

Figure 2–11

A Price Ceiling



Often individuals who are discriminated against by the price system attempt to persuade the government to intervene in the market by requiring producers to sell the good at a lower price. This is only natural, for if we were unable to own a house because we had the wrong hair color, we most certainly would attempt to get the government to pass a law allowing people with our hair color to own a house. But then there would be too few houses to go around, and some other means would have to be used to allocate houses to people.

Suppose that, for whatever reason, the government views the equilibrium price of P^e in Figure 2–11 as "too high" and passes a law prohibiting firms from charging prices above P^c. Such a price is called a **price ceiling**.

price ceiling
The maximum legal price that can be charged in a market.

Do not be confused by the fact that the price ceiling is below the initial equilibrium price; the term *ceiling* refers to that price being the highest permissible price in the market. It does not refer to a price set above the equilibrium price. In fact, if a ceiling were imposed above the equilibrium price, it would be ineffective; the equilibrium price would be below the maximum legal price.

Given the regulated price of P^c, quantity demanded exceeds quantity supplied by the distance from A to B in Figure 2–11; there is a shortage of $Q^d - Q^s$ units. The reason for the shortage is twofold. First, producers are willing to produce less at the lower price, so the available quantity is reduced from Q^e to Q^s. Second, consumers wish to purchase more at the lower price; thus, quantity demanded increases from Q^e to Q^d. The result is that there is not enough of the good to satisfy all consumers willing and able to purchase it at the price ceiling.

How, then, are the goods to be allocated now that it is no longer legal to ration them on the basis of price? In most instances, goods are rationed on the basis of "first come, first served." As a consequence, price ceilings typically result in long lines such as those created in the 1970s due to price ceilings on gasoline. Thus, price ceilings discriminate against people who have a high opportunity cost of time and do not like to wait in lines. If a consumer has to wait in line two hours to buy 10 gallons of gasoline and his or her time is worth \$5 per hour, it costs the consumer $2 \times \$5 = \$10$ to wait in line. Since 10 gallons of gasoline are purchased, this amounts to spending \$1 per gallon waiting in line to purchase the good.

This basic idea can be depicted graphically. Under the price ceiling of P^c, only Q^s units of the good are available. Since this quantity corresponds to point F on the demand curve in Figure 2–11, we see that consumers are willing to pay P^F for another unit of the good. By law, however, they cannot pay the firm more than P^c. The difference $P^F - P^c$ reflects the price per

unit consumers are willing to pay by waiting in line. The **full economic price** paid by a consumer (P^F) is thus the amount paid to the firm (P^c) plus the implicit amount paid by waiting in line ($P^F - P^c$). The latter price is paid not in dollars but through opportunity cost and thus is termed the *nonpecuniary price*.

full economic price The dollar amount paid to a firm under a price ceiling, plus the nonpecuniary price.

$$\underset{\text{Full economic price}}{P^F} = \underset{\text{Dollar price}}{P^c} + \underset{\text{Nonpecuniary price}}{(P^F - P^c)}$$

As Figure 2–11 shows, P^F is greater than the initial equilibrium price, P^e. When opportunity costs are taken into account, the full economic price paid for a good is actually higher after the ceiling is imposed.

Since price ceilings reduce the quantity available in the market, such regulations reduce social welfare even if they do not result in long lines. The dollar value of the lost social welfare is given by the shaded triangle in Figure 2–11. Intuitively, each point on the demand curve represents the amount consumers would be willing to pay for an additional unit, while each point on the supply curve indicates the amount producers would have to receive to induce them to sell an additional unit. The vertical difference between the demand and supply curves at each quantity therefore represents the change in social welfare (consumer value less relevant production costs) associated with each incremental unit of output. Summing these vertical differences for all units between Q^e and Q^s yields the shaded triangle in Figure 2–11 and thus represents the total dollar value of the lost social welfare due to a price ceiling. The triangle in Figure 2–11 is sometimes called "deadweight loss."

DEMONSTRATION PROBLEM 2–5

Based on your answer to the Senate Foreign Relations Committee (Demonstration Problem 2–4), one of the senators raises a concern that the free market price might be too high for the typical Chinese citizen to pay. Accordingly, she asks you to explain what would happen if the Chinese government privatized the market but then set a price ceiling at the Chinese equivalent of $1.50. How do you answer? Assume that the market demand and supply curves (in U.S. dollar equivalent prices) are still given by

$$Q^d = 10 - 2P \text{ and } Q^s = 2 + 2P$$

ANSWER:

Since the price ceiling is below the equilibrium price of $2, a shortage will result. More specifically, when the price ceiling is $1.50, quantity demanded is

$$Q^d = 10 - 2(1.50) = 7$$

and quantity supplied is

$$Q^s = 2 + 2(1.50) = 5$$

Thus, there is a shortage of $7 - 5 = 2$ units.

To determine the full economic price, we simply determine the maximum price consumers are willing to pay for the five units produced. To do this, we first set quantity equal to 5 in the demand formula:

$$5 = 10 - 2P^F$$

or

$$2P^F = 5$$

Next, we solve this equation for P^F to obtain the full economic price, $P^F = \$2.50$. Thus, consumers pay a full economic price of \$2.50 per unit; \$1.50 of this price is in money and \$1 represents the nonpecuniary price of the good. Lastly, we can solve for the deadweight loss generated by the price ceiling. This is equal to $0.5(P^F - P^C)(Q^e - Q^s) = 0.5(2.50 - 1.50)(6 - 5) = 0.5$. (Note that we get $Q^e = 6$ by plugging in the equilibrium price of 2 into either the supply or demand equation.)

Based on the preceding analysis, one may wonder why the government would ever impose price ceilings. One answer might be that politicians do not understand the basics of supply and demand. This probably is not the answer, however.

The answer lies in who benefits from and who is harmed by ceilings. When lines develop due to a shortage caused by a price ceiling, people with high opportunity costs are hurt, while people with low opportunity costs may actually benefit. For example, if you have nothing better to do than wait in line, you will benefit from the lower dollar price; your nonpecuniary price is close to zero. On the other hand, if you have a high opportunity cost of time because your time is valuable to you, you are made worse off by the ceiling. If a particular politician's constituents tend to have a lower-than-average opportunity cost, that politician naturally will attempt to invoke a price ceiling.

Sometimes when shortages are created by a ceiling, goods are not allocated on the basis of lines. Producers may discriminate against consumers on the basis of other factors, including whether or not consumers are regular customers. During the gasoline shortage of the 1970s, many gas stations sold gas only to customers who regularly used the stations. In California during the late 1990s, price ceilings were imposed on the fees that banks charged nondepositors for using their automatic teller machines (ATMs). The banks responded by refusing to let

INSIDE BUSINESS 2–4

Price Ceilings and Price Floors around the Globe

Federal, state, and local authorities around the world are often persuaded to enact laws that restrict the prices that businesses can legally charge their customers. Many states in the United States have usury laws—price ceilings on interest rates—that restrict the rate that banks and other lenders can legally charge their customers. In 2005, Poland passed the Anti-Usury Act, which limited the consumer interest rate to quadruple the security rate of the National Bank of Poland; violators of the Act can face a fine or up to two years of imprisonment. Thailand allowed gasoline prices to be determined by market forces during the 1990s, but its Commerce Ministry imposed a price ceiling in an attempt to hold down the rapidly rising gasoline prices during the early 2000s.

All but five states in the United States have enacted minimum wage legislation—that is, a price floor on the hourly rate a business can legally pay its employees. These restrictions are in addition to the minimum wage set by the federal government, and as of 2019, state minimum wages were higher than the federal minimum wage in 29 states. The effect of these minimum wages is similar to that shown in Figure 2–12. However, since governments do not hire workers who are unable to find employment at the artificially high wage, the "surplus" of labor translates into unemployment. Every Canadian province and territory also have enacted minimum wage laws. In addition, Ontario, British Columbia, and Quebec have established floor prices (called "minimum retail prices") on beer to keep prices artificially high in an attempt to discourage alcohol consumption and to protect Canadian brewers from inexpensive U.S. brands.

SOURCES: "Oil Sales: Ceiling Set on Retail Margin," *The Nation*, June 15, 2002; "An Oil Shock of Our Own Making," *The Nation*, May 20, 2004; "Italian Usury Laws: Mercy Strain'd," *The Economist*, November 23, 2000; "Beer Price War Punishes Mom-and-Pop Shops," *The Gazette*, November 4, 2005; "EU Lawmakers Pass Credit Directive," *Krakow Post*, May 15, 2012; "State Minimum Wages | 2019 Minimum Wage by State," National Conference of State Legislatures, January 7, 2019.

nondepositors use their ATM machines. In other situations, such as ceilings on loan interest rates, banks may allocate money only to consumers who are relatively well-to-do.

The key point is that in the presence of a shortage created by a ceiling, managers must use some method other than price to allocate the goods. Depending on which method is used, some consumers will benefit and others will be worse off.

Price Floors

In contrast to the case of a price ceiling, sometimes the equilibrium competitive price may be considered too low for sellers. In these instances, individuals may lobby for the government to legislate a minimum legal price for a good. Such a price is called a **price floor**. Perhaps the best-known price floor is the minimum wage, the lowest legal wage that can be paid to workers.

price floor
The minimum legal price that can be charged in a market.

If the equilibrium price is above the price floor, the price floor has no effect on the market. But if the price floor is set above the competitive equilibrium level, such as P^f in Figure 2–12, there is an effect. Specifically, when the price floor is set at P^f, quantity supplied is Q^s and quantity demanded is Q^d. In this instance, more is produced than consumers are willing to purchase at that price, and a surplus develops. In the context of the labor market, there are more people looking for work than there are jobs to go around at that wage, and unemployment results. In the context of a product market, the surplus translates into unsold inventories. In a free market, price would fall to alleviate the unemployment or excess inventories, but the price floor prevents this mechanism from working. Buyers end up paying a higher price and purchasing fewer units.

When price floors are above the equilibrium price, there will be consumers with willingness-to-pay that is more than production costs but is less than the price floor. These consumers will be unable to purchase when the price floor is in place, which results in a loss of social welfare. The dollar value of the lost social welfare is given by the blue triangle in Figure 2–12. Similar to the case of a price ceiling, the lost social welfare is the vertical difference between the demand and supply curve for all units between Q^d and Q^e. The difference is that the constraint on units purchased for a price floor comes from constrained quantity demanded—in response to a price floor that is higher than P^e—rather than constrained quantity supplied—in response to a price ceiling that is lower than P^e. The area of the blue triangle in Figure 2–12 is deadweight loss.

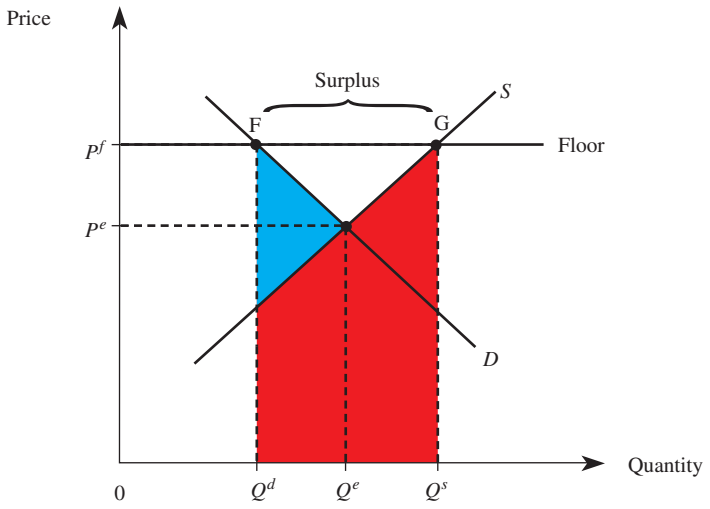


Figure 2–12
A Price Floor

When a price floor is a minimum wage, the deadweight loss that results is fully captured by the blue triangle in Figure 2–12. However, when the price floor applies to a product, the deadweight loss can be even greater. How much additional deadweight loss there is depends on what happens to the unsold inventories. One possibility is that the government purchases and discards the surplus. This is the case with price floors on many agricultural products, such as cheese. This type of price floor, where the government purchases the surplus, is called a *price support*. Revisiting Figure 2–12, the quantity of unsold products is given by the distance from G to F, and this surplus is the amount of product the government purchases at the price floor. The total cost to the government then is $P^f(Q^s - Q^d)$. If the government discards the surplus it purchases, this results in additional deadweight loss, as indicated by the red trapezoid. This additional deadweight loss is the cost of producing the product that was discarded. Again, if producers of cheese are receiving the price support, this additional deadweight loss is the cost of producing the cheese that the government purchased and discarded.

DEMONSTRATION PROBLEM 2–6

One of the members of the Senate Foreign Relations Committee has studied your analysis of Chinese privatization (Demonstration Problems 2–4 and 2–5) but is worried that the free-market price might be too low to enable producers to earn a fair rate of return on their investment. He asks you to explain what would happen if the Chinese government privatized the market but agreed to purchase (and discard) unsold units of the good at a floor price of $3.50. What do you tell the senator? Assume that the market demand and supply curves (in U.S. dollar equivalent prices) are still given by

$$Q^d = 10 - 2P \text{ and } Q^s = 2 + 2P$$

ANSWER:

Since the price floor is above the equilibrium price of $2, the floor results in a surplus. More specifically, when the price is $3.50, quantity demanded is

$$Q^d = 10 - 2(3.50) = 3$$

and quantity supplied is

$$Q^s = 2 + 2(3.50) = 9$$

Thus, there is a surplus of $9 - 3 = 6$ units. Consumers pay a higher price ($3.50), and producers have unsold inventories of 6 units. However, the Chinese government must purchase the amount consumers are unwilling to purchase at the price of $3.50. Therefore, the cost to the Chinese government of buying the surplus of 6 units is $\$3.50 \times 6 = \$21$.

Lastly, the deadweight loss is comprised of the two shaded regions illustrated in Figure 2–12. The first part, corresponding to the blue triangle, is $(1/2)(3.50 - 0.50)(6 - 3) = 4.5$. Note that the figure of 0.50 in this formula is the price at which producers will supply 3 units (which is the quantity demanded at the price floor). The second part of the deadweight loss, corresponding to the red trapezoid, is $\$21 - (1/2)(3.50 - 0.50)(9 - 3) = 12$. Here, we calculate the area of the trapezoid by first taking the area of the rectangle representing government expenditure ($21) and then subtracting the portion of that expenditure that adds to producer surplus (i.e., the area of the triangle below the price floor and above the supply curve for the surplus units). Thus, total deadweight loss is $\$4.50 + \$12.00 = \$16.50$.

COMPARATIVE STATICS

You now understand how equilibrium is determined in a competitive market and how government policies such as price ceilings and price floors affect the market. Next, we show how

managers can use supply and demand to analyze the impact of changes in market conditions on the competitive equilibrium price and quantity. The study of the movement from one equilibrium to another is known as *comparative static analysis*. Throughout this analysis, we assume that no legal restraints, such as price ceilings or floors, are in effect and that the price system is free to work to allocate goods among consumers.

Changes in Demand

Suppose that *The Wall Street Journal* reports that consumer incomes are expected to rise by about 2.5 percent over the next year, and the number of individuals over 25 years of age will reach an all-time high by the end of the year. We can use our supply and demand apparatus to examine how these changes in market conditions will affect car rental agencies like Avis, Hertz, and National. It seems reasonable to presume that rental cars are normal goods: A rise in consumer incomes will most likely increase the demand for rental cars. The increased number of consumers aged 25 and older will also increase demand since at many locations those who rent cars must be at least 25 years old.

We illustrate the ultimate effect of this increase in the demand for rental cars in Figure 2–13. The initial equilibrium in the market for rental cars is at point A, where demand curve D^0 intersects the market supply curve S. The changes reported in *The Wall Street Journal* suggest that the demand for rental cars will increase over the next year, from D^0 to some curve like D^1. The equilibrium moves to point B, where car rental companies rent more cars and charge a higher price than before the demand increase.

The reason for the rise in rental car prices is as follows: The growing number of consumers aged 25 or older, coupled with the rise in consumer incomes, increases the demand for rental cars. At the old price of $45 per day, there are only 100,000 cars available. This is fewer than the 108,000 cars that customers want to rent at that price. Car rental companies thus find it in their interest to raise their prices and to increase their quantity supplied of rental cars until ultimately enough cars are available at the new equilibrium price of $49 to exactly equal the quantity demanded at this higher price.

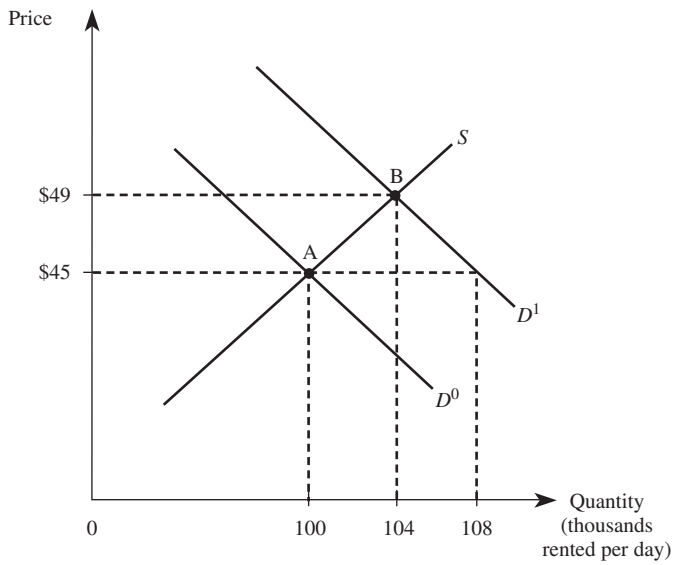


Figure 2–13
Effect of a Change in Demand for Rental Cars

DEMONSTRATION PROBLEM 2–7

The manager of a fleet of cars currently rents them out at the market price of $49 per day, with renters paying for their own gasoline and oil. In a front-page newspaper article, the manager learns that economists expect gasoline prices to rise dramatically over the next year due to increased tensions in the Middle East. What should she expect to happen to the price of the cars her company rents?

ANSWER:

Since gasoline and rental cars are complements, the increase in gasoline prices will decrease the demand for rental cars. To see the impact on the market price and quantity of rental cars, let D^1 in Figure 2–13 represent the initial demand for rental cars, so that the initial equilibrium is at point B. An increase in the price of gasoline will shift the demand curve for rental cars to the left (to D^0), resulting in a new equilibrium at point A. Thus, she should expect the price of rental cars to fall.

INSIDE BUSINESS 2–5

Globalization and the Supply of Automobiles

In today's global economy, the number of firms in the market critically depends on the entry and exit decisions of foreign firms. After a long period of weak exports to emerging markets, several Chinese automakers—including the country's biggest domestic brand, Geely Automotive Holdings—renewed efforts to expand overseas by targeting Europe and several major emerging markets.

Entry by Geely and other Chinese manufacturers into developed European automobile markets would shift the supply curve to the right. Other things equal, this will negatively impact the bottom lines of firms that currently sell in these markets: The increase in supply will reduce the equilibrium prices of automobiles and the profits of existing European automakers.

SOURCE: "Chinese Automakers Renew Drive to Go Global," *Automotive News Europe*, March 15, 2019.

Changes in Supply

We can also use our supply and demand framework to predict how changes in one or more supply shifters will affect the equilibrium price and quantity of goods or services. For instance, consider a bill before Congress that would require all employers, small and large alike, to provide health care to their workers. How would this bill affect the prices charged for goods at retailing outlets?

This health care mandate would increase the cost to retailers and other firms of hiring workers. Many retailers rely on semiskilled workers who earn relatively low wages, and the cost of providing health insurance to these workers is large relative to their annual wage earnings. While firms might lower wages to some extent to offset the mandated health insurance costs paid, the net effect would be to raise the total cost to the firm of hiring workers. These higher labor costs, in turn, would decrease the supply of retail goods. The final result of the legislation would be to increase the prices charged by retailing outlets and to reduce the quantity of goods sold there.

We can see this more clearly in Figure 2–14. The market is initially in equilibrium at point A, where demand curve D intersects the market supply curve, S^0. Higher input prices decrease supply from S^0 to S^1, and the new competitive equilibrium moves to point B. In this instance, the market price rises from P^0 to P^1, and the equilibrium quantity decreases from Q^0 to Q^1.

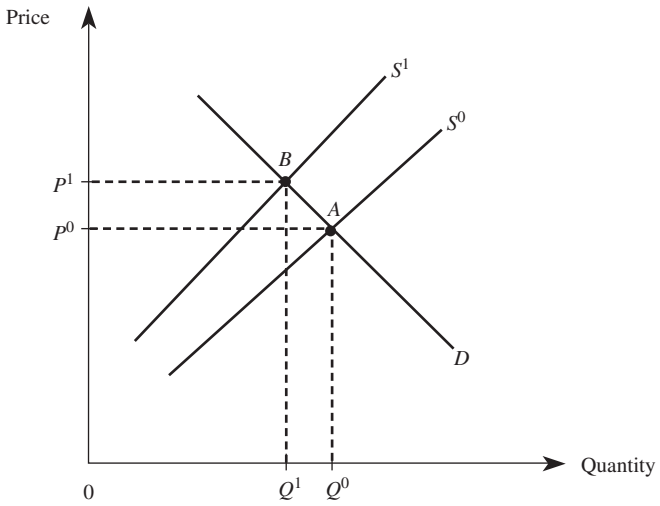


Figure 2–14
Effect of a Change in Supply

Simultaneous Shifts in Supply and Demand

Managers in both the private and public sectors sometimes encounter events that lead to simultaneous shifts in both demand and supply. A tragic example occurred at the end of the last century when an earthquake hit Kobe, Japan. The earthquake did considerable damage to Japan's sake wine industry, and the nation's supply of sake wine decreased as a result. Unfortunately, the stress caused by the earthquake led many to increase their demand for sake and other alcoholic beverages. We can use the tools of this chapter to examine how these simultaneous changes in supply and demand affected the equilibrium price and quantity of sake.

INSIDE BUSINESS 2–6

Using a Spreadsheet to Calculate Equilibrium in the Supply and Demand Model

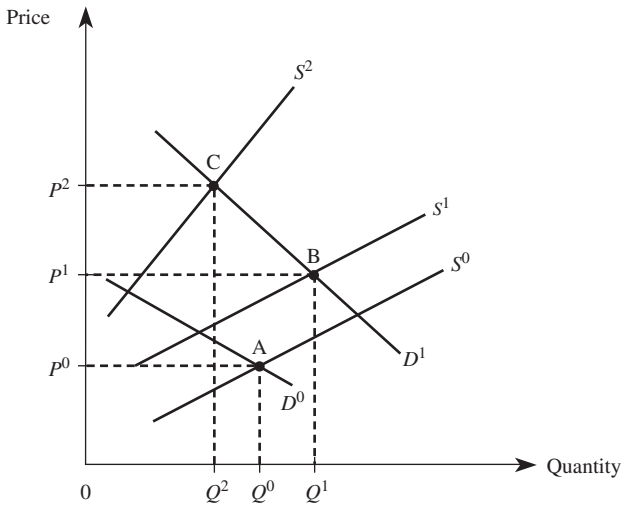
The website for the tenth edition, www.mhhe.com/baye10e, contains a file named *SupplyandDemandSolver.xls*. With a few clicks, you can use this tool to determine equilibrium in the linear supply and demand model under different scenarios by accessing different tabs in the file. You can also use this program to see how equilibrium prices and quantities change through "real-time" comparative static exercises.

Additionally, this tool permits you to calculate both producer and consumer surplus and investigate how their magnitudes change when demand and supply parameters change. You can also use it to examine the quantitative impact of price regulations, such as price ceilings and price floors, and the resulting lost social welfare (or deadweight loss) associated with prices that are regulated at levels above or below the equilibrium price.

It is important to stress that this tool is not a substitute for being able to perform these tasks without the aid of the tool. But the tool will help you visualize how different demand and supply parameters lead to different quantitative effects. Just as important, you can create a never-ending number of practice problems and solve them by hand, and then use this tool to check your answers. For Connect users, the algorithmic versions of the end-of-chapter problems will allow you to solve many versions of these types of equilibrium problems with immediate feedback on your performance.

Figure 2–15

A Simultaneous Increase in Demand and Decrease in Supply Raises the Equilibrium Price



In Figure 2–15, the market is initially in equilibrium at point A, where demand curve D^0 intersects market supply curve S^0. Since the earthquake led to a simultaneous decrease in supply and increase in demand for sake, suppose supply decreases from S^0 to S^1 and demand increases from D^0 to D^1. In this instance, a new competitive equilibrium occurs at point B; the price of sake increases from P^0 to P^1, and the quantity consumed increases from Q^0 to Q^1.

As the curves are drawn in Figure 2–15, the effect of the decrease in supply and increase in demand was to increase both the price and the quantity. But what if, instead of shifting from S^0 to S^1, the supply curve shifted much farther to the left to S^2 so that it intersected the new demand curve at point C instead of B? In this instance, price would still be higher than the initial equilibrium price, P^0. But the resulting quantity would be lower than the initial equilibrium (point C implies a lower quantity than point A). Thus, we have seen that when demand increases and supply decreases, the market price rises, but the market quantity may rise or fall depending on the relative magnitude of the shifts.

When using supply and demand analysis to predict the effects of simultaneous changes in demand and supply, you must be careful that the predictions are not artifacts of how far you have shifted the curves. As shown in Table 2–2, simultaneous changes in demand and supply generally lead to ambiguities regarding whether the equilibrium price or quantity will rise or fall. A valuable exercise is to draw various simultaneous shifts in supply and demand to verify the results summarized in Table 2–2.

Table 2–2

Equilibrium Price and Quantity: The Impact of Simultaneous Shifts in Demand and Supply

Nature of the Change	Increase in Demand	Decrease in Demand
Increase in Supply	Price: Ambiguous	Price: Decreases
	Quantity: Increases	Quantity: Ambiguous
Decrease in Supply	Price: Increases	Price: Ambiguous
	Quantity: Ambiguous	Quantity: Decreases

DEMONSTRATION PROBLEM 2–8

For a video walkthrough of this problem, visit www.mhhe.com/baye10e

Suppose you are the manager of a chain of computer stores. For obvious reasons you have been closely following developments in the computer industry, and you have just learned that Congress has passed a two-pronged program designed to further enhance the U.S. computer industry's position in the global economy. The legislation provides increased funding for computer education in primary and secondary schools, as well as tax breaks for firms that develop computer software. As a result of this legislation, what do you predict will happen to the equilibrium price and quantity of software?

ANSWER:

The equilibrium quantity certainly will increase, but the market price may rise, remain the same, or fall, depending on the relative changes in demand and supply. To see this, note that the increased funding for computer education at primary and secondary schools will lead to an increase in the demand for computer software since it is a normal good. The reduction in taxes on software manufacturers will lead to an increase in the supply of software. You should draw a figure to verify that if the rightward shift in supply is small compared to the rightward shift in demand, both the equilibrium price and quantity will increase. If supply increases by the same amount as demand, there will be no change in the price, but the equilibrium quantity will rise. Finally, if supply increases more than the increase in demand, the resulting equilibrium will entail a lower price and a greater quantity. In all cases, the equilibrium quantity increases. But the effect on the market price depends on the relative magnitudes of the increases in demand and supply.

ANSWERING THE headLINE

Now that we have developed a formal apparatus for understanding how markets work, we will return to the story that opened this chapter.

Sam recognized that a cut in chip production will ultimately lead to higher chip prices. Since chips are a key input in the production of PCs, an increase in the price of chips would in turn lead to a decrease in the market supply of PCs, as indicated by the change in supply from S^0 to S^1 in Figure 2–16. Notice that total quantity of PCs sold in the market falls as the equilibrium moves from point A to point B. In light of this anticipated decline in PC sales, Sam and Jane discussed the wisdom of going ahead with their plan to double PC Solutions' workforce at this time.

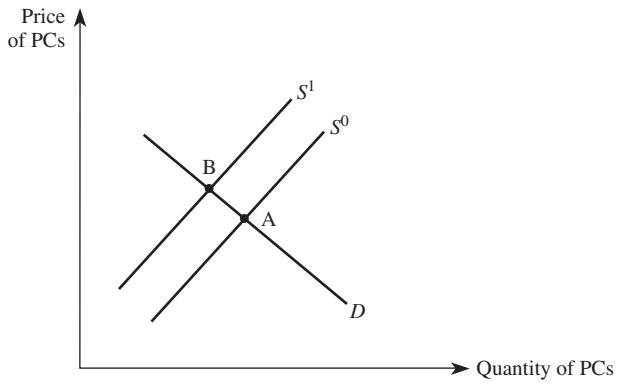


Figure 2–16
Rising Chip Prices Decrease the Supply of PCs

SUMMARY

This chapter provided an overview of supply and demand and the interaction of these forces. We covered applications of demand, supply, price ceilings, price floors, and comparative statics. By reading this chapter and working through the demonstration problems presented, you should have a basic understanding of how to analyze the workings of a competitive market.

The model of supply and demand is just a starting point for this text. Throughout the remainder of the text, we assume you have a thorough understanding of the concepts presented in this chapter. In the next chapter, we will present the concepts of elasticity and show how to use them in making managerial decisions.

KEY TERMS AND CONCEPTS

ad valorem tax
change in demand
change in quantity demanded
change in quantity supplied
change in supply
comparative static analysis
complements
consumer expectations
consumer surplus
decrease in demand
decrease in supply
demand
demand function
demand shifters
equilibrium price
equilibrium quantity
excise tax
full economic price
increase in demand
increase in supply
inferior good
informative advertising
inverse demand function
inverse supply function
law of demand
law of supply
linear demand function
linear supply function
market demand curve
market supply curve
nonpecuniary price
normal good
persuasive advertising
price ceiling
price floor
price support
producer expectations
producer surplus
shortage
stockpiling
substitutes
supply
supply function
supply shifters
surplus

CONCEPTUAL AND COMPUTATIONAL QUESTIONS



1. The X-Corporation produces a good (called *X*) that is a normal good. Its competitor, Y-Corp., makes a substitute good that it markets under the name *Y*. Good *Y* is an inferior good. *(LO1)*
   a. How will the demand for good *X* change if consumer incomes decrease?
   b. How will the demand for good *Y* change if consumer incomes increase?
   c. How will the demand for good *X* change if the price of good *Y* increases?
   d. Is good *Y* a lower-quality product than good *X?* Explain.
2. Good *X* is produced in a competitive market using input A. Explain what would happen to the supply of good *X* in each of the following situations: *(LO1, LO4)*
   a. The price of input *A* decreases.
   b. An excise tax of $3 is imposed on good *X*.
   c. An ad valorem tax of 7 percent is imposed on good *X*.
   d. A technological change reduces the cost of producing additional units of good *X*.
3. Suppose the supply function for product *X* is given by $Q_x^s = -30 + 2P_x - 4P_z$. *(LO1)*
   a. How much of product *X* is produced when $P_x = \$600$ and $P_z = \$60$?
   b. How much of product *X* is produced when $P_x = \$80$ and $P_z = \$60$?
   c. Suppose $P_z = \$60$. Determine the supply function and inverse supply function for good *X*. Graph the inverse supply function.
4. The demand for good *X* is given by

$$Q_x^d = 6{,}000 - \frac{1}{2}P_x - P_y + 9P_z + \frac{1}{10}M$$

Research shows that the prices of related goods are given by $P_y = \$6{,}500$ and $P_z = \$100$, while the average income of individuals consuming this product is $M = \$70{,}000$. *(LO1)*

a. Indicate whether goods *Y* and *Z* are substitutes or complements for good *X*.

b. Is *X* an inferior or a normal good?

c. How many units of good *X* will be purchased when $P_x = \$5{,}230$?

d. Determine the demand function and inverse demand function for good *X*. Graph the demand curve for good *X*.

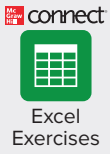
5. The demand curve for product *X* is given by $Q_x^d = 500 - 4P_x$. *(LO2)*

a. Find the inverse demand curve.

b. How much consumer surplus do consumers receive when $P_x = \$50$?

c. How much consumer surplus do consumers receive when $P_x = \$35$?

d. In general, what happens to the level of consumer surplus as the price of a good falls?



6. Suppose demand and supply are given by $Q^d = 60 - P$ and $Q^s = P - 20$. *(LO3, LO4)*

a. What are the equilibrium quantity and price in this market?

b. Determine the quantity demanded, the quantity supplied, and the magnitude of the surplus if a price floor of \$50 is imposed in this market.

c. Determine the quantity demanded, the quantity supplied, and the magnitude of the shortage if a price ceiling of \$32 is imposed in this market. Also, determine the full economic price paid by consumers.

7. Suppose demand and supply are given by: *(LO3, LO4)*

$$Q_x^d = 14 - \frac{1}{2}P_x \text{ and } Q_x^s = \frac{1}{4}P_x - 1$$

a. Determine the equilibrium price and quantity. Show the equilibrium graphically.

b. Suppose a \$12 excise tax is imposed on the good. Determine the new equilibrium price and quantity.

c. How much tax revenue does the government earn with the \$12 tax?

8. Use the accompanying graph to answer these questions. *(LO2, LO3, LO4)*

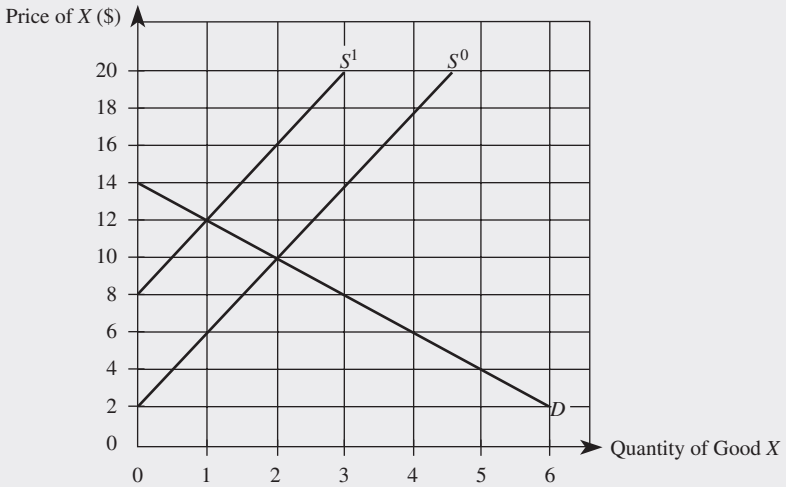
a. Suppose demand is *D* and supply is S^0. If a price ceiling of \$6 is imposed, what are the resulting shortage and full economic price?

b. Suppose demand is *D* and supply is S^0. If a price support of \$12 is imposed, what is the resulting surplus? What is the cost to the government of purchasing any and all unsold units?

c. Suppose demand is *D* and supply is S^0 so that the equilibrium price is \$10. If an excise tax of \$6 is imposed on this product, what happens to the equilibrium price paid by consumers? The price received by producers? The number of units sold?

d. Calculate the level of consumer and producer surplus when demand and supply are given by *D* and S^0 respectively.

e. Suppose demand is *D* and supply is S^0. Would a price ceiling of \$2 benefit any consumers? Explain.



9. The supply curve for product X is given by $Q_x^s = -380 + 20P_x$. *(LO2)*
   a. Find the inverse supply curve.
   b. How much surplus do producers receive when $Q_x = 460$? When $Q_x = 1{,}100$?
10. Consider a market where supply and demand are given by $Q_x^s = -14 + P_x$ and $Q_x^d = 85 - 2P_x$. Suppose the government imposes a price floor of $38 and agrees to purchase and discard any and all units consumers do not buy at the floor price of $38 per unit. *(LO3, LO4, LO5)*
    a. Determine the cost to the government of buying firms' unsold units.
    b. Compute the lost social welfare (deadweight loss) that stems from the $38 price floor.

PROBLEMS AND APPLICATIONS



11. You are the manager of a midsized company that assembles personal computers. You purchase most components—such as random access memory (RAM)—in a competitive market. Based on your marketing research, consumers earning over $80,000 purchase 1.5 times more RAM than consumers with lower incomes. One morning, you pick up a copy of *The Wall Street Journal* and read an article indicating that input components for RAM are expected to rise in price, forcing manufacturers to produce RAM at a higher unit cost. Based on this information, what can you expect to happen to the price you pay for random access memory? Would your answer change if, in addition to this change in RAM input prices, the article indicated that consumer incomes are expected to fall over the next two years as the economy dips into recession? Explain. *(LO1, LO3, LO5)*
12. You are the manager of a firm that produces and markets a generic type of soft drink in a competitive market. In addition to the large number of generic products in your market, you also compete against major brands such as Coca-Cola and Pepsi. Suppose that, due to the successful lobbying efforts of sugar producers in the United States, Congress is going to levy a $0.50 per pound tariff on all imported raw sugar—the primary input for your product. In addition, Coke and Pepsi plan to launch an aggressive advertising campaign designed to persuade consumers that their branded products are superior to generic soft drinks. How will these events impact the equilibrium price and quantity of generic soft drinks? *(LO1, LO3, LO5)*
13. Some have argued that higher cigarette prices do not deter smoking. While there are many arguments both for and against this view, some find the following argument to be the most persuasive of all: "The laws of supply and demand indicate that higher prices are ineffective in reducing smoking. In particular, higher cigarette prices will reduce the demand for cigarettes. This reduction in demand will push the equilibrium price back down to its original level. Since the equilibrium price will remain unchanged, smokers will consume the same number of cigarettes." Do you agree or disagree with this view? Explain. *(LO1, LO3, LO5)*
14. You are the manager of an organization in America that distributes blood to hospitals in all 50 states and the District of Columbia. A recent report indicates that nearly 50 Americans contract HIV each year through blood transfusions. Although every pint of blood donated in the United States undergoes a battery of nine different tests, existing screening methods can detect only the antibodies produced by the body's immune system—not foreign agents in the blood. Since it takes weeks or even months for these antibodies to build up in the blood, newly infected HIV donors can pass along the virus through blood that has passed existing screening tests. Happily, researchers have developed a series of new tests aimed at detecting and removing infections from donated blood before it is used in transfusions. The obvious benefit of these tests is the reduced incidence of infection through blood transfusions. The report indicates that the current price of decontaminated blood is $60 per pint. However, if the new screening methods

are adopted, the demand and supply for decontaminated blood will change to $Q^d = 210 - 1.5P$ and $Q^s = 2.5P - 150$. What price do you expect to prevail if the new screening methods are adopted? How many units of blood will be used in the United States? What is the level of consumer and producer surplus? Illustrate your findings in a graph. *(LO2, LO3)*

15. As a result of increased tensions in the Middle East, oil production is down by 1.21 million barrels per day—a 5 percent reduction in the world's supply of crude oil. Explain the likely impact of this event on the market for gasoline and the market for small cars. *(LO1, LO3, LO5)*
16. You are an assistant to a senator who chairs an ad hoc committee on reforming taxes on telecommunication services. Based on your research, AT&T has spent over $15 million on related paperwork and compliance costs. Moreover, depending on the locale, telecom taxes can amount to as much as 25 percent of a consumer's phone bill. These high tax rates on telecom services have become quite controversial, due to the fact that the deregulation of the telecom industry has led to a highly competitive market. Your best estimates indicate that, based on current tax rates, the monthly market demand for telecommunication services is given by $Q^d = 350 - 4P$ and the market supply (including taxes) is $Q^s = 4P - 130$ (both in millions), where P is the monthly price of telecommunication services. The senator is considering tax reform that would dramatically cut tax rates, leading to a supply function under the new tax policy of $Q^s = 4.3P - 130$. How much money per unit would a typical consumer save each month as a result of the proposed legislation? *(LO2, LO3)*
17. G.R. Dry Foods Distributors specializes in the wholesale distribution of dry goods, such as rice and dry beans. The firm's manager is concerned about an article he read in this morning's *Wall Street Journal* indicating that the incomes of individuals in the lowest income bracket are expected to increase by 10 percent over the next year. While the manager is pleased to see this group of individuals doing well, he is concerned about the impact this will have on G.R. Dry Foods. What do you think is likely to happen to the price of the products G.R. Dry Foods sells? Why? *(LO1, LO3, LO5)*
18. From California to New York, legislative bodies across the United States are considering eliminating or reducing the surcharges that banks impose on noncustomers, who make $10 million in withdrawals from other banks' ATM machines. On average, noncustomers earn a wage of $22 per hour and pay ATM fees of $3.50 per transaction. It is estimated that banks would be willing to maintain services for 4 million transactions at $1.00 per transaction, while noncustomers would attempt to conduct 20 million transactions at that price. Estimates suggest that, for every 1 million gap between the desired and available transactions, a typical consumer will have to spend an extra minute traveling to another machine to withdraw cash. Based on this information, use a graph to carefully illustrate the impact of legislation that would place a $1.00 cap on the fees banks can charge for noncustomer transactions. *(LO3, LO4)*



19. Rapel Valley in Chile is renowned for its ability to produce high-quality wine at a fraction of the cost of many other vineyards around the world. Rapel Valley produces over 20 million bottles of wine annually, of which 5 million are exported to the United States. Each bottle entering the United States is subjected to a $0.50 per bottle excise tax, which generates about $2.5 million in tax revenues. Strong La Niña weather patterns have caused unusually cold temperatures, devastating many of the wine producers in that region of Chile. How will La Niña affect the price of Chilean wine? Assuming La Niña does not impact the California wine-producing region, how will La Niña impact the market for Californian wines? *(LO1, LO3, LO5)*
20. Viking InterWorks is one of many manufacturers that supply memory products to original equipment manufacturers (OEMs) of desktop systems. The CEO recently read an article in a trade publication that reported the projected demand for desktop systems to

be $Q^d_{desktop} = 1{,}600 - 2P_{desktop} + .6M$ (in millions of units), where $P_{desktop}$ is the price of a desktop system and M is consumer income. The same article reported that the incomes of the desktop systems' primary consumer demographic would increase 4.2 percent this year to $61,300 and that the selling price of a desktop would decrease to $980, both of which the CEO viewed favorably for Viking. In a related article, the CEO read that the upcoming year's projected demand for 32 GB desktop memory modules is $Q^d_{memory} = 11{,}200 - 100P_{memory} - 2P_{desktop}$ (in thousands of units), where P_{memory} is the market price for a 32 GB memory module and $P_{desktop}$ is the selling price of a desktop system. The report also indicated that five new, small start-ups entered the 32 GB memory module market, bringing the total number of competitors to 100 firms. Furthermore, suppose that Viking's CEO commissioned an industrywide study to examine the industry capacity for 32 GB memory modules. The results indicate that when the industry is operating at maximum efficiency, this competitive industry supplies modules according to the following function: $Q^S_{memory} = 1{,}000 + 25P_{memory} + N$ (in thousands), where P_{memory} is the price of a 32 GB memory module and N is the number of memory module manufacturers in the market. Viking's CEO provides you, the production manager, with this information and requests a report containing the market price for memory modules and the number of units to manufacture in the upcoming year based on the assumption that all firms producing 32 GB modules supply an equal share to the market. How would your report change if the price of desktops were $1,080? What does this indicate about the relationship between memory modules and desktop systems? *(LO1, LO3)*

21. Seventy-two percent of the members of the United Food and Commercial Workers Local 655 voted to strike against Stop 'n Shop in the St. Louis area. In fear of similar union responses, two of Stop 'n Shop's larger rivals in the St. Louis market—Dierberg's and Schnuck's—decided to lock out their union employees. The actions of these supermarkets, not surprisingly, caused Local 655 union members to picket and boycott each of the supermarkets' locations. While the manager of Mid Towne IGA—one of many smaller competing grocers—viewed the strike as unfortunate for both sides, he was quick to point out that the strike provided an opportunity for his store to increase market share. To take advantage of the strike, the manager of Mid Towne IGA increased newspaper advertising by pointing out that Mid Towne employed Local 655 union members and that it operated under a different contract than "other" grocers in the area. Use a graph to describe the expected impact of advertising on Mid Towne IGA (how the equilibrium price and quantity change). Identify the type of advertising in which Mid Towne IGA engaged. Do you believe the impact of advertising will be permanent? Explain. *(LO1, LO3, LO5)*

22. Florida, like several other states, has passed a law that prohibits "price gouging" immediately before, during, or after the declaration of a state of emergency. Price gouging is defined as "selling necessary commodities such as food, gas, ice, oil, and lumber at a price that grossly exceeds the average selling price for the 30 days prior to the emergency." Many consumers attempt to stock up on emergency supplies, such as bottled water, immediately before and after a hurricane or other natural disaster hits an area. Also, many supply shipments to retailers are interrupted during a natural disaster. Assuming that the law is strictly enforced, what are the economic effects of the price gouging statute? Explain carefully. *(LO1, LO3, LO5)*

23. In a recent speech, the governor of your state announced: "One of the biggest causes of juvenile delinquency in this state is the high rate of unemployment among 16 to 19 year olds. The low wages offered by employers in the state have given fewer teenagers the incentive to find summer employment. Instead of working all summer, the way we used to, today's teenagers slack off and cause trouble. To address this problem, I propose to raise the state's minimum wage by $1.50 per hour. This will give teens the proper incentive to go out and find meaningful employment when they are not in school." Evaluate the governor's plan to reduce juvenile delinquency. *(LO3, LO4, LO5)*

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3 Quantitative Demand Analysis

LEARNING OBJECTIVES

After completing this chapter, you will be able to:

- **LO1** Apply various elasticities of demand as a quantitative tool to forecast changes in revenues, prices, and/or units sold.
- **LO2** Illustrate the relationship between the elasticity of demand and total revenues.
- **LO3** Discuss three factors that influence whether the demand for a given product is relatively elastic or inelastic.
- **LO4** Explain the relationship between marginal revenue and the own price elasticity of demand.
- **LO5** Show how to determine elasticities from linear and log-linear demand functions.
- **LO6** Explain how regression analysis may be used to estimate demand functions and how to interpret and use the output of a regression.

headLINE

Walmart Hoping for Another Big Holiday Showing

In October of every year, Walmart's national sales director knows the calls are coming for his holiday forecasts. This year, the firm's holiday performance is especially important, after disappointing sales to date.

While the director has no problem expressing his hope for strong holiday sales, investors and reporters—as well as local managers—are seeking a prediction that has evidence to back it. Consequently, he turns to his analytics department, which has been collecting wide swaths of data for Walmart over many years across the 381 metropolitan statistical areas (MSAs) in the United States. Some variables of particular interest include holiday sales, average prices, and consumer confidence. Using these data, the analysts arrive at the following equation, designed to predict HolidaySales (measured as revenues):

$$\ln(\textit{HolidaySales}) = 25.8 - 0.8 \ln(\textit{Price}) + 0.9 \ln(\textit{Consumer Confidence})$$

The director notes that most MSAs saw a decrease in consumer confidence of approximately 4 percent. Based on this information, does the evidence support optimism for holiday sales if prices remain unchanged? Could a change in price help to bolster revenues?

INTRODUCTION

In Chapter 2 we saw that the demand for a firm's product (Q_x^d) depends on its price (P_x), the prices of substitutes or complements (P_y), consumer incomes (M), and other variables (H) such as advertising, the size of the population, or consumer expectations:

$$Q_x^d = f(P_x, P_y, M, H)$$

Until now, our analysis of the impact of changes in prices and income on consumer demand has been qualitative rather than quantitative; that is, we focused on the "big picture" to identify only the directions of the changes and said little about their magnitude.

While seeing the big picture is an important first step to sound managerial decisions, the successful manager is also adept at providing "detailed" quantitative answers to questions like these:

- How much do we have to cut our price to achieve 3.2 percent sales growth?
- If we cut prices by 6.5 percent, how many more units will we sell? Do we have sufficient inventories on hand to accommodate this increase in sales? If not, do we have enough personnel to increase production? How much will our revenues and cash flows change as a result of this price cut?
- How much will our sales change if rivals cut their prices by 2 percent or a recession hits and household incomes decline by 2.5 percent?

In this chapter, we show how a manager can use elasticities of demand as a quantitative forecasting tool to answer these and hundreds of other questions asked each day by managers in charge of pricing decisions; inventory management; yield (revenue) management; production decisions; strategic (competitor) analysis; and other operations, including human resource management. Quantitative measures such as elasticity don't come from nowhere, so at various points in the chapter, we discuss how a manager can use data-driven analysis via regression to arrive at relevant elasticity measures.

THE ELASTICITY CONCEPT

Suppose some variable, such as the price of a product, increased by 10 percent. What would happen to the quantity demanded of the good? Based on the analysis in Chapter 2 and the law of demand, we know that the quantity demanded would fall. It would be useful for a manager to know whether the quantity demanded would fall by 5 percent, 10 percent, or some other amount.

The primary tool used to determine the magnitude of such a change is elasticity analysis. Indeed, the most important concept introduced in this chapter is elasticity. Elasticity is a very general concept. An **elasticity** measures the responsiveness of one variable to changes in another variable. For example, the elasticity of your grade with respect to studying, denoted $E_{G,S}$, is the percentage change in your grade ($\%\Delta G$) that will result from a given percentage change in the time you spend studying ($\%\Delta S$). In other words,

$$E_{G,S} = \frac{\%\Delta G}{\%\Delta S}$$

elasticity
A measure of the responsiveness of one variable to changes in another variable; the percentage change in one variable that arises due to a given percentage change in another variable.

Since $\%\Delta G = \Delta G/G$ and $\%\Delta S = \Delta S/S$, we may also write this as $E_{G,S} = (\Delta G/\Delta S) \times (S/G)$. Notice that $\Delta G/\Delta S$ represents the slope of the functional relation between G and S; it tells the change in G that results from a given change in S. By multiplying this by S/G, we

convert each of these changes into percentages, which means that the elasticity measure does not depend on the units in which we measure the variables G and S.

A CALCULUS ALTERNATIVE

If the variable G depends on S according to the functional relationship $G = f(S)$, the elasticity of G with respect to S may be found using calculus:

$$E_{G,S} = \frac{dG}{dS}\frac{S}{G}$$

Two aspects of an elasticity are important: (1) whether it is positive or negative and (2) whether it is greater than 1 or less than 1 in absolute value. The sign of the elasticity determines the relationship between G and S. If the elasticity is positive, an increase in S leads to an increase in G. If the elasticity is negative, an increase in S leads to a decrease in G.

Whether the absolute value of the elasticity is greater or less than 1 determines how responsive G is to changes in S. If the absolute value of the elasticity is greater than 1, the numerator is larger than the denominator in the elasticity formula, and we know that a small percentage change in S will lead to a relatively large percentage change in G. If the absolute value of the elasticity is less than 1, the numerator is smaller than the denominator in the elasticity formula. In this instance, a given percentage change in S will lead to a relatively small percentage change in G. It is useful to keep these points in mind as we define some specific elasticities.

OWN PRICE ELASTICITY OF DEMAND

own price elasticity of demand
A measure of the responsiveness of the quantity demanded of a good to a change in the price of that good; the percentage change in quantity demanded divided by the percentage change in the price of the good.

We begin with a very important elasticity concept: the **own price elasticity of demand**, which measures the responsiveness of quantity demanded to a change in price. Later in this section we will see that managers can use this measure to determine the quantitative impact of price hikes or cuts on the firm's sales and revenues. The own price elasticity of demand for good X, denoted E_{Q_x, P_x}, is defined as

$$E_{Q_x, P_x} = \frac{\%\Delta Q_x^d}{\%\Delta P_x}$$

If the own price elasticity of demand for a product is -2, for instance, we know that a 10 percent increase in the product's price leads to a 20 percent decline in the quantity demanded of the good since $-20\%/10\% = -2$.

A CALCULS ALTERNATIVE

The own price elasticity of demand for a good with a demand function $Q_x^d = f(P_x, P_y, M, H)$ may be found using calculus:

$$E_{Q_x, P_x} = \frac{\partial Q_x^d}{\partial P_x}\frac{P_x}{Q_x}$$

Recall that two aspects of an elasticity are important: (1) its sign and (2) whether it is greater or less than 1 in absolute value. By the law of demand, there is an inverse relation between price and quantity demanded; thus, the own price elasticity of demand is a negative number. The absolute value of the own price elasticity of demand can be greater or less than 1, depending on several factors that we will discuss next. However, it is useful to introduce some terminology to aid in this discussion.

First, demand is said to be **elastic** if the absolute value of the own price elasticity is greater than 1:

$$|E_{Q_x, P_x}| > 1$$

Second, demand is said to be **inelastic** if the absolute value of the own price elasticity is less than 1:

$$|E_{Q_x, P_x}| < 1$$

Finally, demand is said to be **unitary elastic** if the absolute value of the own price elasticity is equal to 1:

$$|E_{Q_x, P_x}| = 1$$

Conceptually, the quantity consumed of a good is relatively responsive to a change in the price of the good when demand is elastic and relatively unresponsive to changes in price when demand is inelastic. This means that price increases will reduce consumption very little when demand is inelastic. However, when demand is elastic, a price increase will reduce consumption considerably.

elastic demand
Demand is elastic if the absolute value of the own price elasticity is greater than 1.

inelastic demand
Demand is inelastic if the absolute value of the own price elasticity is less than 1.

unitary elastic demand
Demand is unitary elastic if the absolute value of the own price elasticity is equal to 1.

Elasticity and Total Revenue

Table 3–1 shows the hypothetical prices and quantities demanded of software, the own price elasticity, and the total revenue ($TR = P_x Q_x$) for the linear demand function, $Q_x^d = 80 - 2P_x$. Notice that the absolute value of the own price elasticity gets larger as price increases. In particular, the slope of this linear demand function is constant ($\Delta Q_x^d / \Delta P_x = -2$), which implies that $E_{Q_x, P_x} = (\Delta Q_x^d / \Delta P_x)\,(P_x / Q_x)$ increases in absolute value as P_x increases. Thus, the own price elasticity of demand varies along a linear demand curve.

When the absolute value of the own price elasticity is less than 1 (points A through D in Table 3–1), an increase in price increases total revenue. For example, an increase in price from \$5 to \$10 per unit increases total revenue by \$250. Notice that for these two prices, the corresponding elasticity of demand is less than 1 in absolute value.

When the absolute value of the own price elasticity is greater than 1 (points F through I in Table 3–1), an increase in price leads to a reduction in total revenue. For example,

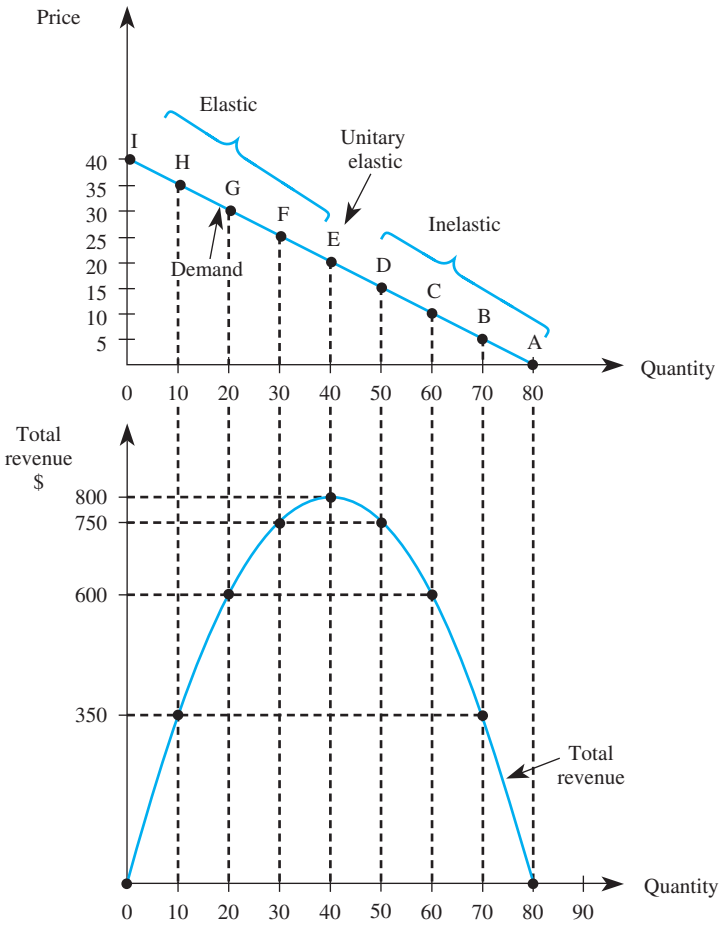
Table 3–1

Total Revenue and Elasticity ($Q_x^d = 80 - 2P_x$)

	Price of Software (P_x)	Quantity of Software Sold (Q_x)	Own Price Elasticity (E_{Q_x, P_x})	Total Revenue ($P_x Q_x$)
A	\$ 0	80	0.00	\$ 0
B	5	70	−0.14	350
C	10	60	−0.33	600
D	15	50	−0.60	750
E	20	40	−1.00	800
F	25	30	−1.67	750
G	30	20	−3.00	600
H	35	10	−7.00	350
I	40	0	−∞	0

Figure 3–1

Demand, Elasticity, and Total Revenue



when the price increases from $25 (where the own price elasticity is −1.67) to $30 (where the own price elasticity is −3), we see that total revenue decreases by $150. The price–quantity combination that maximizes total revenue in Table 3–1 is at point E, where the own price elasticity equals −1.

The demand curve corresponding to the data in Table 3–1 is presented in the top panel of Figure 3–1, while the total revenue associated with each price–quantity combination on the demand curve is graphed in the lower panel. As we move up the demand curve from point A to point I, demand becomes increasingly elastic. At point E, where demand is unitary elastic, total revenue is maximized. At points to the northwest of E, demand is elastic and total revenue decreases as price increases. At points to the southeast of E, demand is inelastic and total revenue increases when price increases. This relationship among the changes in price, elasticity, and total revenue is called the *total revenue test*.

PRINCIPLE

Total Revenue Test

If demand is elastic, an increase (decrease) in price will lead to a decrease (increase) in total revenue. If demand is inelastic, an increase (decrease) in price will lead to an increase (decrease) in total revenue. Finally, total revenue is maximized at the point where demand is unitary elastic.

Businesses around the globe use the total revenue test to help manage cash flows. For instance, using data-driven analysis, LiveNation recently discovered that, similar to findings for the travel industry, demand for aisle seats at their concerts notably differs from demand for nearby seats that are further into the row. By recognizing demand for these seats was inelastic at current prices, it was able to substantially increase revenue by increasing the price for these "premium" seats.

To see why, suppose analysts for a concert ticket agency estimate that the own price elasticity of demand for aisle concert seats is −0.3. If the agency raises prices by 5 percent, will ticket sales fall by a small enough amount so that revenues will increase? We can answer this question by setting $-0.3 = E_{Q_x, P_x}$ and $5 = \%\Delta P_x$ in the formula for the own price elasticity of demand:

$$-0.3 = \frac{\%\Delta Q_x^d}{5}$$

Solving this equation for $\%\Delta Q_x^d$ yields $\%\Delta Q_x^d = -1.5$. In other words, the quantity of aisle seats sold will fall by 1.5 percent if prices are increased by 5 percent. Since the percentage decrease in quantity demanded is less than the percentage increase in prices ($|E_{Q_x, P_x}| < 1$), the price hike will raise the firm's sales revenues. Expressed differently, since demand is inelastic, a price increase results in a less than proportional decrease in sales and thus increases the firm's total revenues.

In extreme cases the demand for a good may be perfectly elastic or perfectly inelastic. Demand is **perfectly elastic** if the own price elasticity of demand is infinite in absolute value. Demand is **perfectly inelastic** if the own price elasticity of demand is zero.

perfectly elastic demand
Demand is perfectly elastic if the own price elasticity is infinite in absolute value. In this case the demand curve is horizontal.

perfectly inelastic demand
Demand is perfectly inelastic if the own price elasticity is zero. In this case the demand curve is vertical.

When demand is perfectly elastic, a manager who raises price even slightly will find that none of the good is purchased. In this instance the demand curve is horizontal, as illustrated in Figure 3–2(a). Producers of generic (unbranded) products, such as aspirin, may face a demand curve that is perfectly elastic; a small increase in price may induce their customers to stop buying their product, in favor of a competing generic version of the product. In contrast, when demand is perfectly inelastic, consumers do not respond at all to changes in price. In this case, the demand curve is vertical, as shown in Figure 3–2(b). Many perceive products and services in the health care industry (such as life-saving drugs) to have demand curves that are perfectly inelastic. While many have highly inelastic demand curves, they generally are not perfectly inelastic (see Inside Business 3–1 for a more thorough discussion).

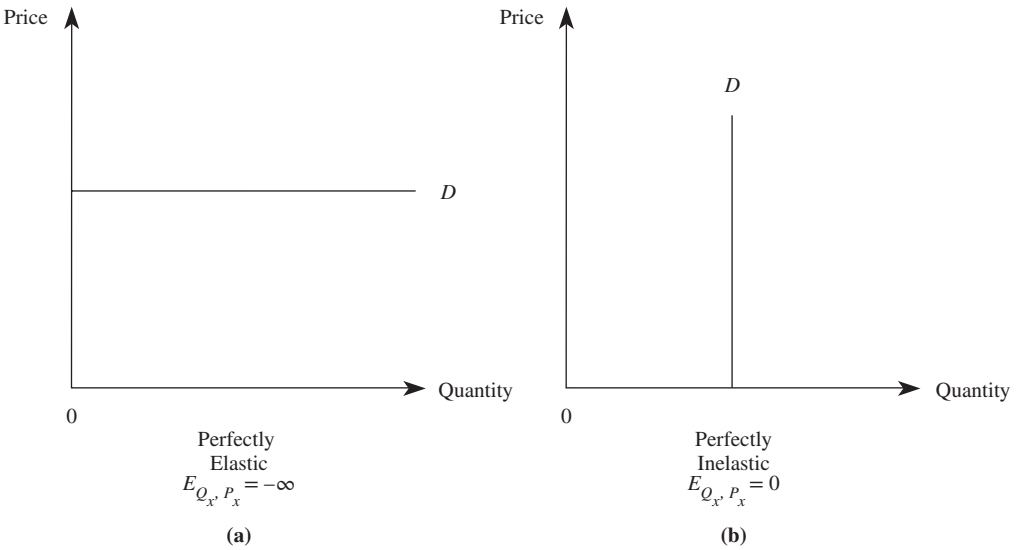


Figure 3–2

Perfectly Elastic and Inelastic Demand

INSIDE BUSINESS 3–1

Inelastic Demand for Prescription Drugs

Many people perceive the demand for prescription drugs and other pharmaceutical products to be perfectly inelastic. After all, a patient needing an expensive cardiovascular drug might die in the absence of treatment. Moreover, in many instances the cost of medication is paid by an insurance company and not by the patient. These two factors do tend to make the demand for many pharmaceutical products relatively inelastic. However, since surgery and lifestyle changes are substitutes for many life-saving drugs, economic theory predicts that the demand for such products is unlikely to be perfectly inelastic.

The accompanying table summarizes results from a recent study that confirms this prediction: The demand for pharmaceutical products is inelastic, but not perfectly so. For instance, the own price elasticity of demand for statins is −0.4, while the own price elasticity of demand for beta-blockers is more inelastic at −0.1. Consequently, a 10 percent increase in the price of statins reduces their use by 4 percent. A 10 percent increase in the price of beta-blockers results in only a 1 percent reduction in quantity demanded.

The own price elasticities of demand reported here are based on the industry demand for each type of drug. The demand for particular brands within each industry is even more responsive to price changes.

Type of Drug	Own Price Elasticity
Statins	−0.4
Beta-blockers	−0.1
Proton-pump inhibitors	−0.7
Biguanides	−0.2

SOURCE: K. Yeung, A. Basu, R. Hansen, and S. Sullivan, "Price Elasticities of Pharmaceuticals in a Value-Based-Formulary Setting," NBER working paper (June 2016).

Usually, demand is neither perfectly elastic nor perfectly inelastic. In these instances knowledge of the particular value of an elasticity can be useful for a manager. Large firms, the government, and universities commonly hire economists or statisticians to estimate the demand for products. The manager's job is to know how to interpret and use such estimates, as we discuss at various points in this chapter and throughout the book.

Factors Affecting the Own Price Elasticity

Now that you understand what the own price elasticity is and how it can be used to assess the impact of price changes on sales volume and revenues, we will discuss three factors that affect the magnitude of the own price elasticity of a good: available substitutes, time, and expenditure share.

Available Substitutes

One key determinant of the elasticity of demand for a good is the number of close substitutes for that good. Intuitively, the more substitutes available for the good, the more elastic the demand for it. In these circumstances, a price increase leads consumers to substitute toward another product, thus reducing considerably the quantity demanded of the good. When there are few close substitutes for a good, demand tends to be relatively inelastic. This is because consumers cannot readily switch to a close substitute when the price increases.

A key implication of the effect of the number of close substitutes on the elasticity of demand is that the demand for broadly defined commodities tends to be more inelastic than the demand for specific commodities. For example, the demand for food (a broad commodity) is more inelastic than the demand for beef. Short of starvation, there are no close substitutes for

Table 3–2

Selected Own Price Elasticities

Market	Own Price Elasticity
Whole milk	−1.1
Milk	−0.2
Meat	−0.4
Beef	−0.6
Steak	−1.1
Tea	−1.4
Pepper	−0.2

SOURCE: U.S. Department of Agriculture, Economic Research Service, https://data.ers.usda.gov/reports.aspx?ID=17825, accessed May 30, 2019. Reported elasticities are from most recent research listed by the service.

food, and thus the quantity demanded of food is much less sensitive to price changes than is a particular type of food, such as beef. When the price of beef increases, consumers can substitute toward other types of food, including chicken, pork, and fish. Thus, the demand for beef is more elastic than the demand for food.

Table 3–2 shows some own price elasticities from agricultural market studies in the United States, made public by the U.S. Department of Agriculture. These studies reveal that broader categories of goods indeed have more inelastic demand than more specifically defined categories. The own price elasticity of milk (any type) is highly inelastic, whereas the elasticity of whole milk, a specific type of milk, is elastic. We would expect this outcome because there are many substitutes for whole milk (including other types of milk), but substantially fewer substitutes exist for milk in general. Table 3–2 also reveals that the demand for beef is more elastic than the demand for meat in general (a broader category).

Finally, consider the reported own price elasticities for meat, beef, and steak. Meat is the most broadly defined group, followed by beef and then steak. Therefore, we would expect the demand for meat to be most elastic, followed by beef and then steak. The numbers in Table 3–2 are consistent with these expectations; market studies support the statement that demand is more elastic when there are more close substitutes for a product.

Time

Demand tends to be more inelastic in the short term than in the long term. The more time consumers have to react to a price change, the more elastic the demand for the good. Conceptually, time allows the consumer to seek out available substitutes. For example, if a consumer has 30 minutes to catch a flight, he or she is much less sensitive to the price charged for a taxi ride to the airport than would be the case if the flight were several hours later. Given enough time, the consumer can seek alternative modes of transportation such as a bus, a friend's car, or even on foot. But in the short term, the consumer does not have time to seek out the available substitutes, and the demand for taxi rides is more inelastic.

Revisiting Table 3–2, note that all of the elasticities presented are for the short run. While not provided, it is safe to say that were the time period for these measures extended, the elasticities would increase in absolute value. For example, if the price of tea increases, over a longer period of time, consumers may be more willing and able to shift their purchases to substitutes such as coffee, perhaps by investing in a coffee maker.

Expenditure Share

Goods that comprise a relatively small share of consumers' budgets tend to be more inelastic than goods for which consumers spend a sizable portion of their incomes. In the extreme case, where a consumer spends her or his entire budget on a good, the consumer must decrease consumption when the price rises. In essence, there is nothing to give up but the good itself. When a good comprises only a small portion of the budget, the consumer can reduce the consumption of other goods when the price of the good increases. For example, most consumers spend very little on salt; a small increase in the price of salt would reduce quantity demanded very little since salt constitutes a small fraction of consumers' total budgets.

Would you expect the own price elasticity of demand for meat to be more or less elastic than that for pepper? Since meat is a much greater necessity than pepper (after all, many diets are heavily dependent on meat for nutrition, whereas pepper just adds flavor), you might expect the demand for meat to be more inelastic than the demand for pepper. However, Table 3–2 reveals that the demand for pepper is more inelastic than the demand for meat. How can this be true?

The answer lies in the percentage of income Americans spend on meat and pepper. The average U.S. consumer spends substantially more on meat than pepper. Even though, from a nutritional standpoint, meat is more important than pepper for many households, the demand for meat tends to be more elastic because a much larger proportion of people's budgets is spent on meat.

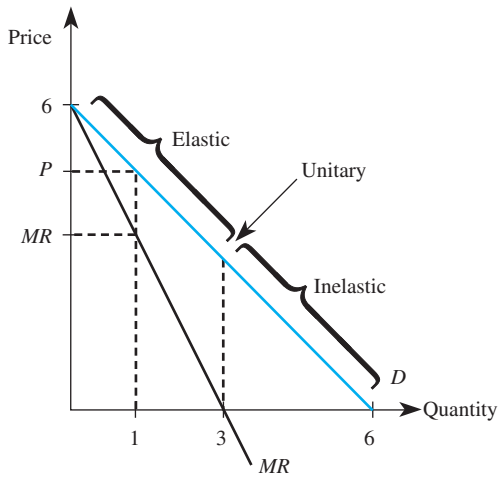
Marginal Revenue and the Own Price Elasticity of Demand

We learned in Chapter 1 that *marginal revenue (MR)* is the change in total revenue due to a change in output, and that to maximize profits a firm should produce where marginal revenue equals marginal cost. We will explore profit-maximizing output and pricing decisions in detail later in this book, but it is useful at this point to show how a firm's marginal revenue is linked to the own price elasticity of demand for the firm's product.

The line labeled *MR* in Figure 3–3 is the marginal revenue associated with each price–output pair on the demand curve. Notice that for a linear demand curve, the marginal revenue schedule lies exactly halfway between the demand curve and the vertical axis. Furthermore, marginal revenue is less than the price for each unit sold.

Why is marginal revenue less than the price charged for the good? To induce consumers to purchase more of a good, a firm must lower its price. When the firm charges the same price

Figure 3–3
Demand and Marginal Revenue



for each unit sold, this lower price is received not only on the last unit sold, but also on those units that could have been sold at a higher price had the firm not lowered its price. To be concrete, suppose consumers purchase 1 unit of output at a price of \$5 per unit, for total expenditures (revenues to producers) of $\$5 \times 1 = \$5$. Consumers will purchase an additional unit of the good only if the price falls, say from \$5 to \$4 per unit. Now the firm receives \$4 on the first unit sold and \$4 on the second unit sold. In effect, the firm loses \$1 in revenue because the first unit now brings \$4 instead of \$5. Total revenue rises from \$5 to \$8 as output is increased by 1 unit, so marginal revenue is $\$8 - \$5 = \$3$, which is less than price.

Notice in our example that by decreasing price from \$5 to \$4, quantity demanded increased from 1 unit to 2 units, and total revenues increased from \$5 to \$8. By the total revenue test, this means that demand is elastic over this range. In contrast, had the price reduction increased quantity demanded but decreased total revenues, demand would be inelastic over the

INSIDE BUSINESS 3–2

Calculating and Using the Arc Elasticity: An Application to the Housing Market

While in many instances managers can obtain estimates of elasticities from the library or the firm's research staff, sometimes managers are confronted with situations where elasticity estimates are not readily available. Fortunately, all is not lost in these instances thanks to a concept called the *arc elasticity of demand*.

To be specific, suppose a manager has data that show when the price of some good was P_1, consumers purchased Q_1 units of the good, and when the price changed to P_2, Q_2 units were purchased. Other things being equal, these data can be used to approximate the own price elasticity of demand for the good by using the arc elasticity formula:

$$E^{Arc} = \frac{\Delta Q^d}{\Delta P} \times \frac{Average\ P}{Average\ Q}$$

In the formula, the average Q is $(Q_1 + Q_2)/2$ and the average P is $(P_1 + P_2)/2$.

In order to illustrate how this formula can be used to compute an elasticity based on real-world data, we can analyze data on sales and price for existing single-family homes in the United States. According to the National Association of Realtors, the median sales price for such homes in October was \$160,800, and at this price 343,000 homes were sold. Thus, $P_1 = \$160{,}800$ and $Q_1 = 343{,}000$ represent one point on the demand curve—the price and quantity of existing single-family homes in October.

Similarly, $P_2 = \$164{,}000$ and $Q_2 = 335{,}000$ represent the price and quantity of existing single-family homes one month later. Interest rates and income—the two primary determinants of the demand for housing—were roughly constant between October and November. Thus, it is reasonable to assume that demand was stable (did not shift) over this one-month period, and that this price–quantity pair represents another point on the demand curve for single-family homes in the United States.

Based on these two points on the demand curve, we may approximate the own price elasticity of demand for existing single-family homes in the United States by using the arc elasticity formula:

$$\begin{aligned} E^{Arc} &= \frac{(Q_1 - Q)(P_1 + P_2)/2}{(P_1 - P_2)(Q_1 + Q_2)/2} \\ &= \frac{343{,}000 - 335{,}000}{160{,}800 - 164{,}000} \times \frac{(160{,}800 + 164{,}000)/2}{(343{,}000 + 335{,}000)/2} \\ &= -1.2 \end{aligned}$$

The own price elasticity of demand is greater than 1 in absolute value, so by the total revenue test we know that the increase in housing prices over the period resulted in lower total expenditures on housing. We might also speculate that the incomes of real estate agents fell over this period due to the lower real estate commissions generated by these reduced expenditures on housing.

It is important to point out that the arc elasticity technique described here only approximates the true elasticity of demand for housing. The accuracy of the approximation depends crucially on the assumption that the demand curve did not shift between October and November. If the demand for single-family housing in the United States shifted over the period, due to unusually good househunting weather, for instance, then the true elasticity of demand will differ from our approximation.

SOURCE: www.realtor.org/topics/existing-home-sales/data

range and marginal revenue would be negative. In fact, the more inelastic the demand for a product, the greater the decline in revenue that results from a price cut, despite the increased quantity demanded.

This intuition leads to the following general relationship between marginal revenue and the elasticity of demand:

$$MR = P\left[\frac{1+E}{E}\right]$$

This formula, which is formally derived in Chapter 8, simplifies notation by dropping subscripts: P is the price of the good and E is the own price elasticity of demand for the good. Notice that when $-\infty < E < -1$, demand is elastic, and the formula implies that MR is positive. When $E = -1$, demand is unitary elastic, and marginal revenue is zero. As we learned in Chapter 1, the point where marginal revenue is zero corresponds to the output at which total revenue is maximized. Finally, when $-1 < E < 0$, demand is inelastic, and marginal revenue is negative. These general results are consistent with what you saw earlier in Table 3–1 for the case of linear demand.

CROSS-PRICE ELASTICITY

cross-price elasticity
A measure of the responsiveness of the demand for a good to changes in the price of a related good; the percentage change in the quantity demanded of one good divided by the percentage change in the price of a related good.

Another important elasticity is the **cross-price elasticity** of demand, which reveals the responsiveness of the demand for a good to changes in the price of a related good. This elasticity helps managers ascertain how much its demand will rise or fall due to a change in the price of another firm's product. The cross-price elasticity of demand between goods X and Y, denoted E_{Q_x, P_y}, is mathematically defined as

$$E_{Q_x, P_y} = \frac{\%\Delta Q_x^d}{\%\Delta P_y}$$

For instance, if the cross-price elasticity of demand between a subscription to Hulu and a subscription to Netflix is 3, a 10 percent hike in the price of Netflix will increase the demand for Hulu by 30 percent since $30\%/10\% = 3$. This increase in demand for Hulu occurs because consumers substitute away from Netflix and toward Hulu, due to the price increase.

A CALCULUS ALTERNATIVE

When the demand function is $Q_x^d = f(P_x, P_Y, M, H)$, the cross-price elasticity of demand between goods X and Y may be found using calculus:

$$E_{Q_x, P_y} = \frac{\partial Q_x^d}{\partial P_y}\frac{P_y}{Q_x}$$

More generally, whenever goods X and Y are substitutes, an increase in the price of Y leads to an increase in the demand for X. Thus, $E_{Q_x, P_y} > 0$ whenever goods X and Y are substitutes. When goods X and Y are complements, an increase in the price of Y leads to a decrease in the demand for X. Thus, $E_{Q_x, P_y} < 0$ whenever goods X and Y are complements.

Table 3–3 provides some representative cross-price elasticities. For example, meat and dairy have a cross-price elasticity of −0.21. This means that if the price of dairy increases by 10 percent, the demand for meat will decrease by 2.1 percent; meat and dairy are complements. More important, these data provide a quantitative measure of the impact of a change in the price of dairy on the consumption of meat.

Table 3–3

Selected Cross-Price Elasticities

	Cross-Price Elasticity
Meat and dairy	−0.21
Bread and cereal	0.02
Coffee and juice	0.07

SOURCE: U.S. Department of Agriculture, Economic Research Service, https://data.ers.usda.gov/reports.aspx?ID=17825, accessed May 30, 2019. Reported elasticities are from most recent research listed by the service.

Based on the data summarized in Table 3–3, are coffee and juice complements or substitutes? If the price of juice increased by 20 percent, what would happen to the demand for coffee? These questions are embedded in the following problem.

DEMONSTRATION PROBLEM 3–1

You have just opened a new grocery store. You recently read an article in *The Wall Street Journal* reporting that the price of juice is expected to increase by 20 percent. How will this affect your store's sales of coffee products?

ANSWER:

Table 3–3 reveals that the cross-price elasticity of demand for coffee and juice is 0.07. If we insert the given information into the formula for the cross-price elasticity, we get

$$0.07 = \frac{\%\Delta Q_x^d}{20}$$

Solving this equation for $\%\Delta Q_x^d$, we get

$$\%\Delta Q_x^d = 1.4$$

Thus, coffee and juice are substitutes. If the price of juice increases by 20 percent, you can expect the demand for coffee to increase by 1.4 percent.

Cross-price elasticities play an important role in the pricing decisions of firms that sell multiple products. Indeed, many fast-food restaurants offer hamburgers for under $1.00 because their managers realize that hamburgers and sodas are complements: When consumers buy a hamburger, a soda typically accompanies the purchase. Thus, by lowering the price of burgers, a restaurant affects its revenues from both burger sales and soda sales. The precise impact on these revenues depends on the own price and cross-price elasticities of demand.

Specifically, we know from the total revenue test that a reduction in the price of hamburgers will increase (decrease) revenues from hamburger sales when the own price elasticity of demand for hamburgers is elastic (inelastic). In addition, since hamburgers and sodas are complements, reducing the price of hamburgers increases the quantity demanded of sodas, thus increasing soda revenues. The magnitude of the increase in soda revenues will depend on the magnitude of the cross-price elasticity of demand between burgers and soda.

INSIDE BUSINESS 3–3

Using Cross-Price Elasticities to Guide Strategies in Digital Markets

In the digital age, you don't just compete against other firms, you often also have substantial competition with illegal providers, engaged in piracy. One digital market where piracy is of great concern is subscription television. Consumers around the globe choose not just among competing firms offering subscription packages, but typically can also find some or all of the same content for free within an illegal (pirate) market. How much does the illegal television market compete with the legal one?

Researchers Christian Rojas and Arturo Briceno set out to answer this question for subscription television in Peru. They find that the cross-price elasticity for illegal television content is comparable to cross-price elasticities with respect to major competing firms. For example, the cross-price elasticity between Telefonica (the largest television subscription firm in Peru) and illegal providers is 0.39. This means a 10 percent increase in the Telefonica's price translates into a 3.9 percent increase in the quantity demanded for illegal content. As a comparison, the cross-price elasticity between Telefonica and America Movil, its top legal competitor, is 0.42.

At the time of the analysis, Telefonica had a dominant position in the television subscription market, with market share exceeding 60 percent. By understanding relevant cross-price elasticities, Telfonica can account for the full scope of the market for television content and the range of customers it can draw to its product from a price decrease. In fact, these results suggest Telefonica's position may not be so dominant in this market after accounting for piracy—a relevant finding for antitrust concerns, discussed later in the book.

SOURCE: C. Rojas and A. Briceno, "The Effects of Piracy on Competition: Evidence from Subscription TV," *International Journal of Industrial Organization* 63 (2019), pp. 18–43.

More generally, suppose a firm's revenues are derived from the sales of two products, X and Y. We may express the firm's revenues as $R = R_x + R_y$, where $R_x = P_xQ_x$ denotes revenues from the sale of product X and $R_y = P_yQ_y$ represents revenues from product Y. The impact of a small percentage change in the price of product X ($\%\Delta P_x = \Delta P_x/P_x$) on the total revenues of the firm is[1]

$$\Delta R = \left[R_x\left(1 + E_{Q_x, P_x}\right) + R_y E_{Q_y, P_x}\right] \times \%\Delta P_x$$

To illustrate how to use this formula, suppose a restaurant earns \$4,000 per week in revenues from hamburger sales (product X) and \$2,000 per week from soda sales (product Y). Thus, $R_x = \$4{,}000$ and $R_y = \$2{,}000$. If the own price elasticity of demand for burgers is $E_{Q_x, P_x} = -1.5$ and the cross-price elasticity of demand between sodas and hamburgers is $E_{Q_y, P_x} = -4.0$, what would happen to the firm's total revenues if it reduced the price of hamburgers by 1 percent? Plugging these numbers into the formula reveals

$$\begin{aligned}\Delta R &= [\$4{,}000(1 - 1.5) + \$2{,}000(-4.0)](-1\%)\\ &= \$20 + \$80\\ &= \$100\end{aligned}$$

In other words, lowering the price of hamburgers 1 percent increases total revenues by \$100. Notice that \$20 of this increase comes from increased burger revenues (the demand for burgers is elastic, so the reduction in the price of burgers increases hamburger revenues) and \$80 of the increase is from additional soda sales (the demand for soda increases by 4 percent, resulting in additional revenues of \$80 from soft-drink sales).

[1]This formula is an approximation for large changes in price.

INCOME ELASTICITY

Income elasticity is a measure of the responsiveness of consumer demand to changes in income. Mathematically, the income elasticity of demand, denoted $E_{Q_x, M}$, is defined as

$$E_{Q_x, M} = \frac{\%\Delta Q_x^d}{\%\Delta M}$$

income elasticity
A measure of the responsiveness of the demand for a good to changes in consumer income; the percentage change in quantity demanded divided by the percentage change in income.

A CALCULUS ALTERNATIVE

The income elasticity for a good with a demand function $Q_x^d = f(P_x, P_y, M, H)$ may be found using calculus:

$$E_{Q_x, M} = \frac{\partial Q_x^d}{\partial M} \frac{M}{Q_x}$$

When good X is a normal good, an increase in income leads to an increase in the consumption of X. Thus, $E_{Q_x, M} > 0$ when X is a normal good. When X is an inferior good, an increase in income leads to a decrease in the consumption of X. Thus, $E_{Q_x, M} < 0$ when X is an inferior good.

Table 3–4 provides several income elasticities. Consider, for example, the income elasticity for organic potatoes, 2.26. This number gives us two important pieces of information about the relationship between income and the demand for organic potatoes. First, since the income elasticity is positive, we know that consumers increase the amount they spend on organic potatoes when their incomes rise. Organic potatoes thus are a normal good. Second, since the income elasticity for organic potatoes is greater than 1, we know that expenditures on organic potatoes grow more rapidly than income.

The second row of Table 3–4 reveals that meat also is a normal good since the income elasticity of meat is 0.11. Since the income elasticity is less than 1, an increase in income will increase the expenditure on meat by a lower percentage than the percentage increase in income. When income declines, expenditures on meat decrease less rapidly than income.

The third row of Table 3–4 presents the income elasticity for ordinary (as opposed to craft) beer. The income elasticity for beer is negative; hence, we know that beer is an inferior good. The consumption of beer will decrease by 0.83 percent for every 1 percent rise in consumer income. Therefore, managers of grocery stores should decrease their orders of beer during economic booms and increase their orders during recessions.

Table 3–4

Selected Income Elasticities

	Income Elasticity
Organic potatoes	2.26
Meat	0.11
Beer	−0.83

SOURCES: For meat and beer: United States Department of Agriculture Economic Research Service, https://data.ers.usda.gov/reports.aspx?ID=17825, accessed May 30, 2019. Reported elasticities are from most recent research listed by the service. For organic potatoes: F. Zhang, C. Huang, B-H Lin, and J. Epperson, "National Demand for Fresh Organic and Conventional Vegetables: Scanner Data Evidence," *Journal of Food Products Marketing* 17 (2011), pp. 441–458.

DEMONSTRATION PROBLEM 3–2

Your firm's research department has estimated the income elasticity of demand for organic potatoes to be 2.26. You have just read in *The Wall Street Journal* that due to a downturn in the economy, consumer incomes are expected to fall by 10 percent over the next three years. As a manager of an organic food retailer, how will this forecast affect your purchases of organic potatoes?

ANSWER:

Set $E_{Q_x, M} = 2.26$ and $\%\Delta M = -10$ in the formula for the income elasticity of demand to obtain

$$2.26 = \frac{\%\Delta Q_x^d}{-10}$$

Solving this equation for $\%\Delta Q_x^d$ yields -22.6. Since organic potatoes have an income elasticity of 2.26 and consumer income is expected to fall by 10 percent, you can expect to sell 22.6 percent fewer organic potatoes over the next three years. Therefore, you should decrease your purchases of organic potatoes by 22.6 percent, unless something else changes.

OTHER ELASTICITIES

Given the general notion of an elasticity, it is not difficult to conceptualize how the impact of changes in other variables, such as advertising, may be analyzed in elasticity terms. For example, the *own advertising elasticity* of demand for good X is the ratio of the percentage change in the consumption of X to the percentage change in advertising spent on X. The *cross-advertising elasticity* between goods X and Y would measure the percentage change in the consumption of X that results from a 1 percent change in advertising directed toward Y.

Table 3–5 shows estimates of the advertising elasticities for best-, and second best-, selling statin (cholesterol-reducing drug) brands. Here, advertising is in the form of direct-to-consumer ads. Both elasticities are positive and less than 1. The fact that they are positive reveals, as you might expect, that increases in advertising lead to an increase in the demand for the products; that is, if a brand increases its advertising to consumers, it can expect to sell more of its product at any given price. However, the fact that the advertising elasticity for the second-place brand is 0.10 means that a 10 percent increase in advertising will increase the demand for its statin by only 1 percent. Hence, this brand is not very advertising elastic.

To illustrate how managers can use estimates such as these, imagine that you have just been hired by the leading statin brand manufacturer to help boost sales of the product. Your boss knows you recently took a course in managerial economics and asks you how much she should increase advertising to increase the demand for your firm's statin by 15 percent.

Table 3–5

Selected Advertising Elasticities

	Advertising Elasticity
Top statin brand	0.32
Second statin brand	0.10

SOURCE: M. Sinkinson and A. Starc, "Ask Your Doctor? Direct-to-Consumer Advertising of Pharmaceuticals," *Review of Economic Studies*, 86 (2019), pp. 836–81. In the paper, the top brand is Crestor and second brand is Lipitor. Calculations simplified by the authors by assuming price does not change with advertising.

From Table 3–5, we know that $E_{Q_x A_x} = 0.32$. Plugging this and $\%\Delta Q_x^d = 15$ into the general formula for the elasticity of Q_x^d with respect to A_x yields

$$0.32 = \frac{\%\Delta Q_x^d}{\%\Delta A_x} = \frac{15}{\%\Delta A_x}$$

Solving this equation for the percentage change in advertising shows that advertising must increase by approximately 47 percent to increase the demand for your leading statin by 15 percent.

OBTAINING ELASTICITIES FROM DEMAND FUNCTIONS

Now that you understand what elasticities are and how to use them to make managerial decisions, we will examine how to calculate elasticities from demand functions. First, we will consider elasticities based on linear demand functions. Then we will see how to calculate elasticities from particular nonlinear demand functions.

Elasticities for Linear Demand Functions

Given an estimate of a linear demand function, it is quite easy to calculate the various elasticities of demand.

Formula: Elasticities for Linear Demand. If the demand function is linear and given by

$$Q_x^d = \alpha_0 + \alpha_x P_x + \alpha_y P_y + \alpha_M M + \alpha_H H$$

the elasticities are

Own price elasticity: $E_{Q_x, P_x} = \alpha_x \frac{P_x}{Q_x}$

Cross-price elasticity: $E_{Q_x, P_y} = \alpha_y \frac{P_y}{Q_x}$

Income elasticity: $E_{Q_x, M} = \alpha_M \frac{M}{Q_x}$

A CALCULUS ALTERNATIVE

The elasticities for a linear demand curve may be found using calculus. Specifically,

$$E_{Q_x, P_x} = \frac{\partial Q_x^d}{\partial P_x} \frac{P_x}{Q_x} = \alpha_x \frac{P_x}{Q_x}$$

and similarly for the cross-price and income elasticities.

Thus, for a linear demand curve, the elasticity of demand with respect to a given variable is simply the coefficient of the variable multiplied by the ratio of the variable to the quantity demanded. For instance, the own price elasticity of demand is simply the coefficient of P_x (which is α_x in the demand function) multiplied by the ratio of the price of X to the quantity consumed of X.

For a linear demand curve, the value of an elasticity depends on the particular price and quantity at which it is calculated. This means that the own price elasticity is not the same as the slope of the demand curve. In fact, for a linear demand function, demand is elastic at high

prices and inelastic at lower prices. To see this, note that when $P_x = 0$, $|E_{Q_x, P_x}| = \left|\alpha_x \frac{0}{Q_x}\right| = 0 < 1$.

In other words, for prices near zero, demand is inelastic. On the other hand, when prices rise, Q_x decreases and the absolute value of the elasticity increases.

For a video walkthrough of this problem, visit www.mhhe.com/baye10e

DEMONSTRATION PROBLEM 3–3

The daily demand for Invigorated PED shoes is estimated to be

$$Q_x^d = 100 - 3P_x + 4P_y - .01M + 2A_x$$

where A_x represents the amount of advertising spent on shoes (X), P_x is the price of good X, P_y is the price of good Y, and M is average income. Suppose good X sells at \$25 a pair, good Y sells at \$35, the company utilizes 50 units of advertising, and average consumer income is \$20,000. Calculate and interpret the own price, cross-price, and income elasticities of demand.

ANSWER:

To calculate the own price elasticity for linear demand, we use the formula

$$E_{Q_x, P_x} = \alpha_x \frac{P_x}{Q_x}$$

Here $\alpha_x = -3$ and $P_x = 25$. The only other information we need to calculate the elasticity is the quantity consumed of X. To find Q_x, we substitute the given values of prices, income, and advertising into the demand equation to get

$$Q_x^d = 100 - 3(25) + 4(35) - .01(20{,}000) + 2(50) = 65 \text{ units}$$

Hence the own price elasticity of demand is given by

$$E_{Q_x, P_x} = -3\left(\frac{25}{65}\right) = -1.15$$

If Invigorated PED raises shoe prices, the percentage decline in the quantity demanded of its shoes will be greater in absolute value than the percentage rise in price. Consequently, demand is elastic: Total revenues will fall if it raises shoe prices.

Similarly, the cross-price elasticity of demand is

$$E_{Q_x, P_y} = 4\left(\frac{35}{65}\right) = 2.15$$

Since this is positive, good Y is a substitute for Invigorated PED shoes. The income elasticity of demand for Invigorated PED's shoes is

$$E_{Q_x, M} = -0.01\left(\frac{20{,}000}{65}\right) = -3.08$$

Invigorated PED's shoes are inferior goods since this is a negative number.

Elasticities for Nonlinear Demand Functions

Managers frequently encounter situations where a product's demand is not a linear function of prices, income, advertising, and other demand shifters. In this section we demonstrate that the tools we developed can easily be adapted to these more complex environments.

Suppose the demand function is not a linear function but instead is given by

$$Q_x^d = cP_x^{\beta_x} P_y^{\beta_y} M^{\beta_M} H^{\beta_H}$$

where c is a constant. In this case, the quantity demanded of good X is not a linear function of prices and income but a nonlinear function. If we take the natural logarithm of this equation, we obtain an expression that is linear in the logarithms of the variables:[2]

$$\ln Q_x^d = \beta_0 + \beta_x \ln P_x + \beta_y \ln P_y + \beta_M \ln M + \beta_H \ln H$$

where $\beta_0 = \ln(c)$ and the β_i's are arbitrary real numbers. This relation is called a **log-linear demand** function.

log-linear demand
Demand is log-linear if the logarithm of demand is a linear function of the logarithms of prices, income, and other variables.

As in the case of linear demand, the sign of the coefficient of ln P_y determines whether goods X and Y are substitutes or complements, whereas the sign of the coefficient of ln M determines whether X is a normal or an inferior good. For example, if β_y is a positive number, an increase in the price of good Y will lead to an increase in the consumption of good X; in this instance, X and Y are substitutes. If β_y is a negative number, an increase in the price of good Y will lead to a decrease in the consumption of good X; in this instance, goods X and Y are complements. Similarly, if β_M is a positive number, an increase in income leads to an increase in the consumption of good X, and X is a normal good. If β_M is a negative number, an increase in income leads to a decrease in the consumption of good X, and X is an inferior good.

Formula: Elasticities for Log-Linear Demand. When the demand function for good X is log-linear and given by

$$\ln Q_x^d = \beta_0 + \beta_x \ln P_x + \beta_y \ln P_y + \beta_M \ln M + \beta_H \ln H$$

the elasticities are

Own price elasticity: $E_{Q_x, P_x} = \beta_x$
Cross-price elasticity: $E_{Q_x, P_y} = \beta_y$
Income elasticity: $E_{Q_x, M} = \beta_M$

A CALCULUS ALTERNATIVE

The elasticity formulas for log-linear demand may also be derived using calculus. Taking the anti-logarithm of the equation for log-linear demand gives

$$Q_x^d = cP_x^{\beta_x} P_y^{\beta_y} M^{\beta_M} H^{\beta_H}$$

where c is a constant. Using the calculus formula for an elasticity yields

$$E_{Q_x, P_x} = \frac{\partial Q_x^d}{\partial P_x}\left(\frac{P_x}{Q_x}\right) = \beta_x c P_x^{\beta_x - 1} P_y^{\beta_y} M^{\beta_M} H^{\beta_H}\left(\frac{P_x}{cP_x^{\beta_x} P_y^{\beta_y} M^{\beta_M} H^{\beta_H}}\right) = \beta_x$$

and similarly for the cross-price and income elasticities.

Notice that when demand is log-linear, the elasticity with respect to a given variable is simply the coefficient of the corresponding logarithm. The own price elasticity of demand is the coefficient of ln (P_x), and, in fact, the coefficient of *any* other logarithm on the right-hand side of the log-linear demand relation tells us the elasticity of demand with respect to that demand shifter. Since all of these coefficients are constants, none of the elasticities depend on the value of variables like prices, income, or advertising.

Table 3–6 shows the results of a statistical study that found the demand for retail gasoline to be log-linear. Since this is a log-linear demand relation, we know that the coefficients may be interpreted as elasticities.

[2]Here, ln denotes the *natural logarithm*. In some spreadsheets (such as Excel), this function is denoted LN.

Table 3–6

The Log-Linear Demand for Retail Gasoline in the United States

$$\ln(Q_G) = -1.697 - 0.042 \ln(P_G) + 0.53 \ln(Y)$$

Q_G = per capita consumption of gasoline in gallons

P_G = real retail price of gasoline

Y = real per capita disposable income

SOURCE: Adapted from J. Hughes, C. Knittel, and D. Sperling, "Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand," *The Energy Journal* 29, no. 1 (2008), pp. 93–114.

The study summarized in Table 3–6 focused on the price elasticity of demand for gasoline for the early 2000s. The coefficient of the logarithm of price is −0.042. This shows that the demand for gasoline is highly inelastic and downward sloping. Furthermore, an increase of 10 percent in the price of retail gasoline will decrease the quantity of retail gasoline demanded by only 0.4 percent, and therefore would raise the revenues of retail gasoline stations. The coefficient of the logarithm of income is 0.53, indicating that retail gasoline is a normal good. A 10 percent increase in consumers' per capita income would result in a 5.3 percent increase in retail gasoline demand.

As a final check of your ability to utilize elasticities, try to work the following problem.

DEMONSTRATION PROBLEM 3–4

An analyst for a major apparel company estimates that the demand for its raincoats is given by

$$\ln Q_x^d = 10 - 1.2 \ln P_x + 3 \ln R - 2 \ln A_y$$

where R denotes the daily amount of rainfall and A_y represents the level of advertising on good Y. What would be the impact on demand of a 10 percent increase in the daily amount of rainfall? What would be the impact of a 10 percent reduction in the amount of advertising directed toward good Y? Can you think of a good that might be good Y in this example?

ANSWER:

We know that for log-linear demand functions, the coefficient of the logarithm of a variable gives the elasticity of demand with respect to that variable. Thus, the elasticity of demand for raincoats with respect to rainfall is

$$E_{Q_x, R} = \beta_R = 3$$

Furthermore,

$$E_{Q_x, R} = \beta_R = \frac{\%\Delta Q_x^d}{\%\Delta R}$$

Hence,

$$3 = \frac{\%\Delta Q_x^d}{10}$$

Solving this equation yields $\%\Delta Q_x^d = 30$. In other words, the 10 percent increase in rainfall will lead to a 30 percent increase in the demand for raincoats.

To examine the impact on the demand for raincoats of a 10 percent reduction in advertising spent on good Y, again note that for log-linear demand functions, each coefficient gives the elasticity of demand with respect to that variable. Thus, the elasticity of demand for raincoats with respect to advertising directed toward good Y is

$$E_{Q_x, A_y} = \beta_{A_y} = -2$$

Furthermore,

$$E_{Q_x, A_y} = \beta_{A_y} = \frac{\%\Delta Q_x^d}{\%\Delta A_y}$$

Hence,

$$-2 = \frac{\%\Delta Q_x^d}{-10}$$

Solving this equation yields $\%\Delta Q_x^d = 20$. In other words, the 10 percent reduction in advertising directed toward good Y leads to a 20 percent increase in the demand for raincoats. Perhaps good Y is umbrellas, for one would expect the demand for raincoats to increase whenever fewer umbrella advertisements are made.

DATA-DRIVEN DEMAND CURVES

The preceding analysis assumes the manager knows the demand for the firm's product. We pointed out several studies that provide explicit estimates of demand elasticities and functional forms for demand functions. As we discussed in Chapter 1, you may obtain these estimates yourself using regression analysis or utilize estimates provided to you from published studies or professional analysts.

We now discuss specifically how to apply and utilize regression analysis for demand curve estimation. To begin, recall our example from Chapter 1 relating quantity and price for televisions, using data from 10 outlets in Pittsburgh last month. Suppose now that the data were generated as part of a field experiment, where experts carefully varied the prices charged at each outlet with the intent of learning about television demand. We can then use the regression estimates relating quantity and price as our demand curve. Table 3–7, which recreates select rows of Table 1–3, contains the regression estimates along with measures of their significance. We now can interpret these figures as an estimate for the demand curve for our televisions, written as:

$$Q = 1631.47 - 2.60P$$

Recall that the large (in absolute value) t-stats and small P-values for both the intercept and coefficient on price tell us that both parameters are statistically significant.

Using this simple estimated demand curve, we can now calculate own price elasticities at different price points. For example, own price elasticity when price is 400 is $-1.76 = (-2.60)(400)/(1631.47 - 2.60(400))$. Given we are using a linear demand curve, we know own price elasticity goes up in absolute value when price is higher. We can see this by calculating own price elasticity when price is 500, which is $-3.92 = (-2.60)(500)/(1631.47 - 2.60(500))$.

Table 3–7

Estimated Demand for Televisions

	A	B	C	D	E	F	G
1	**Observation**	**Quantity**	**Price**				
12	**Average**	450.50	455.00				
15							
30		***Coefficients***	***Standard Error***	***t-Statistic***	***P-Value***	***Lower 95%***	***Upper 95%***
31							
32	Intercept	1631.47	243.97	6.69	0.0002	1068.87	2194.07
33	Price	−2.60	0.53	−4.89	0.0012	−3.82	−1.37

We can also use regression analysis to estimate log-linear demand functions, a common application of regression for nonlinear functions. We walk through an example of log-linear demand estimation in Demonstration Problem 3–5.

DEMONSTRATION PROBLEM 3–5

During the 31 days this past March, an online ticket agent offered varying price discounts on Broadway tickets in order to gather information needed to estimate the demand for its tickets. A file named *Demo03-05.xls* is available at www.mhhe.com/baye10e. If you open this file and view the tab labeled *Data*, you will find information about the quantity of Broadway tickets the company sold at various prices in March. Use these data to estimate a log-linear demand function. Use an equation to summarize your findings.

ANSWER:

The first step is to transform the price and quantity data into natural logarithms, using the relevant spreadsheet command. You can see how to do this step by viewing the tab labeled *Transformed* in the *Demo03-05.xls* file. The second step is to perform a linear regression on the transformed data. These regression results are displayed in the *Results* tab of the file. The final step is to summarize the regression results in a demand equation. In this case, the estimates in the *Results* tab imply the following log-linear demand function:

$$\ln Q^d = 8.44 - 1.58 \ln P$$

Written in this manner, the *logarithm* of quantity demanded is a linear function of the *logarithm* of price, and the company's elasticity of demand for tickets is −1.58. Alternatively, one can express the actual quantity demanded as a *nonlinear* function of price by taking the exponential of both sides of the equation:

$$\exp[\ln Q^d] = \exp[8.44] \exp[-1.58 \ln P]$$
$$Q^d = \exp[8.44]\, P^{-1.58}$$
$$Q^d = 4629\, P^{-1.58}$$

In general, the demand for a good will depend not only on the good's price, but also on demand shifters. Using what we know from multiple regression, we can estimate demand curves with multiple explanatory variables. For the case of a linear demand relation, one might specify the demand function as

$$Q_x^d = \alpha_0 + \alpha_x P_x + \alpha_y P_y + \alpha_M M + \alpha_H H + e$$

where the α's are the parameters to be estimated; P_y, M, and H are demand shifters; and e is the random error term that has a zero mean. Alternatively, a log-linear specification might be appropriate if the quantity demanded is not linearly related to the explanatory variables:

$$\ln Q_x^d = \beta_0 + \beta_x \ln P_x + \beta_y \ln P_y + \beta_M \ln M + \beta_H \ln H + e$$

Demonstration Problem 3–6 expands on Demonstration Problem 1–4, illustrating how to apply and utilize multiple regression for demand estimation.

DEMONSTRATION PROBLEM 3–6

Recall that FCI owns 10 apartment buildings in a college town, which it rents exclusively to students. Each apartment building contains 100 rental units, but the owner is having cash flow problems due to an average vacancy rate of nearly 50 percent. The apartments in each building have comparable floor plans, but some buildings are closer to campus than others. The owner of FCI has data from last year on the number of apartments rented, the rental price (in dollars), and the amount spent on advertising (in hundreds of dollars) at each of the 10 apartments. Table 3–8 contains the averages for each

of these variables (row 2), along with regression estimates and measures of their significance (rows 6 through 9). What is the estimated demand function for FCI's rental units? If FCI increased its advertising by $600, what would you expect to happen to the number of units rented? If FCI raised rents at an average apartment building, what would happen to FCI's total revenues?

ANSWER:

Letting P, A, and D represent price, advertising, and distance from campus, the estimated coefficients imply the following demand for rental units at an apartment building:

$$Q_x^d = 135.15 - 0.14P + 0.54A - 5.78D$$

Since the coefficient of advertising is 0.54, a $600 increase in advertising (meaning A increases by 6) increases the quantity demanded at an apartment building by about 3 units ($6 \times 0.54 = 3.24$). However, since advertising is not statistically significant, this estimated impact of advertising is with little confidence—the true effect of advertising could easily be negligible.

The own price elasticity of demand for FCI's rental units, calculated at the average price and quantity, is $(-.14)(420/53.10) = -1.11$. Since demand is elastic, raising the rent at an average apartment building would decrease not only the number of units rented, but total revenues as well. Consequently, it appears a lowering of price is what's needed if FCI wishes to increase revenues.

Table 3–8

Estimated Demand for Televisions Using Multiple Regression

	A	B	C	D	E	F	G
1	**Observation**	**Quantity**	**Price**	**Advertising**	**Distance**		
2	**Average**	53.10	420.00	20.50	5.70		
3							
4		***Coefficients***	***Standard Error***	***t-Statistic***	***P-Value***	***Lower 95%***	***Upper 95%***
5							
6	Intercept	135.15	20.65	6.54	0.0006	84.61	185.68
7	Price	−0.14	0.06	−2.41	0.0500	−0.29	0.00
8	Advertising	0.54	0.64	0.85	0.4296	−1.02	2.09
9	Distance	−5.78	1.26	−4.61	0.0037	−8.86	−2.71

INSIDE BUSINESS 3–4

Using Big Data to Estimate Demand Elasticities for Millions of Gamers

Recently, King Digital Entertainment, one of the world's leading gaming companies, teamed up with several academic economists to learn more about the demand for its products. At the time, King generally offered its games for free (e.g., Candy Crush) but makes profits from customers purchasing in-game content. During the course of play, players have the opportunity to purchase digital currency (in the form of gold bars), which can be used to help complete game levels.

King and the researchers ran a very large field experiment, involving more than 14 million gamers. The experiment consisted of randomly varied discounts for gold bars, which persisted for three months. They then measured differences in the number of gold bars purchased, and the revenues from those purchases, across the different pricing groups. Among other things, their analysis showed that infrequent purchasers are more price elastic than frequent purchasers. From a manager's point of view, this result suggests discounts to infrequent purchasers are more likely to enhance revenues compared to discounts for frequent purchasers.

SOURCE: S. Levitt, J. List, S. Neckermann, and D. Nelson, "Quantity Discounts on a Virtual Good: The Results of a Massive Pricing Experiment at King Digital Entertainment," *Proceedings of the National Academy of Sciences*, 113 (2016), pp. 7323–28.

ANSWERING THE headLINE

At the beginning of the chapter, we asked whether Walmart should expect a good holiday season absent a price change and whether a price change could improve sales (measured as revenues). Recall that the firm's analysts provided the following regression results, linking sales to prices and consumer confidence:

$$\ln(HolidaySales) = 25.8 - 0.8 \ln(Price) + 0.9 \ln(ConsumerConfidence)$$

Since this is a log-linear equation, the coefficients are elasticities. In particular, the coefficient of ln(*ConsumerConfidence*) (0.9) tells us the percentage change in holiday sales (HS) resulting from each 1 percent change in consumer confidence. Consequently, when consumer confidence decreases by 4 percent, this means $0.9 = \%\Delta HS/(-4)$, or $\%\Delta HS = -3.6$. In other words, the director should expect holiday sales to be 3.6 percent lower in MSAs where consumer confidence has declined by 4 percent, and so should not be particularly optimistic about holiday sales this year. The results indicate the director could mitigate the sales decrease by lowering price. For example, the director could recommend a 3 percent price reduction across the board, which, according to the regression, will result in a 2.4 percent increase in holiday sales ($-0.8 = \%\Delta HS/(-3)$, or $\%\Delta HS = 2.4$). However, the director should be sure not to lose sight of any effects a price change would have on profits, as opposed to sales.

In addition to the usual caveat that it should be left to experts to obtain these revenues estimates, note also that the director is not working with a demand curve to make these decisions. Since it is revenues and not quantity as the dependent variable, the sign of the coefficient on price tells us whether demand is elastic or inelastic. In this case, the negative coefficient on price—indicating revenues fall with a price increase—implies an elastic demand curve.

SUMMARY

In this chapter we covered quantitative aspects of demand analysis, including the own price elasticity, income elasticity, and cross-price elasticity of demand. We examined functional forms for demand functions, including linear and log-linear specifications, and discussed the regression procedures used to estimate demand relationships. Armed with these tools, a manager can predict not only the direction of changes in demand, but how far demand will move when one of the determinants of demand changes. Knowing the concepts of elasticity and how data-driven analysis can help estimate it is extremely important when making decisions about how much inventory to hold, how many employees to schedule, and how many units of a product to produce when different determinants of demand change.

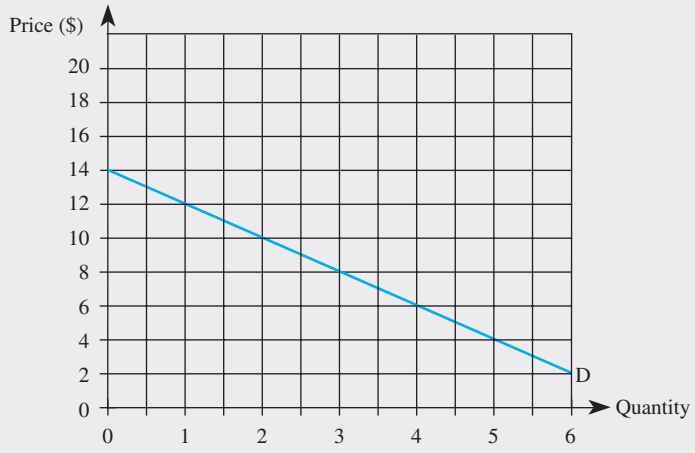
In this chapter, we saw that increasing price does not always increase revenues. If the absolute value of own price elasticity is greater than 1, an increase in price will decrease total revenue. We also covered the magnitude of changes caused by a change in the price of a substitute or a complement.

KEY TERMS AND CONCEPTS

arc elasticity of demand
cross-advertising elasticity
cross-price elasticity
elastic demand
elasticity
income elasticity
inelastic demand
log-linear demand
own advertising elasticity
own price elasticity of demand
perfectly elastic demand
perfectly inelastic demand
total revenue test
unitary elastic demand

CONCEPTUAL AND COMPUTATIONAL QUESTIONS

1. Answer the following questions based on the accompanying diagram. *(LO1, LO2, LO4)*



   a. How much would the firm's revenue change if it lowered the price from $12 to $10? Is demand elastic or inelastic in this range?
   b. How much would the firm's revenue change if it lowered the price from $4 to $2? Is demand elastic or inelastic in this range?
   c. What price maximizes the firm's total revenues? What is the elasticity of demand at this point on the demand curve?

2. Using regression analysis on data from a field experiment, the demand curve for a product is estimated to be $Q_x^d = 1{,}200 - 3\,P_x - 0.1\,P_z$, where $P_z = \$300$. *(LO1, LO4, LO5)*
   a. What is the own price elasticity of demand when $P_x = \$140$? Is demand elastic or inelastic at this price? What would happen to the firm's revenue if it decided to charge a price below $140?
   b. What is the own price elasticity of demand when $P_x = \$240$? Is demand elastic or inelastic at this price? What would happen to the firm's revenue if it decided to charge a price above $240?
   c. What is the cross-price elasticity of demand between good X and good Z when $P_x = \$140$? Are goods X and Z substitutes or complements?

3. Suppose a research report has estimated the demand for a firm's product as

$$\ln Q_x^d = 7 - 1.5 \ln P_x + 2 \ln P_y - 0.5 \ln M + \ln A$$

   where

   $P_x = \$15$,
   $P_y = \$6$,
   $M = \$40{,}000$, and
   $A = \$350$
   (LO1, LO5)

   a. Determine the own price elasticity of demand, and state whether demand is elastic, inelastic, or unitary elastic.
   b. Determine the cross-price elasticity of demand between good X and good Y, and state whether these two goods are substitutes or complements.

c. Determine the income elasticity of demand, and state whether good *X* is a normal or inferior good.
d. Determine the own advertising elasticity of demand.

4. Suppose the own price elasticity of demand for good *X* is −5, its income elasticity is −1, its advertising elasticity is 4, and the cross-price elasticity of demand between it and good *Y* is 3. Determine how much the consumption of this good will change if: *(LO1)*
   a. The price of good *X* decreases by 6 percent.
   b. The price of good *Y* increases by 7 percent.
   c. Advertising decreases by 2 percent.
   d. Income increases by 3 percent.
5. Suppose the cross-price elasticity of demand between goods *X* and *Y* is 2. How much would the price of good *Y* have to change in order to increase the consumption of good *X* by 50 percent? *(LO1)*

connect Excel Exercises

6. You are the manager of a firm that receives revenues of $20,000 per year from product *X* and $80,000 per year from product *Y*. The own price elasticity of demand for product *X* is −3 and the cross-price elasticity of demand between products *Y* and *X* is −1.6. How much will your firm's total revenues (revenues from both products) change if you increase the price of good *X* by 2 percent? *(LO1, LO2)*
7. An econometrics expert from your firm used a linear demand specification to estimate the demand for its product and sent you a hard copy of the results. *(LO6)*
   a. Based on these estimates, write an equation that summarizes the demand for the firm's product.
   b. Which regression coefficients are statistically significant at the 5 percent level?
   c. When price is $10, what is the income elasticity for this product for an income level of 35?

SUMMARY OUTPUT						
Regression Statistics						
Multiple *R*	0.38					
R-Square	0.14					
Adjusted *R*-Square	0.13					
Standard Error	20.77					
Observations	150					
Analysis of Variance						
	Degrees of Freedom	***Sum of Squares***	***Mean Square***	***F***	***Significance F***	
Regression	2	10,398.87	5199.43	12.05	0.00	
Residual	147	63,408.62	431.35			
Total	149	73,807.49				
	Coefficients	***Standard Error***	***t-Statistic***	***P-Value***	***Lower 95%***	***Upper 95%***
Intercept	58.87	15.33	3.84	0.00	28.59	89.15
Price of *X*	−1.64	0.85	−1.93	0.06	−3.31	0.04
Income	1.11	0.24	4.64	0.00	0.63	1.56

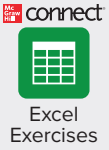
8. Suppose the true inverse demand relation for good *X* is $Q_x^d = a + bP_x + cM + e$, and you estimated the parameters to be $\hat{a} = 22$, $\hat{b} = -1.8$, $\sigma_{\hat{a}} = 2.5$, and $\sigma_{\hat{b}} = 0.7$. Find the approximate 95 percent confidence interval for the true values of *a* and *b*. *(LO6)*

9. The demand function for good X is $Q_x^d = a + bP_x + cM + e$, where P_x is the price of good X and M is income. Least squares regression reveals that $\hat{a} = 8.27$, $\hat{b} = -2.14$, $\hat{c} = 0.36$, $\sigma_{\hat{a}} = 5.32$, $\sigma_{\hat{b}} = 0.41$, and $\sigma_{\hat{c}} = 0.22$. The R-squared is 0.35. *(LO6)*
   a. Compute the t-statistic for each of the estimated coefficients.
   b. Determine which (if any) of the estimated coefficients are statistically different from zero.
   c. Explain, in plain words, what the R-square in this regression indicates.
10. The demand function for good X is $\ln Q_x^d = a + b \ln P_x + c \ln M + e$, where P_x is the price of good X and M is income. Least squares regression reveals that $\hat{a} = 7.42$, $\hat{b} = -2.18$, and $\hat{c} = 0.34$. *(LO5, LO6)*
   a. If $M = 55{,}000$ and $P_x = 4.39$, compute the own price elasticity of demand based on these estimates. Determine whether demand is elastic or inelastic.
   b. If $M = 55{,}000$ and $P_x = 4.39$, compute the income elasticity of demand based on these estimates. Determine whether X is a normal or inferior good.

PROBLEMS AND APPLICATIONS



11. Revenue at a major smartphone manufacturer was $2.3 billion for the nine months ending March 2, up 77 percent over revenues for the same period last year. Management attributes the increase in revenues to a 122 percent increase in shipments, despite a 38 percent drop in the average blended selling price of its line of phones. Given this information, is it surprising that the company's revenue increased when it decreased the average selling price of its phones? Explain. *(LO1, LO4)*
12. You are the manager of a firm that sells a leading brand of alkaline batteries. A file named *Q03-12.xls* with data on the demand for your product is available online at www.mhhe.com/baye10e. Specifically, the file contains data on the natural logarithm of your quantity sold, price, and the average income of consumers in various regions around the world. Use this information to perform a log-linear regression, and then determine the likely impact of a 3 percent decline in global income on the overall demand for your product. *(LO1, LO5, LO6)*
13. For the first time in two years, Big G (the cereal division of General Mills) raised cereal prices by 4 percent. If, as a result of this price increase, the volume of all cereal sold by Big G dropped by 5 percent, what can you infer about the own price elasticity of demand for Big G cereal? Can you predict whether revenues on sales of its Lucky Charms brand increased or decreased? Explain. *(LO1, LO3)*
14. If Starbucks's data analytics department estimates the income elasticity of demand for its coffee to be 1.6, how will the prospect of an economic boom (expected to increase consumers' incomes by 3 percent over the next year) impact the quantity of coffee Starbucks expects to sell? *(LO1)*



15. You are a division manager at Toyota. If your data analytics department estimates that the semiannual demand for the Highlander is $Q = 150{,}000 - 1.5P$, what price should you charge in order to maximize revenues from sales of the Highlander? *(LO1, LO2, LO4, LO5)*
16. You are a manager in charge of monitoring cash flow at a major publisher. Paper books comprise 40 percent of your revenues, which grow about 2 percent annually. You recently received a preliminary report that suggests the growth rate in ebook reading has leveled off and that the cross-price elasticity of demand between paper books and ebooks is −0.3. In 2019, your company earned about $600 million from sales of ebooks and about $400 million from sales of paper books. If your data analytics team estimates the

own price elasticity of demand for paper books is −2, how will a 4 percent decrease in the price of paper books affect your overall revenues from both paper book and ebook sales? *(LO1, LO2)*

17. As newly appointed "Energy Czar," your goal is to reduce the total demand for residential heating fuel in your state. You must choose one of three legislative proposals designed to accomplish this goal: (*a*) a tax that would effectively increase the price of residential heating fuel by $1, (*b*) a subsidy that would effectively reduce the price of natural gas by $3, or (*c*) a tax that would effectively increase the price of electricity (produced by hydroelectric facilities) by $4. To assist you in your decision, an economist in your office has estimated the demand for residential heating fuel using a linear demand specification. The regression results are presented as follows. Based on this information, which proposal would you favor? Explain. *(LO6)*

	A	B	C	D	E	F	G
1	**SUMMARY OUTPUT**						
2							
3	***Regression Statistics***						
4	Multiple *R*	0.76					
5	*R*-square	0.57					
6	Adjusted *R*-square	0.49					
7	Standard error	47.13					
8	Observations	25					
9							
10	***Analysis of Variance***						
11		***Degrees of Freedom***	***Sum of Squares***	***Mean Square***	***F***	***Significance F***	
12	Regression	4	60936.56	15234.14	6.86	.03	
13	Residual	20	44431.27	2221.56			
14	Total	24	105367.84				
15							
16		***Coefficients***	***Standard Error***	***t-Statistic***	***P-Value***	***Lower 95%***	***Upper 95%***
17	Intercept	136.96	43.46	3.15	0.01	50.60	223.32
18	Price of residential heating fuel	−91.69	29.09	−3.15	0.01	−149.49	−33.89
19	Price of natural gas	43.88	9.17	4.79	0.00	25.66	62.10
20	Price of electricity	−11.92	8.35	−1.43	0.17	−28.51	4.67
21	Income	−0.050	0.3500	−0.14	0.90	−0.75	0.65

18. As the owner of Barney's Broilers—a fast-food chain—you see an increase in the demand for broiled chicken as consumers become more health conscious and reduce their consumption of beef and fried foods. As a result, you believe it is necessary to purchase another oven to meet the increased demand. To finance the oven, you go to the bank seeking a loan. The loan officer tells you that your revenues of $750,000 are insufficient to support additional debt. To qualify for the loan, Barney's Broilers's revenue would need to be $50,000 higher. In developing a strategy to generate the additional revenue, you collect data on the price (in cents) per pound you charge customers and the related quantity of chicken consumed per year in pounds. This information is contained in the file called *Q03-18.xls* available online at www.mhhe.com/baye10e. Use these data and a log-linear demand specification to obtain least squares estimates of the demand for broiled chicken. Write an equation that summarizes the demand for broiled chicken, and then determine the percentage price increase or decrease that is needed in order to boost revenues by $50,000. *(LO1, LO4, LO5, LO6)*

19. Suppose the Kalamazoo Brewing Company (KBC) currently sells its microbrews in a seven-state area: Illinois, Indiana, Michigan, Minnesota, Mississippi, Ohio, and Wisconsin. The company's data analytics department has collected data from its distributors in each state. These data consist of the quantity and price (per case) of microbrews sold in each state, as well as the average income (in thousands of dollars) of consumers living in various regions of each state. The data for each state are available online at www.mhhe.com/baye10e under the filename *Q03-19.xls*, where there are multiple tabs at the bottom of the spreadsheet, each referring to one of the seven states selling the Kalamazoo Brewing Company's microbrews. Assuming that the underlying demand relation is a linear function of price and income, use your spreadsheet program to obtain least squares estimates of the state's demand for KBC microbrews. Print the regression output and provide an economic interpretation of the regression results. *(LO6)*

20. With milk sales sagging of late, The Milk Processor Education Program (MPEP) decided to move on from the famous "Got Milk" ad slogan in favor of a new one, "Milk Life." The new tagline emphasizes milk's nutritional benefits, including its protein content. MPEP began collecting data on the number of gallons of milk households consumed weekly (in millions), weekly price per gallon, and weekly expenditures on milk advertising (in hundreds of dollars) for the period following the launch of the new campaign. These data are available online at www.mhhe.com/baye10e in a file named *Q03-20.xls*. Use these data to estimate a linear regression. Suppose that the weekly price of milk is $3.40 per gallon and MPEP decides to ramp up weekly advertising by 35 percent to $150 (in hundreds). Use your regression model to estimate the weekly quantity of milk consumed after this advertising increase. *(LO6)*

21. Suppose that News Corp., which controls the United States' largest satellite-to-TV broadcaster, is contemplating launching a Spaceway satellite that could provide high-speed Internet service. Prior to launching the Spaceway satellite, suppose that News Corp. used least squares to estimate the regression line of demand for satellite Internet services. The best-fitting results indicate that demand is $Q^d_{sat} = 152.5 - .8P_{sat} + 1.2P_{DSL} + .5P_{cable}$ (in thousands), where P_{sat} is the price of satellite Internet service, P_{DSL} is the price of DSL Internet service, and P_{cable} is the price of high-speed cable Internet service. The price of DSL, P_{DSL}, is $25 per month and the monthly price of high-speed cable Internet, P_{cable}, is $50. Furthermore, News Corp. has identified that its monthly revenues need to be at least $15 million to cover its monthly costs. If News Corp. set its monthly subscription price for satellite Internet service at $55, would its revenue be sufficiently high to cover its cost? Is it possible for News Corp. to cover its cost given the current demand function? Justify your answer. *(LO1, LO2, LO4, LO5)*

22. Recently, Verizon Wireless ran a pricing trial in order to estimate the elasticity of demand for its services. The manager selected three states that were representative of its entire service area and increased prices by 5 percent to customers in those areas. One week later, the number of customers enrolled in Verizon's cellular plans declined 4 percent in those states, while enrollments in states where prices were not increased remained flat. The manager used this information to estimate the own price elasticity of demand and, based on her findings, immediately increased prices in all market areas by 5 percent in an attempt to boost the company's 2020 annual revenues. One year later, the manager was perplexed because Verizon's 2020 annual revenues were 10 percent lower than those in 2019—the price increase apparently led to a reduction in the company's revenues. Did the manager make an error? Explain. *(LO1, LO3, LO4)*

23. The owner of a small chain of gasoline stations in a large Midwestern town read an article in a trade publication stating that the own price elasticity of demand for gasoline in the United States is −0.2. Because of this highly inelastic demand in the United States, he is thinking about raising prices to increase revenues and profits. Do you recommend this strategy based on the information he has obtained? Explain. *(LO1, LO3, LO4)*

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4 The Theory of Individual Behavior

LEARNING OBJECTIVES

After completing this chapter, you will be able to:

- **LO1** Explain four basic properties of a consumer's preference ordering and their ramifications for a consumer's indifference curves.
- **LO2** Illustrate how changes in prices and income impact an individual's opportunities.
- **LO3** Illustrate a consumer's equilibrium choice and how it changes in response to changes in prices and income.
- **LO4** Separate the impact of a price change into substitution and income effects.
- **LO5** Show how to derive an individual's demand curve from indifference curve analysis and market demand from a group of individuals' demands.
- **LO6** Illustrate how "buy one, get one free" deals and gift certificates affect a consumer's purchase decisions.
- **LO7** Apply the income–leisure choice framework to illustrate the opportunities, incentives, and choices of workers and managers.

headLINE

Packaging Firm Uses Overtime Pay to Overcome Labor Shortage

Boxes Ltd. produces corrugated paper containers at a small plant in Sunrise Beach, Texas. Sunrise Beach is a retirement community with an aging population, and over the past decade the size of its working population has shrunk. In 2019, this labor shortage hampered Boxes Ltd.'s ability to hire enough workers to meet its growing demand and production targets. This is despite the fact that it pays $16 per hour—almost 30 percent more than the local average—to its workers.

Last year, Boxes Ltd. hired a new manager who instituted an overtime wage plan at the firm. Under her plan, workers earn $16 per hour for the first eight hours worked each day and $24 per hour for each hour worked in a day in excess of eight hours. This plan eliminated the firm's problems, as the firm's production levels and profits are up by 20 percent this year.

Why did the new manager institute the overtime plan instead of simply raising the wage rate in an attempt to attract more workers to the firm?

INTRODUCTION

This chapter develops tools that help a manager understand the behavior of individuals, such as consumers and workers, and the impact of alternative incentives on their decisions. This is not as simple as you might think. Human beings use complicated thought processes to make decisions, and the human brain is capable of processing vast quantities of information. At this very moment your heart is pumping blood throughout your body, your lungs are providing oxygen and expelling carbon dioxide, and your eyes are scanning this page while your brain processes the information on it. The human brain can do what even supercomputers and sophisticated "artificial intelligence" technology are incapable of doing.

Despite the complexities of human thought processes, managers need a model that explains how individuals behave in the marketplace and in the work environment. Of course, attempts to model individual behavior cannot capture the full range of real-world behavior. Life would be simpler for managers of firms if the behavior of individuals were not so complicated. On the other hand, the rewards for being a manager of a firm would be much lower. If you achieve an understanding of individual behavior, you will gain a marketable skill that will help you succeed in the business world.

Our model of behavior will necessarily be an abstraction of the way individuals really make decisions. We must begin with a simple model that focuses on essentials instead of dwelling on behavioral features that would do little to enhance our understanding. Keep these thoughts in mind as we begin our study of an economic model of consumer behavior.

CONSUMER BEHAVIOR

Now that you recognize that any theory about individual behavior must be an abstraction of reality, we may begin to develop a model to help us understand how consumers will respond to the alternative choices that confront them. A *consumer* is an individual who purchases goods and services from firms for the purpose of consumption. As a manager of a firm, you are interested not only in who consumes the good but in who purchases it. A six-month-old baby consumes goods but is not responsible for purchase decisions. If you are employed by a manufacturer of baby food, it is the parent's behavior you must understand, not the baby's.

In characterizing consumer behavior, there are two important but distinct factors to consider: consumer opportunities and consumer preferences. *Consumer opportunities* represent the possible goods and services consumers can afford to consume. *Consumer preferences* determine which of these goods will be consumed. The distinction is very important: While I can afford (and thus have the opportunity to consume) one pound of beef liver each week, my preferences are such that I would be unlikely to choose to consume beef liver at all. Keeping this distinction in mind, let us begin by modeling consumer preferences.

In today's global economy literally millions of goods are offered for sale. However, to focus on the essential aspects of individual behavior and to keep things manageable, we will assume that only two goods exist in the economy. This assumption is made purely to simplify our analysis: All of the conclusions that we draw from this two-good setting remain valid when there are many goods. We will let X represent the quantity of one good and Y the quantity of the other good. By using this notation to represent the two goods, we have a very

general model in the sense that X and Y can be any two goods rather than restricted to, say, beef and pork.

Assume a consumer is able to order his or her preferences for alternative bundles or combinations of goods from best to worst. We will let $\succ$ denote this ordering and write $A \succ B$ whenever the consumer prefers bundle A to bundle B. If the consumer views the two bundles as equally satisfying, we will say she or he is indifferent between bundles A and B and use $A \sim B$ as shorthand notation. If $A \succ B$, then, if given a choice between bundle A and bundle B, the consumer will choose bundle A. If $A \sim B$, the consumer, given a choice between bundle A and bundle B, will not care which bundle he or she gets. The preference ordering is assumed to satisfy four basic properties: completeness, more is better, diminishing marginal rate of substitution, and transitivity. Let us examine these properties and their implications in more detail.

Property 4–1: Completeness. For any two bundles—say, A and B—either $A \succ B$, $B \succ A$, or $A \sim B$.

By assuming that preferences are *complete*, we assume the consumer is capable of expressing a preference for, or indifference among, all bundles. If preferences were not complete, there might be cases where a consumer would claim not to know whether he or she preferred bundle A to B, preferred B to A, or was indifferent between the two bundles. If the consumer cannot express her or his own preference for or indifference among goods, the manager can hardly predict that individual's consumption patterns with reasonable accuracy.

Property 4–2: More Is Better. If bundle A has at least as much of every good as bundle B and more of some good, bundle A is preferred to bundle B.

If *more is better*, the consumer views the products under consideration as "goods" instead of "bads." Graphically, this implies that as we move in the northeast direction in Figure 4–1, we move to bundles that the consumer views as being better than bundles to the southwest. For example, in Figure 4–1 bundle A is preferred to bundle D because it has the same amount of good X and more of good Y. Bundle C is also preferred to bundle D because it has more of both goods. Similarly, bundle B is preferred to bundle D.

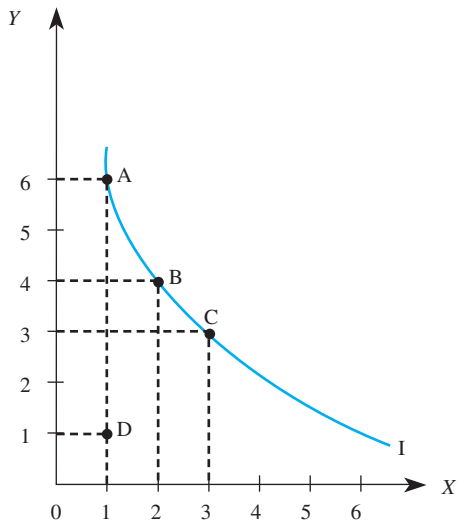


Figure 4–1
The Indifference Curve

While the assumption that more is better provides important information about consumer preferences, it does not help us determine a consumer's preference for all possible bundles. For example, note in Figure 4–1 that the "more is better" property does not reveal whether bundle *B* is preferred to bundle *A* or bundle *A* is preferred to bundle *B*. To be able to make such comparisons, we will need to make some additional assumptions.

indifference curve
A curve that defines the combinations of two goods that give a consumer the same level of satisfaction.

An **indifference curve** defines the combinations of goods *X* and *Y* that give the consumer the same level of satisfaction; that is, the consumer is indifferent between any combination of goods along an indifference curve. A typical indifference curve is depicted in Figure 4–1. By definition, all combinations of *X* and *Y* located on the indifference curve provide the consumer with the same level of satisfaction. For example, if you asked the consumer, "Which would you prefer—bundle *A*, bundle *B*, or bundle *C*?" the consumer would reply, "I don't care" because bundles *A*, *B*, and *C* all lie on the same indifference curve. In other words, the consumer is indifferent among the three bundles.

The shape of the indifference curve depends on the consumer's preferences. Different consumers generally will have indifference curves of different shapes. One important way to summarize information about a consumer's preferences is in terms of the marginal rate of substitution. The **marginal rate of substitution (*MRS*)** is the absolute value of the slope of an indifference curve. The marginal rate of substitution between two goods is the rate at which a consumer is willing to substitute one good for the other and still maintain the same level of satisfaction.

marginal rate of substitution (*MRS*)
The rate at which a consumer is willing to substitute one good for another good and still maintain the same level of satisfaction.

The concept of the marginal rate of substitution is actually quite simple. In Figure 4–1, the consumer is indifferent between bundles *A* and *B*. In moving from *A* to *B*, the consumer gains 1 unit of good *X*. To remain on the same indifference curve, she or he gives up 2 units of good *Y*. Thus, in moving from point A to point B, the marginal rate of substitution between goods *X* and *Y* is 2.

The careful reader will note that the marginal rate of substitution associated with moving from A to B in Figure 4–1 differs from the rate at which the consumer is willing to substitute between the two goods in moving from B to C. In particular, in moving from B to C, the consumer gains 1 unit of good *X*. But now he or she is willing to give up only 1 unit of good *Y* to get the additional unit of *X*. The reason is that this indifference curve satisfies the property of the *diminishing marginal rate of substitution*.

Property 4–3: Diminishing Marginal Rate of Substitution. As a consumer obtains more of good *X*, the amount of good *Y* he or she is willing to give up to obtain another unit of good *X* decreases.

This assumption implies that indifference curves are convex from the origin; that is, they look like the indifference curve in Figure 4–1. To see how the locations of various indifference curves can be used to illustrate different levels of consumer satisfaction, we must make an additional assumption: that preferences are *transitive*.

Property 4–4: Transitivity. For any three bundles, *A*, *B*, and *C*, if $A \succ B$ and $B \succ C$, then $A \succ C$. Similarly, if $A \sim B$ and $B \sim C$, then $A \sim C$.

The assumption of transitive preferences, together with the more-is-better assumption, implies that indifference curves do not intersect one another. It also eliminates the possibility that the consumer is caught in a perpetual cycle in which she or he never makes a choice.

To see this, suppose Billy's preferences are such that he prefers jelly beans to licorice, licorice to chocolate, and chocolate to jelly beans. He asks the clerk to fill a bag with jelly beans because he prefers jelly beans to licorice. When the clerk hands him a bagful of jelly

INSIDE BUSINESS 4–1

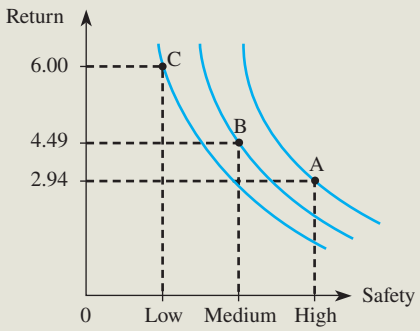
Indifference Curves and Risk Preferences

Have you ever wondered why some individuals choose to undertake risky prospects, such as skydiving and investing in risky financial assets, while others choose safer activities? Indifference curve analysis provides an answer to this question.

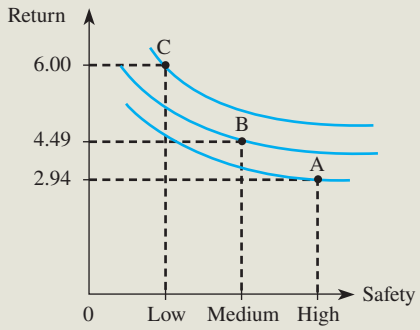
The accompanying figures plot three potential investment options (represented by points A, B, and C), each with different expected returns and risks. Option A is the safest investment, but it offers the lowest return (2.94 percent); option B is of medium safety, with a moderate return (4.49 percent); and fund C is the least safe, but it carries the highest potential return (6.00 percent).

Investors view safety and the level of the return on an investment as "goods"; investments with higher returns and higher levels of safety are preferred to investments with lower returns and lower levels of safety. Investors are willing to substitute between the level of return and the level of safety. Given the three options, from an investor's viewpoint, there is a trade-off between a higher reward (return) and the level of safety of the investment.

The relatively steep indifference curves drawn in panel (a) describe an investor who has a high marginal rate of substitution between return and safety; she or he must receive a large return to be induced to give up a small amount of safety. The relatively flat indifference curves drawn in panel (b) indicate an investor with a low marginal rate of substitution between return and safety. This individual is willing to give up a lot of safety to get a slightly higher return. An investor with indifference curves such as those in panel (a) finds investment option A most attractive, because it is associated with the highest indifference curve. In contrast, an investor with indifference curves such as those in panel (b) achieves the highest indifference curve with investment option C. Both types of investors are rational, but one investor is willing to give up some additional financial return for more safety.



(a): Safety Chooser

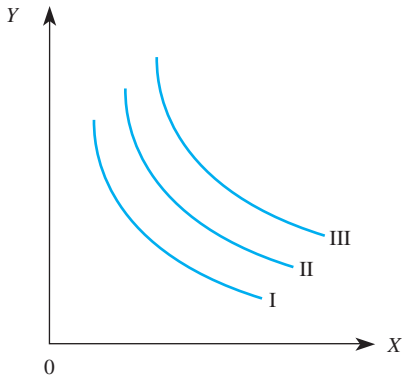


(b): Risk Chooser

beans, Billy tells her he likes chocolate even more than jelly beans. When the clerk hands him a bagful of chocolate, he tells her he likes licorice even more than chocolate. When the clerk hands him a bagful of licorice, Billy tells her he likes jelly beans even more than licorice. The clerk puts back the licorice and hands Billy a bagful of jelly beans. Now Billy is right back where he started! He is unable to choose the "best" kind of candy because his preferences for kinds of candy are not transitive.

The implications of these four properties are conveniently summarized in Figure 4–2, which depicts three indifference curves. Every bundle on indifference curve III is preferred to those on curve II, and every bundle on indifference curve II is preferred to those on curve I.

Figure 4–2
A Family of Indifference Curves



The three indifference curves are convex and do not cross. Curves farther from the origin imply higher levels of satisfaction than curves closer to the origin.

CONSTRAINTS

In making decisions, individuals face *constraints*. There are legal constraints, time constraints, physical constraints, and, of course, budget constraints. To maintain our focus on the essentials of managerial economics without delving into issues beyond the scope of this course, we will examine the role prices and income play in constraining consumer behavior.

The Budget Constraint

Simply stated, the *budget constraint* restricts consumer behavior by forcing the consumer to select a bundle of goods that is affordable. If a consumer has only $30 in his or her pocket when reaching the checkout line in the supermarket, the total value of the goods the consumer presents to the cashier cannot exceed $30.

To demonstrate how the presence of a budget constraint restricts the consumer's choice, we need some additional shorthand notation. Let M represent the consumer's income, which can be any amount. By using M instead of a particular value of income, we gain generality in that the theory is valid for a consumer with any income level. We will let P_x and P_y represent the prices of goods X and Y, respectively. Given this notation, the opportunity set (also called the **budget set**) may be expressed mathematically as

budget set
The bundles of goods a consumer can afford.

$$P_xX + P_yY \leq M$$

In words, the budget set defines the combinations of goods X and Y that are affordable for the consumer: The consumer's expenditures on good X, plus her or his expenditures on good Y, do not exceed the consumer's income. Note that if the consumer spends his or her entire income on the two goods, this equation holds with equality. This relation is called the **budget line**:

budget line
The bundles of goods that exhaust a consumer's income.

$$P_xX + P_yY = M$$

In other words, the budget line defines all the combinations of goods X and Y that exactly exhaust the consumer's income.

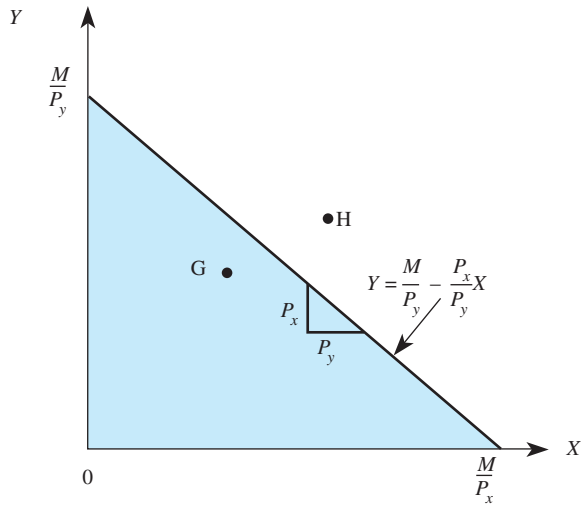


Figure 4–3
The Budget Set

It is useful to manipulate the equation for the budget line to obtain an alternative expression for the budget constraint in slope-intercept form. If we multiply both sides of the budget line by $1/P_y$, we get

$$\frac{P_x}{P_y}X + Y = \frac{M}{P_y}$$

Solving for Y yields

$$Y = \frac{M}{P_y} - \frac{P_x}{P_y}X$$

Note that Y is a linear function of X with a vertical intercept of M/P_y and a slope of $-P_x/P_y$.

The consumer's budget constraint is graphed in Figure 4–3. The shaded area represents the consumer's budget set, or opportunity set. In particular, any combination of goods X and Y within the shaded area, such as point G, represents an affordable combination of X and Y. Any point above the shaded area, such as point H, represents a bundle of goods that is unaffordable.

The upper boundary of the budget set in Figure 4–3 is the budget line. If a consumer spent her or his entire income on good X, the expenditures on good X would exactly equal the consumer's income:

$$P_xX = M$$

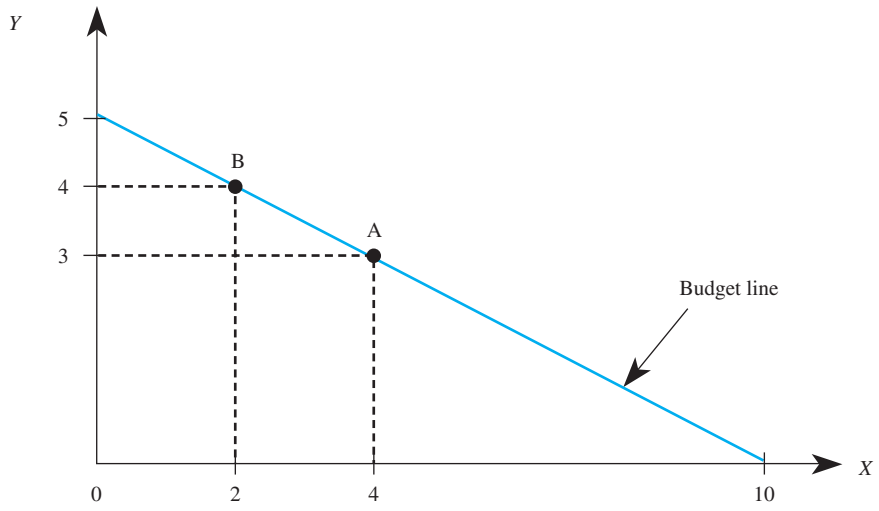
By manipulating this equation, we see that the maximum affordable quantity of good X consumed is

$$X = \frac{M}{P_x}$$

This is why the horizontal intercept of the budget line is

$$\frac{M}{P_x}$$

Figure 4–4
The Budget Line



Similarly, if the consumer spent his or her entire income on good Y, expenditures on Y would exactly equal income:

$$P_y Y = M$$

Consequently, the maximum quantity of good Y that is affordable is

$$Y = \frac{M}{P_y}$$

market rate of substitution
The rate at which one good may be traded for another in the market; slope of the budget line.

The slope of the budget line is given by $-P_x/P_y$ and represents the **market rate of substitution** between goods X and Y. To obtain a better understanding of the market rate of substitution between goods X and Y, consider Figure 4–4, which presents a budget line for a consumer who has \$10 in income and faces a price of \$1 for good X and a price of \$2 for good Y. If we substitute these values of P_x, P_y, and M into the formula for the budget line, we observe that the vertical intercept of the budget line (the maximum amount of good Y that is affordable) is $M/P_y = 10/2 = 5$. The horizontal intercept is $M/P_x = 10/1 = 10$ and represents the maximum amount of good X that can be purchased. The slope of the budget line is $-P_x/P_y = -(1/2)$.

The reason the slope of the budget line represents the market rate of substitution between the two goods is as follows: Suppose a consumer purchased bundle A in Figure 4–4, which represents the situation where the consumer purchases 3 units of good Y and 4 units of good X. If the consumer purchased bundle B instead of bundle A, she would gain one additional unit of good Y. But to afford this, she must give up 2 units $(4 - 2 = 2)$ of good X. For every unit of good Y the consumer purchases, she must give up 2 units of good X in order to be able to afford the additional unit of good Y. Thus the market rate of substitution is $\Delta Y/\Delta X = (4 - 3)/(2 - 4) = -1/2$, which is the slope of the budget line.

Changes in Income

The consumer's opportunity set depends on market prices and the consumer's income. As these parameters change, so will the consumer's opportunities. Let us now examine the effects on the opportunity set of changes in income by assuming prices remain constant.

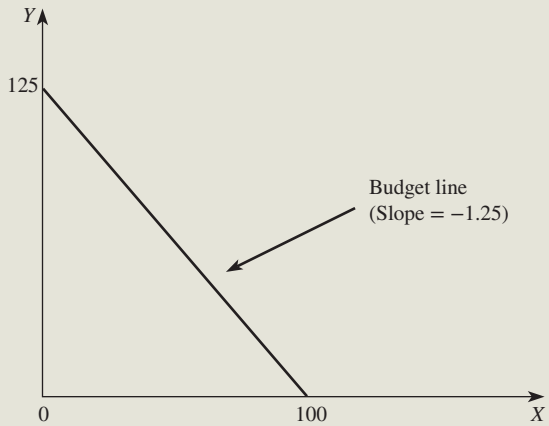
INSIDE BUSINESS 4–2

The Budget Constraint and Credit Cards

In today's economy, many consumers choose to make purchases using credit cards rather than cash. How does access to a credit card affect a consumer's budget constraint? A key aspect of credit cards is that they allow us to consume today and pay later. We can capture this feature of credit cards within our framework by considering a consumer's decision about purchasing a product—for example, music downloads—at different points in time.

Let X be music downloads today (period 1) and Y be music downloads one period later (period 2). For simplicity, let the price of a music download in both periods be \$1. Suppose in period 1, Kate is considering purchasing some music downloads but has no more cash on hand. However, she has access to \$100 of credit on her credit card, which she must pay off in period 2. The interest rate on her card is 25 percent. Since, regardless of her purchase timing, she does not make any payments until period 2, we can construct her budget line in terms of income and prices in period 2. The price of a music download in period 2 is \$1; however, the price of a music download in period 1 will cost her \$1.25 in period 2 money since she must borrow the \$1 price at an interest rate of 25 percent.

From the preceding discussion, Kate's budget line in terms of period 2 money has the following features: $M = \$125$, $P_x = \$1.25$, and $P_y = \$1$. This budget line is illustrated in the accompanying figure. The slope of −1.25 represents the amount of music downloads she must give up from period 2 to buy one more in period 1.



Suppose the consumer's initial income in Figure 4–5 is M^0. What happens if M^0 increases to M^1 while prices remain unchanged? Recall that the slope of the budget line is given by $-P_x/P_y$. Under the assumption that prices remain unchanged, the increase in income will not affect the slope of the budget line.

However, the vertical and horizontal intercepts of the budget line both increase as the consumer's income increases because more of each good can be purchased at the higher income. Thus, when income increases from M^0 to M^1, the budget line shifts to the right in a

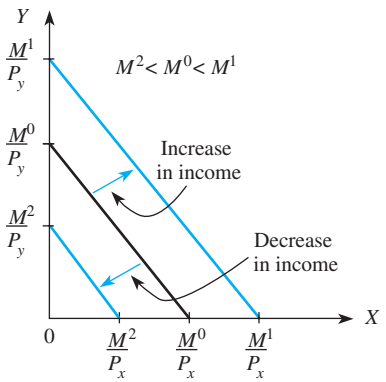
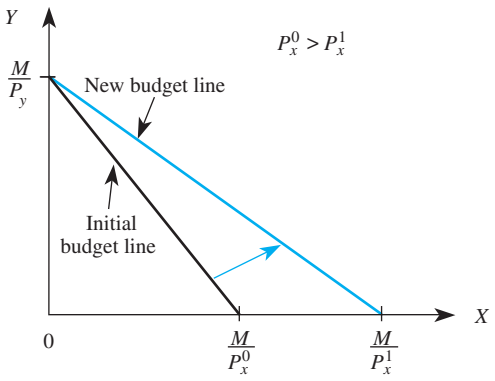


Figure 4–5
Changes in Income Shrink or Expand Opportunities

Figure 4–6
A Decrease in the Price of Good *X*



parallel fashion. This reflects an increase in the consumer's opportunity set because more goods are affordable after the increase in income than before. Similarly, if income decreases to M^2 from M^0, the budget line shifts toward the origin and the slope of the budget line remains unchanged.

Changes in Prices

Now suppose the consumer's income remains fixed at M, but the price of good X decreases to $P_x^1 < P_x^0$. Furthermore, suppose the price of good Y remains unchanged. Since the slope of the budget line is given by $-P_x/P_y$, the reduction in the price of good X changes the slope, making it flatter than before. Since the maximum amount of good Y that can be purchased is M/P_y, a reduction in the price of good X does not change the Y intercept of the budget line. But the maximum amount of good X that can be purchased at the lower price (the X intercept of the budget line) is M/P_x^1, which is greater than M/P_x^0. Thus, the ultimate effect of a reduction in the price of good X is to rotate the budget line counterclockwise, as in Figure 4–6. Similarly, an increase in the price of good X leads to a clockwise rotation of the budget line, as the next demonstration problem indicates.

DEMONSTRATION PROBLEM 4–1

A consumer has an initial income of \$100 and faces prices of $P_x = \$1$ and $P_y = \$5$. Graph the budget line, and show how it changes when the price of good X increases to $P_x^1 = \$5$.

ANSWER:

Initially, if the consumer spends his entire income on good X, he can purchase $M/P_x = 100/1 = 100$ units of X. This is the horizontal intercept of the initial budget line in Figure 4–7. If the consumer spends his entire income on good Y, he can purchase $M/P_y = 100/5 = 20$ units of Y. This is the vertical intercept of the initial budget line. The slope of the initial budget line is $-P_x/P_y = -1/5$.

When the price of good X increases to 5, the maximum amount of X the consumer can purchase is reduced to $M/P_x = 100/5 = 20$ units of X. This is the horizontal intercept of the new budget line in Figure 4–7. If the consumer spends his entire income on good Y, he can purchase $M/P_y = 100/5 = 20$ units of Y. Thus, the vertical intercept of the budget line remains unchanged; the slope changes to $-P_x^1/P_y = -5/5 = -1$.

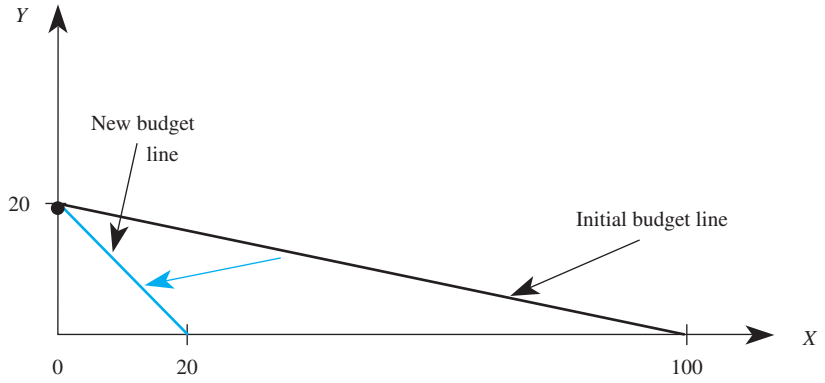


Figure 4–7
An Increase in the Price of Good *X*

CONSUMER EQUILIBRIUM

The objective of the consumer is to choose the consumption bundle that maximizes his or her utility, or satisfaction. If there was no scarcity, the *more-is-better* property would imply that the consumer would want to consume bundles that contained infinite amounts of goods. However, one implication of scarcity is that the consumer must select a bundle that lies inside the budget set, that is, an affordable bundle. Let us combine our theory of consumer preferences with our analysis of constraints to see how the consumer goes about selecting the best affordable bundle.

Consider a bundle such as *A* in Figure 4–8. This combination of goods *X* and *Y* lies on the budget line, so the cost of bundle *A* completely exhausts the consumer's income. Given the income and prices corresponding to the budget line, can the consumer do better—that is, can the consumer achieve a higher indifference curve? Clearly, if the consumer consumed bundle *B* instead of bundle *A*, she or he would be better off since the indifference curve through *B* lies above the one through *A*. Moreover, bundle *B* lies on the budget line and thus is affordable. In short, it is inefficient for the consumer to consume bundle *A* because bundle *B* both is affordable and yields a higher level of well-being.

Is bundle *B* optimal? The answer is no. Bundle *B* exhausts the consumer's budget, but there is another affordable bundle that is even better: bundle *C*. Note that there are bundles, such as *D*, that the consumer prefers more than bundle *C*, but those bundles are not affordable. Thus, we say bundle *C* represents the consumer's *equilibrium choice*. The term *equilibrium*

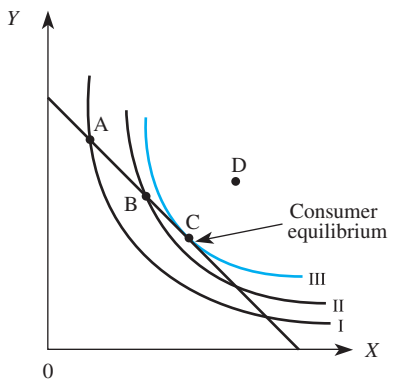


Figure 4–8
Consumer Equilibrium

refers to the fact that the consumer has no incentive to change to a different affordable bundle once this point is reached.

consumer equilibrium The equilibrium consumption bundle is the affordable bundle that yields the greatest satisfaction to the consumer.

An important property of **consumer equilibrium** is that at the equilibrium consumption bundle, the slope of the indifference curve is equal to the slope of the budget line. Recalling that the absolute value of the slope of the indifference curve is called the *marginal rate of substitution* and the slope of the budget line is given by $-P_x/P_y$, we see that at a point of consumer equilibrium,

$$MRS = \frac{P_x}{P_y}$$

If this condition did not hold, the personal rate at which the consumer is willing to substitute between goods X and Y would differ from the market rate at which he or she is able to substitute between the goods. For example, at point A in Figure 4–8, the slope of the indifference curve is steeper than the slope of the budget line. This means the consumer is willing to give up more of good Y to get an additional unit of good X than she or he actually has to give up, based on market prices. Consequently, it is in the consumer's interest to consume less of good Y and more of good X. This substitution continues until ultimately the consumer is at a point such as C in Figure 4–8, where the MRS is equal to the ratio of prices.

COMPARATIVE STATICS

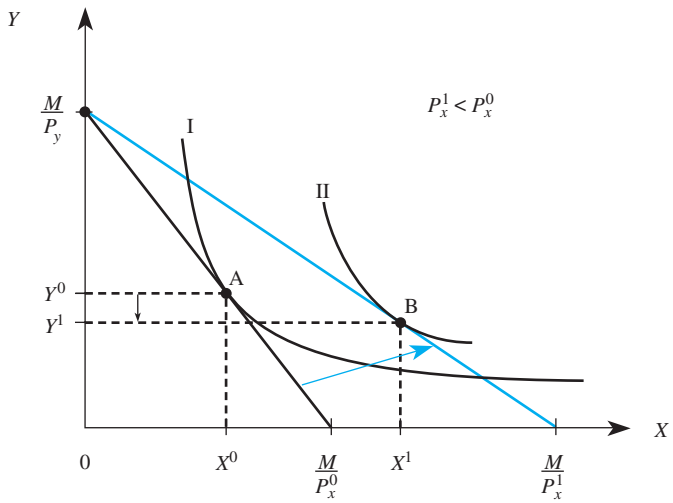
Price Changes and Consumer Behavior

A change in the price of a good will lead to a change in the equilibrium consumption bundle. To see this, recall that a reduction in the price of good X leads to a counterclockwise rotation of the budget line. Thus, if the consumer initially is at equilibrium at point A in Figure 4–9, when the price of good X falls to P_x^1, his or her opportunity set expands. Given this new opportunity set, the consumer can achieve a higher level of satisfaction. This is illustrated as a movement to the new equilibrium point, B, in Figure 4–9.

Precisely where the new equilibrium point lies along the new budget line after a price change depends on consumer preferences. Accordingly, it is useful to recall the definitions of substitutes and complements that were introduced in Chapter 2.

Figure 4–9

Change in Consumer Equilibrium Due to a Decrease in the Price of Good *X* (Note that good *Y* is a substitute for *X*.)



INSIDE BUSINESS 4–3

Price Changes and Inventory Management for Multiproduct Firms

One of the more important decisions a manager must make is how much inventory to have on hand. Too little inventory means an insufficient quantity of products to meet the demand of consumers, in which case your customers may defect to another store. The opportunity cost of inventory is the forgone interest that could be earned on the money tied up in inventory, storage costs, and so on. In performing inventory management, an effective manager recognizes the relationship that exists among products in the store and the impact of a change in the price of one product on the required inventories of other products. For example, a decline in the price of video game *consoles* not only increases the quantity demanded of game consoles, but also increases the demand for video *games*, which are complementary goods. This result has obvious implications for inventory management.

A more subtle aspect of a reduction in the price of a product is its impact on the demand for, and optimal inventories of, substitute goods. If a retailer sells many products, and some of the products are substitutes, a reduction in the price of one product will lead to a reduction in the retailer's sales of these substitute goods. For instance, when the price of Xbox One Series X game consoles is reduced, the consumption of Xbox One Series X consoles increases as a direct consequence of the price reduction. However, note that the consumption of substitutes like PS5 game consoles will decrease as a result of the reduction in the price of Xbox One Series X game consoles. If the manager does not account for the impact of a price reduction on the consumption of substitute goods, he or she is likely to face a buildup of inventories of PS5 consoles when the price of Xbox One Series X game consoles decreases.

First, goods X and Y are called *substitutes* if an increase (decrease) in the price of X leads to an increase (decrease) in the consumption of Y. Most consumers would view Coke and Pepsi as substitutes. If the price of Pepsi increased, most people would tend to consume more Coke. If goods X and Y are substitutes, a reduction in the price of X would lead the consumer to move from point A in Figure 4–9 to a point such as B, where less of Y is consumed than at point A.

Second, goods X and Y are called *complements* if an increase (decrease) in the price of good X leads to a decrease (increase) in the consumption of good Y. Beer and pretzels are an example of complementary goods. If the price of beer increased, most beer drinkers would decrease their consumption of pretzels. When goods X and Y are complements, a reduction in the price of X would lead the consumer to move from point A in Figure 4–10 to a point such as B, where more of Y is consumed than before.

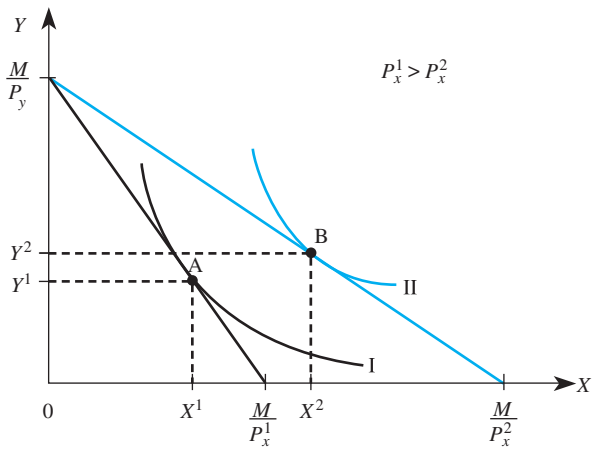


Figure 4–10
When the Price of Good *X* Falls, the Consumption of Complementary Good *Y* Rises

From a managerial perspective, the key thing to note is that changes in prices affect the market rate at which a consumer can substitute among various goods. Therefore, changes in prices will change the behavior of consumers. Price changes might occur because of updated pricing strategies within your own firm. Or they might arise because of price changes made by rivals or firms in other industries. Ultimately, price changes alter consumer incentives to buy different goods, thereby changing the mix of goods they purchase in equilibrium. The primary advantage of indifference curve analysis is that it allows a manager to see how price changes affect the mix of goods that consumers purchase in equilibrium. As we will see below, indifference curve analysis also allows us to see how changes in *income* affect the mix of goods consumers purchase.

Income Changes and Consumer Behavior

A change in income also will lead to a change in the consumption patterns of consumers. The reason is that changes in income either expand or contract the consumer's budget constraint, and the consumer therefore finds it optimal to choose a new equilibrium bundle. For example, assume the consumer initially is at equilibrium at point A in Figure 4–11. Now suppose the consumer's income increases to M^1 so that his or her budget line shifts out. Clearly the consumer can now achieve a higher level of satisfaction than before. This particular consumer finds it in her or his interest to choose bundle *B* in Figure 4–11, where the indifference curve through point B is tangent to the new budget line.

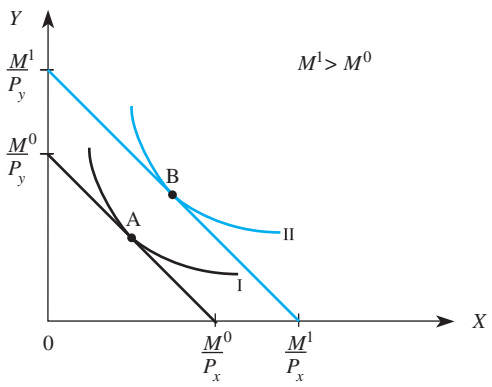
As in the case of a price change, the exact location of the new equilibrium point will depend on consumer preferences. Let us now review our definitions of normal and inferior goods.

Recall that good *X* is a *normal good* if an increase (decrease) in income leads to an increase (decrease) in the consumption of good *X*. Normal goods include goods such as steak, airline travel, and designer jeans. As income goes up, consumers typically buy more of these goods. Note in Figure 4–11 that the consumption of both goods *X* and *Y* increased due to the increase in consumer income. Thus, the consumer views *X* and *Y* as normal goods.

Recall that good *X* is an *inferior good* if an increase (decrease) in income leads to a decrease (increase) in the consumption of good *X*. Bologna, bus travel, and generic jeans are examples of inferior goods. As income goes up, consumers typically consume less of these goods and services. It is important to repeat that by calling the goods *inferior*, we do not imply that they are of poor quality; it is simply a term used to define products consumers purchase less of when their incomes rise.

Figure 4–11

An Increase in Income Increases the Consumption of Normal Goods



INSIDE BUSINESS 4–4

Income Effects and the Business Cycle

An important consideration in running a firm is the impact of changes in prices on the demand for the firm's product. Suppose you are the manager of a firm that sells a product that is a normal good and are considering expanding your product line to include another good. There are several things you may wish to consider in making your decision. Since your product is a normal good, you will sell more of it when the economy is booming (consumer incomes are high) than when times are tough (incomes are low). Your product is a cyclical product; that is, sales vary directly with the economy. This information may be useful to you when considering alternative products to include in your store. If you expand your offerings to include more normal goods, you will continue to have an operation that sells more during an economic boom than during a recession. But if you include in your operation some inferior goods, the demand for these products will increase during bad economic times (when incomes are low) and perhaps offset the decline in demand for normal goods. This is not to say that the optimal mix of products involves a 50–50 mix of normal and inferior goods; indeed, the optimal mix will depend on your own risk preference. The analysis does suggest that running a gourmet food store will likely involve a higher level of risk than running a supermarket. In particular, gourmet shops sell almost exclusively normal goods, while supermarkets have a more "balanced portfolio" of normal and inferior goods. This explains why, during recessions, many gourmet shops go out of business while supermarkets do not.

It is also useful to know the magnitude of the income effect when designing a marketing campaign. If the product is a normal good, it is most likely in the firm's interest to target advertising campaigns toward individuals with higher incomes. These factors should be considered when determining which magazines, television shows, and websites are the best outlets for advertising messages.

Figure 4–12 depicts the effect of an increase in income for the case when good X is an inferior good. When income increases, the consumer moves from point A to point B to maximize his or her satisfaction given the higher income. Since at point B the consumer consumes more of good Y than at point A, we know that good Y is a normal good. However, note that at point B less of good X is consumed than at point A, so we know this consumer views X as an inferior good.

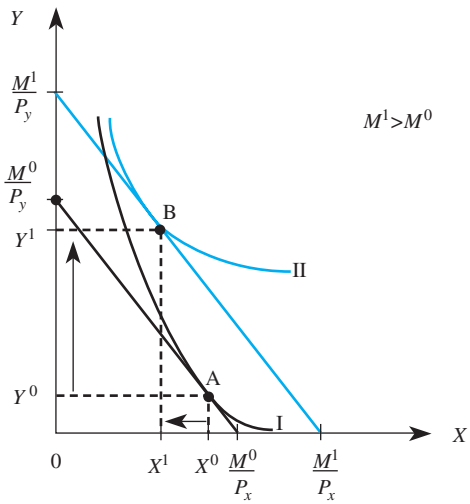


Figure 4–12

An Increase in Income Decreases the Equilibrium Consumption of Good *X*—An Inferior Good

Substitution and Income Effects

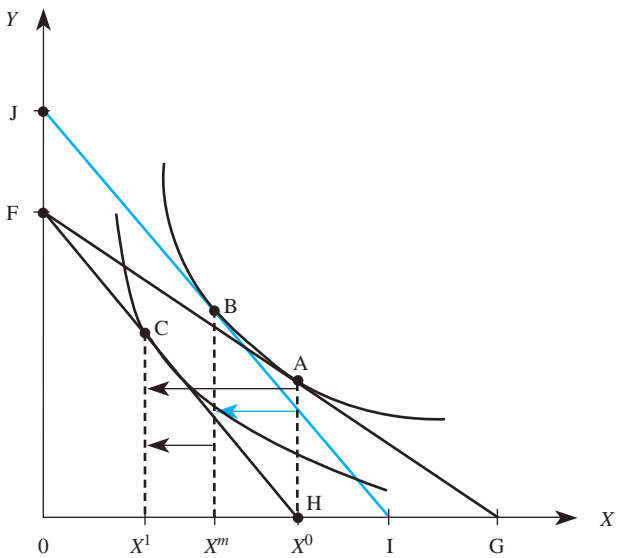
We can combine our analysis of price and income changes to gain a better understanding of the effect of a price change on consumer behavior. Suppose a consumer initially is in equilibrium at point A in Figure 4–13, along the budget line connecting points F and G. Suppose the price of good *X* increases so that the budget line rotates clockwise and becomes the budget line connecting points F and H. There are two things to notice about this change. First, since the budget set is smaller due to the price increase, the consumer will be worse off after the price increase. A lower "real income" will be achieved, as a lower indifference curve is all that can be reached after the price increase. Second, the increase in the price of good *X* leads to a budget line with a steeper slope, reflecting a higher market rate of substitution between the two goods. These two factors lead the consumer to move from the initial consumer equilibrium (point A) to a new equilibrium (point C) in Figure 4–13.

It is useful to isolate the two effects of a price change to see how each effect individually alters consumer choice. In particular, ignore for the moment the fact that the price increase leads to a lower indifference curve. Suppose that after the price increase, the consumer is given enough income to achieve the budget line connecting points J and I in Figure 4–13. This budget line has the same slope as budget line FH, but it implies a higher income than budget line FH. Given this budget line, the consumer will achieve equilibrium at point B, where less of good *X* is consumed than in the initial situation, point A. The movement from A to B is called the **substitution effect**; it reflects how a consumer will react to a different market rate of substitution. The substitution effect is the difference $X^0 - X^m$ in Figure 4–13. Importantly, the movement from A to B leaves the consumer on the same indifference curve, so the reduction in the consumption of good *X* implied by that movement reflects the higher market rate of substitution, not the reduced "real income," of the consumer.

substitution effect
The movement along a given indifference curve that results from a change in the relative prices of goods, holding real income constant.

The consumer does not actually face budget line JI when the price increases but instead faces budget line FH. Let us now take back the income we gave to the consumer to compensate for the price increase. When this income is taken back, the budget line shifts from JI to FH. This shift in the budget line reflects only a reduction in income; the slopes of budget lines

Figure 4–13
An Increase in the Price of Good *X* Leads to a Substitution Effect (A to B) and an Income Effect (B to C)



JI and FH are identical. Thus, the movement from B to C is called the **income effect**. The income effect is the difference $X^m - X^1$ in Figure 4–13; it reflects the fact that when price increases, the consumer's "real income" falls. Because good X is a normal good in Figure 4–13, the reduction in income leads to a further reduction in the consumption of X.

income effect
The movement from one indifference curve to another that results from the change in real income caused by a price change.

The total effect of a price increase thus is composed of substitution and income effects. The substitution effect reflects a movement along an indifference curve, thus isolating the effect of a relative price change on consumption. The income effect results from a parallel shift in the budget line; thus, it isolates the effect of reduced "real income" on consumption and is represented by the movement from B to C. The total effect of a price increase, which is what we observe in the marketplace, is the movement from A to C. The total effect of a change in consumer behavior results not only from the effect of a higher relative price of good X (the movement from A to B) but also from the reduced real income of the consumer (the movement from B to C).

APPLICATIONS OF INDIFFERENCE CURVE ANALYSIS

Choices by Consumers

Buy One, Get One Free

A very popular sales technique at pizza restaurants is to offer the following deal:

Buy one large pizza, get one large pizza free (limit one free pizza per customer).

It is tempting to conclude that this is simply a 50 percent reduction in the price of pizza so that the budget line rotates as it does for any price decrease. This conclusion is invalid, however. A price reduction decreases the price of each unit purchased. The "buy one, get one" pizza deal reduces only the price of the second unit purchased (in fact, it reduces the price of the second large pizza to zero). The offer does not change the price of units below one pizza and above two pizzas.

The *"buy one, get one free"* marketing scheme is quite easy to analyze in our framework. In Figure 4–14, a consumer initially faces a budget line connecting points A and B and is in

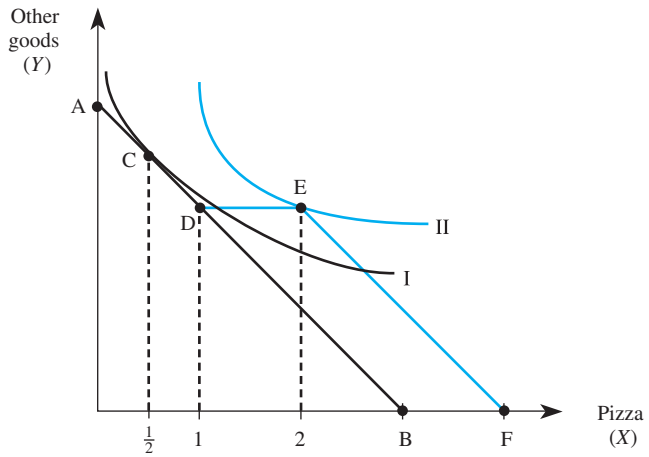


Figure 4–14
A Buy One, Get One Free Pizza Deal

equilibrium at point C. Point C represents one-half of a large pizza (say, a small pizza), so the consumer decides it is best to buy a small pizza instead of a large one. Point D represents the point at which she buys one large pizza, but, as we can see, the consumer prefers bundle C to bundle D since it lies on a higher indifference curve.

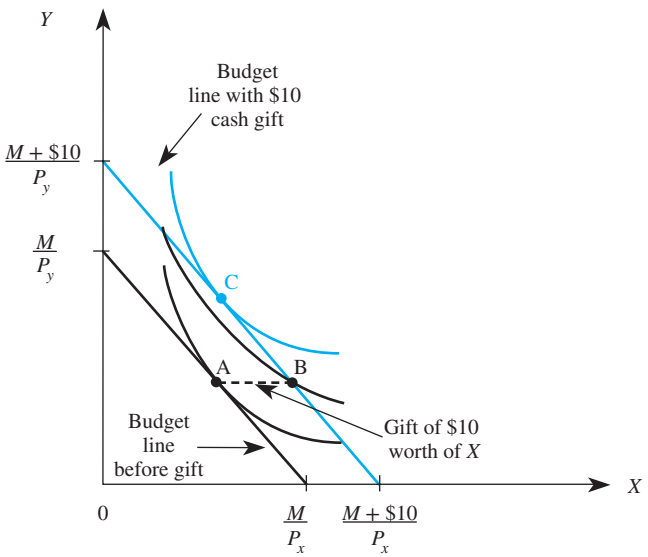
When the consumer is offered the "buy one, get one free" deal, her budget line becomes ADEF. The reason is as follows: If she buys less than one large pizza, she gets no deal, and her budget line to the left of one pizza remains as it was, namely AD. But if she buys one large pizza, she gets a second one free. In this instance, the budget line becomes DEF as soon as she buys one pizza. In other words, the price of pizza is zero for units between one and two large pizzas. This implies that the budget line for pizzas is horizontal between one and two units (recall that the slope of the budget line is $-P_x/P_y$, and for these units P_x is zero). If the consumer wants to consume more than two large pizzas, she must buy them at regular prices. But note that if she spent all of her income on pizza, she could buy one more than she could before (since one of the pizzas is free). Thus, for pizzas in excess of two units, the budget constraint is the line connecting points E and F. After the deal is offered, the opportunity set increases. In fact, bundle *E* is now an affordable bundle. Moreover, it is clear that bundle *E* is preferred to bundle *C*, and the consumer's optimal choice is to consume bundle *E*, as in Figure 4–14. The sales technique has induced the consumer to purchase more pizza than she would have otherwise.

Cash Gifts, In-Kind Gifts, and Gift Cards

Along with death and taxes, lines in refund departments after Christmas appear to be an unpleasant but necessary aspect of life. To understand why, and to be able to pose a potential solution to the problem, consider the following story.

One Christmas morning, a consumer named Sam is in equilibrium, consuming bundle *A* as in Figure 4–15. He opens a package and, to his surprise, it contains a $10 fruitcake (good *X*). He smiles and tells Aunt Sarah that he always wanted a fruitcake. Graphically, when Sam receives the gift, his opportunity set expands to include point B in Figure 4–15. Bundle *B* is just like bundle *A* except that it has one more fruitcake (good *X*) than bundle *A*. Given this

Figure 4–15
A Cash Gift Yields Higher Utility Than an In-Kind Gift



new opportunity set, Sam moves to the higher indifference curve through point B after receiving the gift.

While Sam likes fruitcake and is better off after receiving it, the gift is not what he would have purchased had Aunt Sarah given him the cash she spent on the fruitcake. For concreteness, suppose the cost of the fruitcake was $10. Had Sam been given $10 in cash, his budget line would have shifted out, parallel to the old budget line but through point B, as in Figure 4–15. To see why, note that when Sam gets additional income, prices are not changed, so the slope of the budget line is unchanged. Note also that if Sam used the money to buy one more fruitcake, he would exactly exhaust his income. Thus, the budget line after the cash gift must go through point B—and, given the cash gift, Sam would achieve a higher level of satisfaction at point C compared to the gift of a fruitcake (point B).

Thus, a cash gift generally is preferred to an in-kind gift of equal value, unless the in-kind gift is exactly what the consumer would have purchased personally. This explains why refund departments are so busy after the Christmas holidays; individuals exchange gifts for cash so that they can purchase bundles they prefer.

One way stores attempt to reduce the number of gifts returned is to sell *gift cards*. To see why, suppose Sam received a gift card, good for $10 worth of merchandise at store X, which sells good *X*, instead of the $10 fruitcake. Further, suppose the card is not good at store Y, which sells good *Y*. By receiving a gift card, Sam cannot purchase any more of good *Y* than he could before he received the card. But if he spends all his income on good *Y*, he can purchase $10 worth of good *X* since he has a card worth $10 at store X. And if he spends all his income on good *X*, he can purchase $10 more than he could before because of the gift card. In effect, the gift card is like money that is good only at store X.

Graphically, the effect of receiving a gift card at store X is depicted in Figure 4–16. The straight black line is the budget line before Sam receives the gift card. When he receives the $10 gift card, the budget constraint becomes the kinked blue line. In effect, the gift card allows the consumer up to $10 worth of good *X* without spending a dime of his own money.

The effect of gift cards on consumer behavior depends, among other things, on whether good *X* is a normal or inferior good. To examine what happens to behavior when a consumer receives a gift card, let us suppose a consumer initially is in equilibrium at point A in

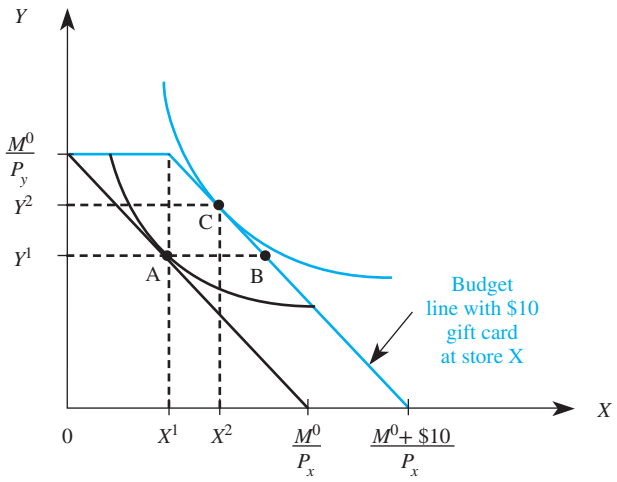


Figure 4–16
A Gift Card Valid at Store X

Figure 4–16, spending $10 on good *X*. What happens if the consumer is given a $10 gift card good only for items in store X? If both *X* and *Y* are normal goods, the consumer will desire to spend more on both goods as income increases. Thus, if both goods are normal goods, the consumer moves from A to C in Figure 4–16. In this instance, the consumer reacts to the gift card just as she or he would have reacted to a cash gift of equal value.

DEMONSTRATION PROBLEM 4–2

How would the analysis of gift cards just presented change if good *X* were an inferior good?

ANSWER:

In this instance, a gift of $10 in cash would result in a movement from point A in Figure 4–17 to a point like D since *X* is an inferior good. However, when a $10 gift card is received, bundle *D* is not affordable, and the best the consumer can do is consume bundle *E*. In other words, had the consumer been given cash, his or her budget line would have extended up along the dotted line, and point D would have been an affordable bundle. If given cash, the consumer would have purchased less of good *X* than she or he did with the gift card. Also, note that the consumer would have achieved a higher indifference curve with the cash than that achieved with the gift card. (Conceptual and Computational Question 4 appearing at the end of this chapter asks you whether a gift card always leads to a lower indifference curve and higher sales than a cash gift when the good is inferior.)

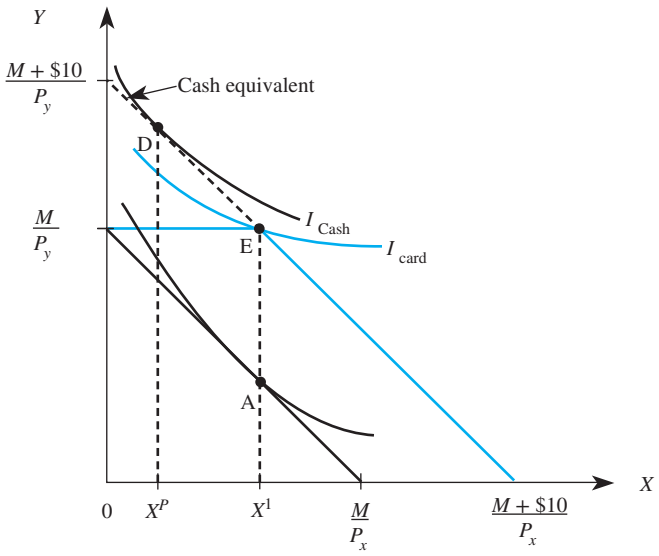


Figure 4–17
Here, a Cash Gift Yields Higher Utility Than a Gift Card of Equal Dollar Value

This analysis reveals two important benefits to a firm that sells gift cards. First, as a manager you can reduce the strain on your refund department by offering gift cards to customers looking for gifts. This is true for both normal and inferior goods. Second, if you sell an inferior good, offering to sell gift cards to those looking for gifts may result in a greater quantity sold than if customers resorted to giving cash gifts. (This assumes you do not permit individuals to redeem gift cards for cash.)

Choices by Workers and Managers

Until now, our analysis of indifference curves has focused on the decisions of consumers of goods and services. Managers and workers also are individuals and therefore have preferences among the alternatives that confront them. In this section, we will see that the indifference curve analysis developed earlier for consumers can easily be modified to analyze the behavior of managers and other individuals employed by firms. In Chapter 6 we will show how these insights into the behavior of workers and managers can be used to construct efficient employment contracts.

A Simplified Model of Income–Leisure Choice

Most workers view both leisure and income as goods and substitute between them at a diminishing rate along an indifference curve. Thus, a typical worker's indifference curve has the usual shape in Figure 4–18, where we measure the quantity of leisure consumed by an employee on the horizontal axis and worker income on the vertical axis. Note that while workers enjoy leisure, they also enjoy income.

To induce workers to give up leisure, firms must compensate them. Suppose a firm offers to pay a worker $10 for each hour of leisure the worker gives up (i.e., spends working). In this instance, opportunities confronting the worker or manager are given by the straight line in Figure 4–18. If the worker chooses to work 24-hour days, he or she consumes no leisure but earns $10 × 24 = $240 per day, which is the vertical intercept of the line. If the worker chooses not to work, he or she consumes 24 hours of leisure but earns no income. This is the horizontal intercept of the line in Figure 4–18.

Worker behavior thus may be examined in much the same way we analyzed consumer behavior. The worker attempts to achieve a higher indifference curve until he or she achieves one that is tangent to the opportunity set at point E in Figure 4–18. In this instance, the worker consumes 16 hours of leisure and works 8 hours to earn a total of $80 per day.

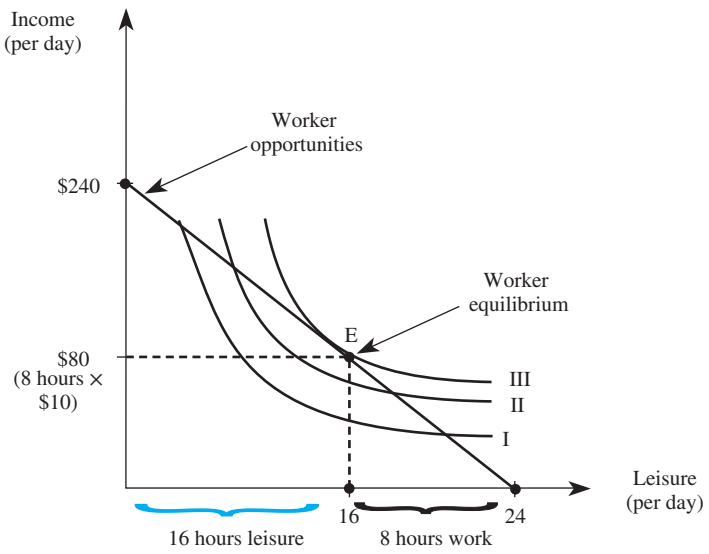


Figure 4–18
Labor–Leisure Choice

INSIDE BUSINESS 4–5

The "Deadweight Loss" of In-Kind Gifts

A perennial, and still growing, favorite among gift-givers is the gift card. A recent survey showed gift cards to be a leading gift choice for major occasions such as birthdays and holidays. The annual total dollar value of gift cards in the United States is in excess of a staggering $100 billion. Why are gift cards such a popular medium of gift-giving?

An economist offered one explanation. Based on data from a group of college students, the researcher estimated that between 10 and 30 percent of the monetary value of the typical in-kind gift is "lost." This loss stems from the discrepancy between the amount actually paid for the gift and how much the recipient values it. These data from the real world indicate that it is indeed difficult to pick a gift that exactly matches that recipient's preferences. For this reason, in-kind gifts create a "deadweight loss" that averages 10 to 30 percent of the amount spent on gifts.

As the text shows, one way of avoiding this deadweight loss is to give cash rather than an in-kind gift. Unfortunately, this creates a different type of loss when there is a stigma associated with giving cash: The gift is "discounted" because the recipient feels that little thought went into it. Gift cards are a happy medium. Ideally, they are able to eliminate both the stigma associated with cash gifts and the deadweight loss that stems from giving a gift that doesn't exactly match the recipient's preferences.

SOURCES: "How America Gives Gifts in 2016," Blackhawk Network's Survey, 2016; "Retail Gift Card Trends in the United States: 2016 in Review," Mercator Advisory Groups, 2017; J. Waldfogel, "The Deadweight Loss of Christmas," *American Economic Review* 83, no. 5 (December 1993), pp. 1328–36.

For a video walkthrough of this problem, visit www.mhhe.com/baye10e

DEMONSTRATION PROBLEM 4–3

Suppose a worker is offered a wage of $5 per hour, plus a fixed payment of $40. What is the equation for the worker's opportunity set in a given 24-hour day? What are the maximum total earnings the worker can earn in a day? The minimum? What is the price to the worker of consuming an additional hour of leisure?

ANSWER:

The total earnings (E) of a worker who consumes L hours of leisure in a 24-hour day is given by

$$E = \$40 + \$5(24 - L)$$

so the combinations of earnings (E) and leisure (L) satisfy

$$E = \$160 - \$5L$$

Thus, the most a worker can earn in a 24-hour day is $160 (by consuming no leisure); the least that can be earned is $40 (by not working at all). The price of a unit of leisure is $5 since the opportunity cost of an hour of leisure is one hour of work.

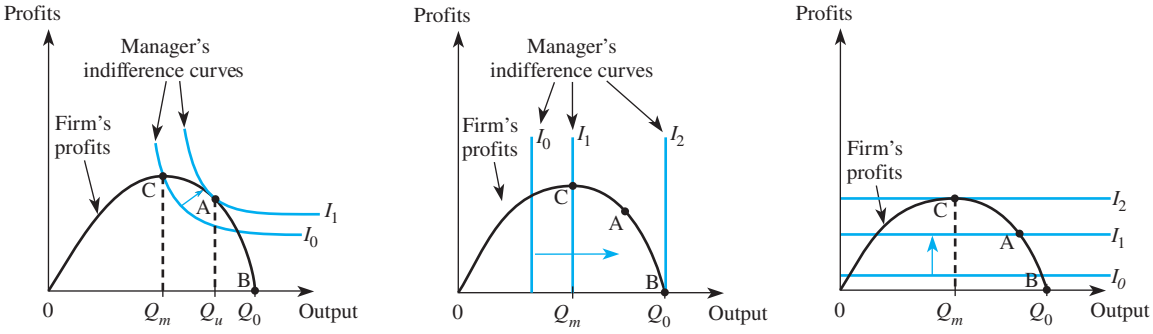
The Decisions of Managers

A classic argument by William Baumol[1] states that many managers derive satisfaction from the underlying output and profits of their firms. According to Baumol, higher profits and sales lead to a larger firm, and larger firms provide more "perks" like spacious offices, executive health clubs, corporate jets, and the like.

[1]William J. Baumol, *Business Behavior, Value, and Growth,* rev. ed. (New York: Harcourt, Brace and World, 1967).

Figure 4–19

A Manager's Preferences: (a) Profits and Output, (b) Output Only, or (c) Profits Only



(a) Profits and output (b) Output only (c) Profits only

Suppose a manager's preferences are such that she or he views the "profits" and the "output" of the firm to be "goods" so that more of each is preferred to less. We are not suggesting that it is optimal for you, as a manager, to have these types of preferences, but there may be instances in which your preferences are so aligned. In many sales jobs, for example, individuals receive a bonus depending on the overall profitability of the firm. But the salesperson's ability to receive reimbursement for certain business-related expenses may depend on that individual's total output (e.g., number of cars sold). Additionally, perks such as a company plane, car, and so forth may be allocated to individuals based on the firm's output and profitability. In all of these scenarios, managerial preferences depend on the firm's output as well as profits.

Panels (a), (b), and (c) of Figure 4–19 show the relation between profits and the output of a firm on the curve labeled "firm's profits." This curve goes from the origin through points C, A, and B and represents the profits of the firm as a function of output. When the firm sells no output, profits are zero. As the firm expands output, profits increase, reach a maximum at Q_m, and then begin to decline until, at point Q_0, they are again zero.

Given this relationship between output and profits, a manager who views output and profits as "goods" (the Baumol hypothesis) has indifference curves like those in Figure 4–19(a). She attempts to achieve higher and higher indifference curves until she eventually reaches equilibrium at point A. Note that this level of output, Q_u, is greater than the profit-maximizing level of output, Q_m. Thus, when the manager views both profits and output as "goods," she produces more than the profit-maximizing level of output.

In contrast, when the manager's preferences depend solely on output, the indifference curves look like those in Figure 4–19(b), which are vertical straight lines. One example of this situation occurs when the owner of a car dealership pays the manager based solely on the number of cars sold (the manager gets nothing if the company goes bankrupt). Since the manager does not care about profits, his or her indifference curves are vertical lines, and satisfaction increases as the lines move farther to the right. A manager with such preferences will attempt to obtain the indifference curves farther and farther to the right until indifference curve I_2 is reached. Point B represents equilibrium for this manager, where Q_0 units of output are produced. Again, in this instance the manager produces more than the profit-maximizing level of output.

Finally, suppose the manager cares solely about the profits of the firm. In this instance, the manager's indifference curves are horizontal straight lines as shown in Figure 4–19(c). The manager maximizes satisfaction at point C, where the indifference curve I_2 is as high as

possible given the opportunity set. In this instance, profits are greater and output is lower than those in the other two cases.

An important issue for the firm's owners is to induce managers to care solely about profits so that the result is the maximization of the underlying value of the firm, as in Figure 4–19(c). We will examine this issue in more detail in Chapter 6.

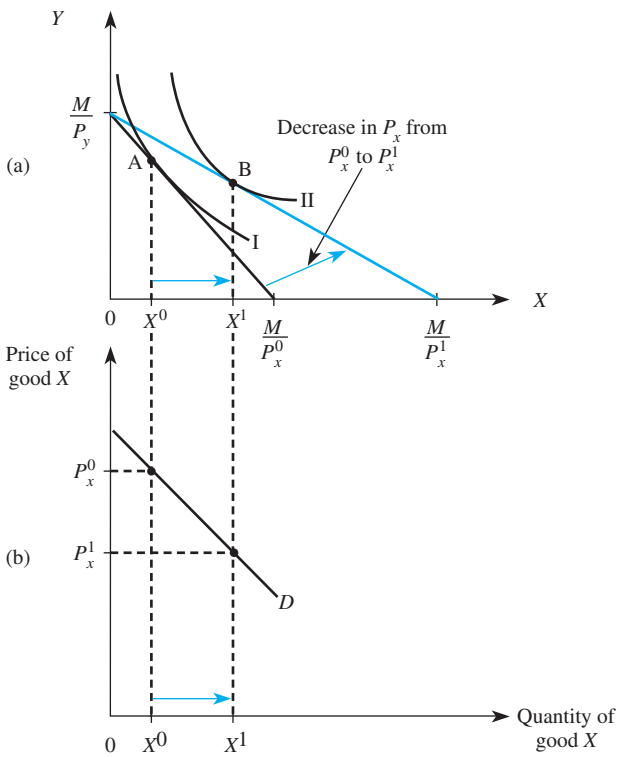
THE RELATIONSHIP BETWEEN INDIFFERENCE CURVE ANALYSIS AND DEMAND CURVES

We have seen how the consumption patterns of an individual consumer depend on variables that include the prices of substitute goods, the prices of complementary goods, tastes (i.e., the shape of indifference curves), and income. The indifference curve approach developed in this chapter, in fact, is the basis for the demand functions we studied in Chapters 2 and 3. We conclude by examining the link between indifference curve analysis and demand curves.

Individual Demand

To see where the demand curve for a normal good comes from, consider Figure 4–20(a). The consumer initially is in equilibrium at point A, where income is fixed at M and prices are P_x^0 and P_y. But when the price of good X falls to the lower level, indicated by P_x^1, the opportunity set expands and the consumer reaches a new equilibrium at point B. The important thing to notice is that the only change that caused the consumer to move from A to B was a change in the price of good X; income and the price of good Y are held constant in the diagram. When

Figure 4–20
Deriving an Individual's Demand Curve



the price of good X is P_x^0, the consumer consumes X^0 units of good X; when the price falls to P_x^1, the consumption of X increases to X^1.

This relationship between the price of good X and the quantity consumed of good X is graphed in Figure 4–20(b) and is the individual consumer's demand curve for good X. This consumer's demand curve for good X indicates that, holding other things constant, when the price of good X is P^0, the consumer will purchase X^0 units of X; when the price of good X is P_x^1, the consumer will purchase X^1 units of X.

Market Demand

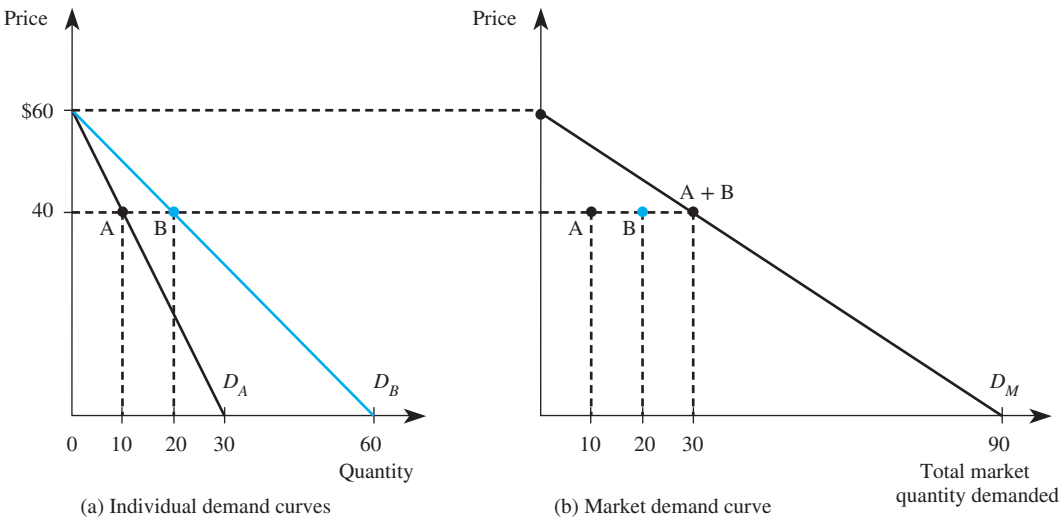
You will usually, in your role as a manager, be interested in determining the total demand by all consumers for your firm's product. This information is summarized in the market demand curve. The market demand curve is the horizontal summation of individual demand curves and indicates the total quantity all consumers in the market would purchase at each possible price.

This concept is illustrated graphically in Figures 4–21(a) and 4-21(b). The curves D_A and D_B represent the individual demand curves of two hypothetical consumers, Ms. A and Mr. B, respectively. When the price is \$60, Ms. A buys 0 units and Mr. B buys 0 units. Thus, at the market level, 0 units are sold when the price is \$60, and this is one point on the market demand curve [labeled D_M in Figure 4–21(b)]. When the price is \$40, Ms. A buys 10 units (point A) and Mr. B buys 20 units (point B). Thus, at the market level [Figure 4–21(b)], 30 units are sold when the price is \$40, and this is another point (point A + B) on the market demand curve. When the price of good X is zero, Ms. A buys 30 units and Mr. B buys 60 units; thus, at the market level, 90 units are sold when the price is \$0. If we repeat the analysis for all prices between \$0 and \$60, we get the curve labeled D_M in Figure 4–21(b).

Thus, the demand curves we studied in Chapters 2 and 3 are based on indifference curve analysis.

Figure 4–21

Deriving the Market Demand Curve



INSIDE BUSINESS 4–6

Public Health Centers and Output-Oriented Incentives

Unlike most private companies, government-run agencies and nonprofit organizations generally are not concerned with maximizing profits; instead they have other objectives, often output maximization. This is largely the case with public health centers, which seek to provide health care to as many citizens as possible. However, the employees at public health centers may not share the government's preference regarding output production.

Several years ago in Rwanda, the country's public health centers suffered several years of poor performance. In response, the Rwandan Ministry of Health along with HealthNet International decided to change their support strategy for Rwandan public health centers. Specifically, in addition to their salaries, employees were compensated via output-based bonuses. In short, as more services were provided, employees received more money.

This output-oriented incentive scheme helped to align employees' preferences with those of the government. In fact, the productivity of the public health centers that experienced this change in payment scheme showed productivity increases exceeding 50 percent!

SOURCE: B. Meesen, J. P. Kashala, and L. Musango, "Output-Based Payment to Boost Staff Productivity in Public Health Centres: Contracting in Kabutare District, Rwanda," *Bulletin of the World Health Organization* 85 (2007), pp. 108–15.

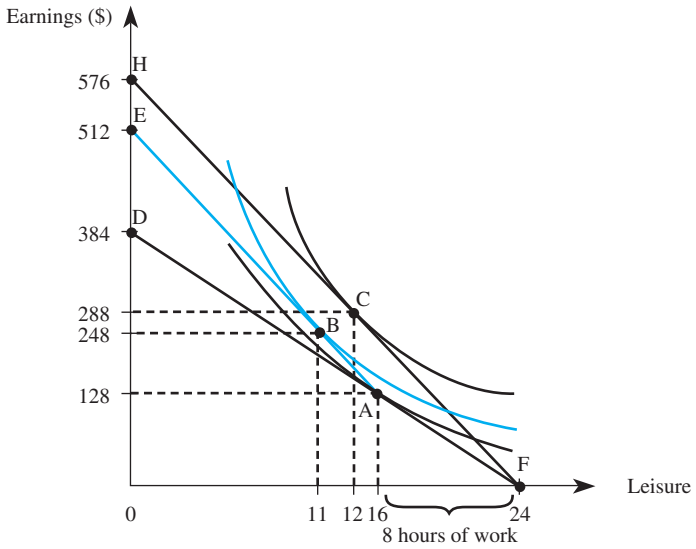
ANSWERING THE headLINE

The question posed at the beginning of the chapter asked why Boxes Ltd. paid a higher overtime wage only on hours in excess of eight hours per day instead of offering workers a higher wage for every hour worked during a given day.

Figure 4–22 presents the analysis of income–leisure choice for a hypothetical worker. When the wage is \$16 per hour, the worker's opportunity set is given by line DF. If the worker consumed no leisure, his earnings would be \$16 × 24 = \$384. However, given a \$16 wage, this worker maximizes satisfaction at point A, where he consumes 16 hours of leisure (works 8 hours per day) to earn \$128 in wage income.

With overtime pay of \$24 for each hour worked in excess of 8 hours, the opportunity set becomes EAF. The reason is simple. If the worker works 8 hours or less, he does not

Figure 4–22
An Overtime Wage Increases Hours Worked



earn overtime pay, and this part of his budget line (AF) remains the same. But if he consumes less than 16 hours of leisure, he gets $24 instead of $16 for these hours worked, so the budget line is steeper (EA). When no leisure is consumed (point E), the first 8 hours given up generate $16 × 8 = $128 in earnings, while the last 16 hours of leisure given up generate $24 × 16 = $384 in earnings. Thus, point E on the overtime budget line corresponds to earnings of $128 + $384 = $512. Given the overtime option, this worker maximizes satisfaction at point B, where he works 13 hours to earn $248. Overtime pay increases the amount of work from 8 hours to 13 hours.

Why doesn't the firm simply increase the wage to $24 instead of initiating the more complicated overtime system? If this worker were paid a wage of $24 for every hour worked, his budget line would be HF. This worker would obtain a higher indifference curve at point C, where 12 hours of leisure are consumed (12 hours of work). When leisure is a normal good, the $24 wage yields fewer hours of work from each worker than does the overtime system. In addition, labor costs are lower with overtime pay (point B) than a $24 wage (point C).

To summarize, we have shown that the manager could get workers who view leisure as a normal good to work longer hours with overtime pay than she could by simply offering a higher wage on all hours worked.

SUMMARY

In this chapter, we provided a basic model of individual behavior that enables the manager to understand the impact of various managerial decisions on the actions of consumers and workers.

After reading and working through the demonstration problems in this chapter, you should understand what a budget constraint is and how it changes when prices or income changes. You should also understand that when there is a change in the price of a good, consumers change their behavior because there is a change in the ratio of prices (which leads to a substitution effect) and a change in real income (which leads to the income effect). The model of consumer behavior also articulates the assumptions underlying the demand curve.

In equilibrium, consumers adjust their purchasing behavior so that the ratio of prices they pay just equals their marginal rate of substitution. This information, along with observations of consumer behavior, helps a manager determine when to use a "buy one, get one free" pricing strategy instead of a half-price offer. During holiday seasons, the same manager will have a sound basis for determining whether offering gift certificates is a wise strategy.

Effective managers also use the theory of consumer behavior to direct the behavior of employees. In this chapter, we examined the benefits to the firm of paying overtime wages; additional issues will be discussed in Chapter 6.

In conclusion, remember that the models of individual behavior developed in this chapter are basic tools for analyzing the behavior of your customers and employees. By taking the time to become familiar with the models and working through the demonstration and end-of-chapter problems, you will be better equipped to make decisions that will maximize the value of your firm.

KEY TERMS AND CONCEPTS

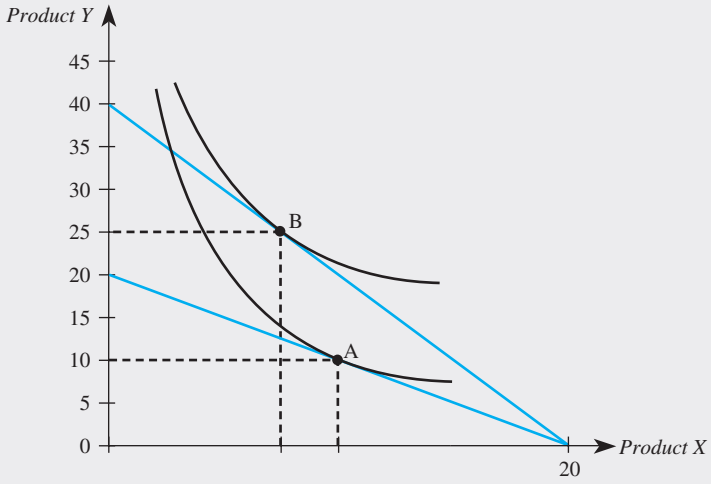
budget constraint
budget line
budget set
"buy one, get one free" deals
completeness
consumer equilibrium
diminishing marginal rate of substitution
gift cards
income effect
indifference curve
marginal rate of substitution (MRS)
market rate of substitution
more is better
substitution effect
transitivity

CONCEPTUAL AND COMPUTATIONAL QUESTIONS

connect

1. A consumer has \$300 to spend on goods *X* and *Y*. The market prices of these two goods are $P_x = \$15$ and $P_y = \$5$. *(LO2)*
   a. What is the market rate of substitution between goods *X* and *Y?*
   b. Illustrate the consumer's opportunity set in a carefully labeled diagram.
   c. Show how the consumer's opportunity set changes if income increases by \$300. How does the \$300 increase in income alter the market rate of substitution between goods *X* and *Y?*

2. A consumer is in equilibrium at point A in the accompanying figure. The price of good *X* is \$5. *(LO2, LO3)*
   a. What is the price of good *Y?*
   b. What is the consumer's income?
   c. At point A, how many units of good *X* does the consumer purchase?
   d. Suppose the budget line changes so that the consumer achieves a new equilibrium at point B. What change in the economic environment led to this new equilibrium? Is the consumer better off or worse off as a result of the price change?



3. A consumer must divide \$600 between the consumption of product *X* and product *Y*. The relevant market prices are $P_x = \$10$ and $P_y = \$40$. *(LO2)*
   a. Write the equation for the consumer's budget line.
   b. Illustrate the consumer's opportunity set in a carefully labeled diagram.
   c. Show how the consumer's opportunity set changes when the price of good *X* increases to \$20. How does this change alter the market rate of substitution between goods *X* and *Y?*

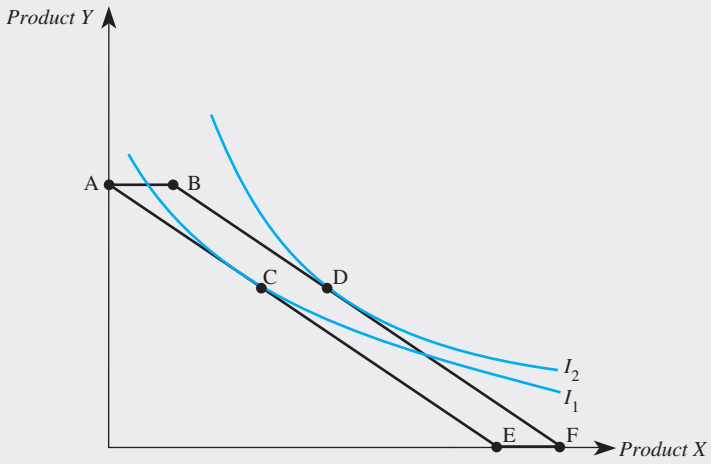
4. In the answer to Demonstration Problem 4–2 in the text, we showed a situation in which a gift certificate leads a consumer to purchase a greater quantity of an inferior good than he or she would consume if given a cash gift of equal value. Is this always the case? Explain. *(LO6)*

5. Provide an intuitive explanation for why a "buy one, get one free" deal is not the same as a "half-price" sale. *(LO6)*

6. In the following figure, a consumer is initially in equilibrium at point C. The consumer's income is \$600, and the budget line through point C is given by $\$600 = \$100X + \$200Y$.

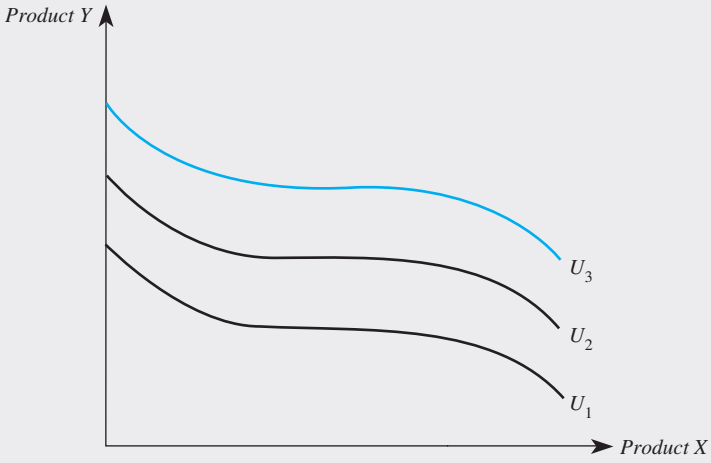
When the consumer is given a $100 gift certificate that is good only at store X, she moves to a new equilibrium at point D. *(LO1, LO3, LO6)*

a. Determine the prices of goods *X* and *Y*.
b. How many units of product *Y* could be purchased at point A?
c. How many units of product *X* could be purchased at point E?
d. How many units of product *X* could be purchased at point B?
e. How many units of product *X* could be purchased at point F?
f. Based on this consumer's preferences, rank bundles *A*, *B*, *C*, and *D* in order from most preferred to least preferred.
g. Is product *X* a normal or an inferior good?



7. A consumer must spend all of her income on two goods (*X* and *Y*). In each of the following scenarios, indicate whether the equilibrium consumption of goods *X* and *Y* will increase or decrease. Assume good *X* is a normal good and good *Y* is an inferior good. *(LO3)*
   a. Income doubles.
   b. Income quadruples and all prices double.
   c. Income and all prices quadruple.
   d. Income is halved and all prices double.

8. Determine which, if any, of Properties 4–1 through 4–4 are violated by the indifference curves shown in the following diagram. *(LO1)*



9. A consumer's budget set for two goods (X and Y) is $800 \geq 4X + 2Y$. *(LO2)*
   a. Illustrate the budget set in a diagram.
   b. Does the budget set change if the prices of both goods double and the consumer's income also doubles? Explain.
   c. Given the equation for the budget set, can you determine the prices of the two goods? The consumer's income? Explain.

10. A worker views leisure and income as "goods" and has an opportunity to work at an hourly wage of $16 per hour. *(LO7)*
   a. Illustrate the worker's opportunity set in a given 24-hour period.
   b. Suppose the worker is always willing to give up $10 of income for each hour of leisure. Do her preferences exhibit a diminishing marginal rate of substitution? How many hours per day will she choose to work?

PROBLEMS AND APPLICATIONS



11. It is common for supermarkets to carry both generic (store-label) and brand-name (producer-label) varieties of sugar and other products. Many consumers view these products as perfect substitutes, meaning that consumers are always willing to substitute a constant proportion of the store brand for the producer brand. Consider a consumer who is always willing to substitute four pounds of a generic store-brand sugar for two pounds of a brand-name sugar. Do these preferences exhibit a diminishing marginal rate of substitution between store-brand and producer-brand sugar? Assume that this consumer has $24 of income to spend on sugar, and the price of store-brand sugar is $1 per pound and the price of producer-brand sugar is $3 per pound. How much of each type of sugar will be purchased? How would your answer change if the price of store-brand sugar was $2 per pound and the price of producer-brand sugar was $3 per pound? *(LO1, LO2, LO3)*

12. The U.S. government spends over $74 billion on its Supplemental Nutrition Assistance Program (SNAP) to provide millions of Americans with the means to purchase food. Beneficiaries use an Electronic Benefits Transfer (EBT) card to transfer their government benefits from a federal account to a retailer account. The funds on an EBT card cannot be sold for cash or used to purchase nonfood items. The average SNAP benefit is about $284 per month. Suppose that, in the absence of SNAP, the average consumer must divide $600 in monthly income between food and "all other goods" such that the following budget constraint holds: $\$600 = \$12A + \$4F$, where A is the quantity of "all other goods" and F is the quantity of food purchased. Using the vertical axis for "all other goods," draw the consumer's budget line in the absence of SNAP. What is the market rate of substitution between food and "all other goods"? On the same graph, show how SNAP alters the average consumer's budget line. Would this consumer benefit from illegally exchanging SNAP benefits for cash? Explain. *(LO2, LO6)*

13. A recent newspaper circular advertised the following special on tires: "Buy three, get the fourth tire for free—limit one free tire per customer." If a consumer has $360 to spend on tires and other goods and each tire usually sells for $40, how does this deal impact the consumer's opportunity set? *(LO6)*

14. During the past major recession, upscale hotels in the United States recently cut their prices by 25 percent in an effort to bolster dwindling occupancy rates among business travelers. A survey performed by a major research organization indicated that businesses were becoming wary of bad economic conditions and began resorting to electronic media, such as the Internet and the telephone, to transact business. Assume a company's budget permits it to spend $6,000 per month on either business travel or electronic media to transact business. Graphically illustrate how a 25 percent decline in the price of

business travel would impact this company's budget set if the price of business travel was initially $1,200 per trip and the price of electronic media was $600 per hour. Suppose that, after the price of business travel drops, the company issues a report indicating that its marginal rate of substitution between electronic media and business travel is −1. Is the company allocating resources efficiently? Explain. *(LO1, LO2, LO3)*

15. Consider an employee who does not receive employer-based health insurance and must divide her $1,000 per week in after-tax income between health insurance and "other goods." Draw this worker's opportunity set if the price of health insurance is $200 per week and the price of "other goods" is $100 per week. On the same graph, illustrate how the opportunity set would change if the employer agreed to give this employee $200 worth of health insurance per week (under current tax laws, this form of compensation is nontaxable). Would this employee be better or worse off if, instead of the health insurance, the employer gave her a $200 per week raise that was taxable at a rate of 25 percent? Explain. *(LO6)*

16. An internal study at Mimeo Corporation—a manufacturer of low-end photocopiers—revealed that each of its workers assembles three photocopiers per hour and is paid $6 for each assembled copier. Although the company does not have the resources needed to supervise the workers, a full-time inspector verifies the quality of each unit produced before a worker is paid for his or her output. You have been asked by your superior to evaluate a new proposal designed to cut costs. Under the plan, workers would be paid a fixed wage of $16 per hour. Would you favor the plan? Explain. *(LO7)*

17. The Einstein Bagel Corp. offers a frequent buyer program whereby a consumer receives a stamp each time she purchases one dozen bagels for $6. After a consumer accrues 10 stamps, she receives one dozen bagels free. This offer is an unlimited offer, valid throughout the year. The manager knows her products are normal goods. Given this information, construct the budget set for a consumer who has $200 to spend on bagels and other goods throughout the year. Does Einstein's frequent buyer program have the same effect on the consumption of its bagels that would occur if it simply lowered the price of one dozen bagels by 3 percent? Explain. *(LO6)*

18. The average 15-year-old purchases 100 song downloads from Apple Music and buys 20 cheese pizzas in a typical year. If cheese pizzas are inferior goods, would the average 15-year-old be indifferent between receiving a $50 gift card for Apple Music and $50 in cash? Explain. *(LO6)*

19. A common marketing tactic among many liquor stores is to offer their clientele quantity (or volume) discounts. For instance, the second-leading brand of wine exported from Chile sells in the United States for $15 per bottle if the consumer purchases up to eight bottles. The price of each additional bottle is only $8. If a consumer has $200 to divide between purchasing this brand of wine and other goods, graphically illustrate how this marketing tactic affects the consumer's budget set if the price of other goods is $1. Assuming a consumer has standard indifference curves (i.e., resembling those in Figure 4–2), will she ever purchase exactly eight bottles of wine? Explain. *(LO6)*

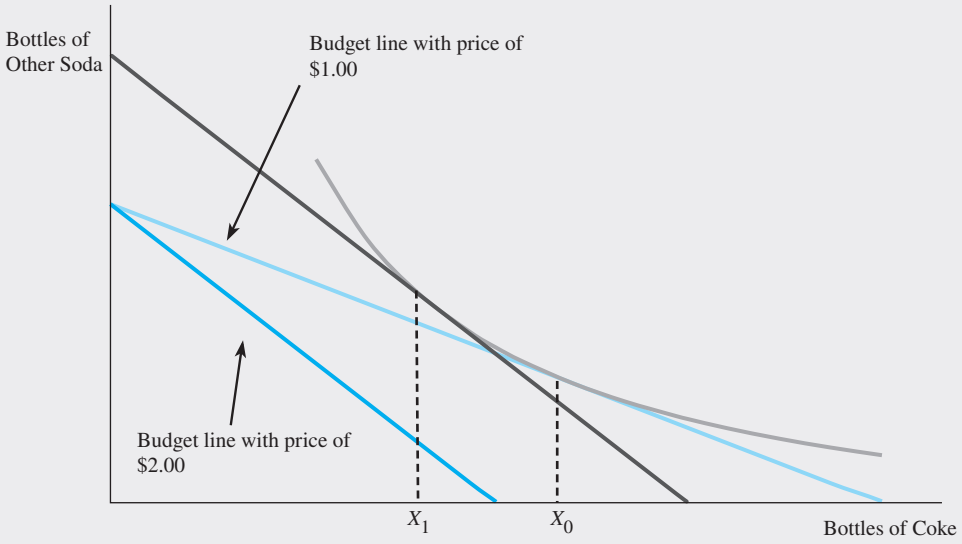
20. Suppose that a CEO's goal is to increase profitability and output from her company by bolstering its sales force, and data analysis has shown that the relationship between profits and output can be expressed as $\pi = 40q - 2q^2$ (in millions of U.S. dollars). Graph the company's profit function. Compare and contrast output and profits using the following compensation schemes based on the assumption that sales managers view output and profits as "goods": (*a*) the company compensates sales managers solely based on output, (*b*) the company compensates sales managers solely based on profits, and (*c*) the company compensates sales managers based on a combination of output and profits. *(LO7)*

21. Suppose that the owner of Boyer Construction is feeling the pinch of increased premiums associated with worker's compensation and has decided to cut the wages of its two employees (Albert and Sid) from $25 per hour to $22 per hour. Assume that Albert and Sid view income and leisure as "goods," that both experience a diminishing rate of marginal substitution between income and leisure, and that the workers have the same before- and after-tax budget constraints at each wage. Draw each worker's opportunity set for each hourly wage. At the wage of $25 per hour, both Albert and Sid are observed to consume 12 hours of leisure (and, equivalently, supply 12 hours of labor). After wages were cut to $22, Albert consumes 10 hours of leisure and Sid consumes 14 hours of leisure. Determine the number of hours of labor each worker supplies at a wage of $22 per hour. How can you explain the seemingly contradictory result that the workers supply a different number of labor hours? *(LO2, LO3, LO7)*

22. Over the past decade, holiday gift cards have become increasingly popular at online retailers. Not long ago, online shoppers had to really hunt at most e-retailers' sites to purchase a gift card, but today it is easier to purchase gift cards online than at traditional retail outlets. Do you think online gift cards are merely a fad? Explain carefully. *(LO6)*

23. Recently, an Internet service provider (ISP) in the United Kingdom implemented a "no-strings U.S.-style flat-rate plan" whereby its commercial subscribers can send and receive unlimited volume (measured in gigabytes) up to a cap of 10,000 gigabytes (per month) via their broadband Internet service for a flat monthly fee of £399.99. Under the old "metered plan," Alistair Willoughby Cook sent and received a grand total of 3,500 gigabytes over his broadband connection and paid £399.99 in usage fees in a typical 30-day month. If all customers are exactly like Alistair, what is the impact of the flat-rate plan on consumer welfare and the company's profits? Explain. *(LO2, LO3)*

24. A large Coca-Cola vendor recently hired some economic analysts to assess the effect of a price increase in its 16-ounce bottles from $1.00 to $2.00. The analysts determined that, on average, the vendor's customers spend about $15.00 on soda (Coke and all other brands) each week, and the average price for other 16-ounce soda bottles is $1.00. The analysts also utilized some focus groups to determine the preferences of the vendor's customers. They used this analysis to build the following graph:



Suppose $X_0 = 9$ and $X_1 = 7$. Should the vendor expect to sell 7, more than 7, or less than 7 bottles of Coke after raising the price to $2.00 if Coke is a normal good? *(LO4)*

25. When trying to assess differences in her customers, Claire—the owner of Claire's Rose Boutique—noticed a difference between the typical demand of her female versus her male customers. In particular, she found her female customers to be more price sensitive in general. After conducting some sales analysis, she determined that her female customers have the following demand curve for roses: $Q^F = 24 - 2P$. Here, Q^F is the quantity of roses demanded by a female customer and P is the price charged per rose. She determined that her male customers have the following demand curve for roses: $Q^M = 27 - P$. Here, Q^M is the quantity of roses demanded by a male customer. If two unaffiliated customers walk into her boutique, one male and one female, determine the demand curve for these two customers combined (i.e., what is their aggregate demand?). *(LO5)*

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APPENDIX
A CALCULUS APPROACH TO INDIVIDUAL BEHAVIOR

THE UTILITY FUNCTION

Suppose the preferences of a consumer are represented by a utility function $U(X, Y)$. Let $A = (X^A, Y^A)$ be the bundle with X^A units of good X and Y^A units of good Y, and let $B = (X^B, Y^B)$ be a different bundle of the two goods. If bundle A is preferred to bundle B, then $U(A) > U(B)$; the consumer receives a higher utility level from bundle A than from bundle B. Similarly, if $U(B) > U(A)$, the consumer views bundle B as "better" than bundle A. Finally, if $U(A) = U(B)$, the consumer views the two bundles to be equally satisfying; she or he is indifferent between bundles A and B.

UTILITY MAXIMIZATION

Given prices of P_x and P_y and a level of income M, the consumer attempts to maximize utility subject to the budget constraint. Formally, this problem can be solved by forming the Lagrangian:

$$\mathcal{L} \equiv U(X, Y) + \lambda(M - P_x X - P_y Y)$$

where λ is the Lagrange multiplier. The first-order conditions for this problem are

$$\frac{\partial \mathcal{L}}{\partial X} = \frac{\partial U}{\partial X} - \lambda P_x = 0 \qquad \text{(A-1)}$$

$$\frac{\partial \mathcal{L}}{\partial Y} = \frac{\partial U}{\partial Y} - \lambda P_y = 0 \qquad \text{(A-2)}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} = M - P_x X - P_y Y = 0$$

Equations (A-1) and (A-2) imply that

$$\frac{\partial U/\partial X}{\partial U/\partial Y} = \frac{P_x}{P_y} \tag{A-3}$$

or, in economic terms, the ratio of the marginal utilities equals the ratio of prices.

THE MARGINAL RATE OF SUBSTITUTION

Along an indifference curve, utility is constant:

$$U(X, Y) = \text{Constant}$$

Taking the total derivative of this relation yields

$$\frac{\partial U}{\partial X}\,dX + \frac{\partial U}{\partial Y}\,dY = 0$$

Solving for dY/dX along an indifference curve yields

$$\left.\frac{dY}{dX}\right|_{\textit{utility constant}} = -\frac{\partial U/\partial X}{\partial U/\partial Y}$$

Thus, the slope of an indifference curve is

$$-\frac{\partial U/\partial X}{\partial U/\partial Y}$$

The absolute value of the slope of an indifference curve is the marginal rate of substitution (*MRS*). Thus,

$$MRS = \frac{\partial U/\partial X}{\partial U/\partial Y} \tag{A-4}$$

THE $MRS = P_x/P_y$ RULE

Substitution of Equation (A-4) into Equation (A-3) reveals that to maximize utility, a consumer equates

$$MRS = \frac{P_x}{P_y}$$

Design Credit: Spreadsheet design icon: Botond1977/Shutterstock

5 The Production Process and Costs

LEARNING OBJECTIVES

After completing this chapter, you will be able to:

- **LO1** Explain alternative ways of measuring the productivity of inputs and the role of the manager in the production process.
- **LO2** Calculate input demand and the cost-minimizing combination of inputs and use isoquant analysis to illustrate optimal input substitution.
- **LO3** Calculate a cost function from a production function and explain how economic costs differ from accounting costs.
- **LO4** Explain the difference between and the economic relevance of fixed costs, sunk costs, variable costs, and marginal costs.
- **LO5** Calculate average and marginal costs from algebraic or tabular cost data and illustrate the relationship between average and marginal costs.
- **LO6** Distinguish between short-run and long-run production decisions and illustrate their impact on costs and economies of scale.
- **LO7** Conclude whether a multiple-output production process exhibits economies of scope or cost complementarities and explain their significance for managerial decisions.

headLINE

Boeing Loses the Battle but Wins the War

After nearly eight weeks, Boeing and its International Association of Machinists and Aerospace Workers Union (IAM) reached an agreement that ended a strike involving 27,000 workers. The strike followed several days of "last minute," around-the-clock talks that began when management and union negotiators failed to reach an agreement over compensation and job protection issues.

As a result of the agreement, IAM workers won benefits in areas that include health care, pensions, wages, and job security for 2,900 workers in inventory management and delivery categories. Boeing also agreed to retrain workers who are laid off or displaced. Despite these concessions, a spokesman for Boeing was quoted as saying that the agreement "gives us the flexibility we need to run the company." The four-year

agreement allows Boeing to retain critical subcontracting provisions it won in past struggles with the union.

Commenting on all this, one analysis concluded that "the union probably won the battle and Boeing probably wins the war." Can you explain what this analyst means?

SOURCES: C. Isidore, "Union Strikes Boeing," *CNNMoney.com,* September 6, 2008; S. Freeman, "Boeing Contract Offers Pay Raise, Job Protections," *The Washington Post,* October 29, 2008.

INTRODUCTION

Companies as well as nonprofit organizations are in the business of producing goods or providing services, and their successful operation requires managers to optimally choose the quantity and types of inputs to use in the production process. The successful operation of a consulting business, for instance, requires getting the right quantity and mix of employees and optimally substituting among these and other inputs as wages and other input prices change.

This chapter provides the economic foundations needed to succeed in managerial positions such as production and pricing management. The concepts of production and costs presented are also important in their own right, as they serve as the basic building blocks for business areas that include human resources, operations, managerial accounting, and strategic management.

THE PRODUCTION FUNCTION

We will begin by describing the technology available for producing output. Technology summarizes the feasible means of converting raw inputs, such as steel, labor, and machinery, into an output such as an automobile. The technology effectively summarizes engineering know-how. Managerial decisions, such as those concerning expenditures on research and development, can affect the available technology. In this chapter, we will see how a manager can exploit an existing technology to its greatest potential. In subsequent chapters, we will analyze the decision to improve a technology.

To begin our analysis, let us consider a production process that utilizes two inputs, *capital* and *labor*, to produce output. We will let K denote the quantity of capital, L the quantity of labor, and Q the level of output produced in the production process. Although we call the inputs capital and labor, the general ideas presented here are valid for any two inputs. However, most production processes involve machines of some sort (referred to by economists as *capital*) and people (*labor*), and this terminology will serve to solidify the basic ideas.

production function
A function that defines the maximum amount of output that can be produced with a given set of inputs.

The technology available for converting capital and labor into output is summarized in the production function. The **production function** is an engineering relation that defines the maximum amount of output that can be produced with a given set of inputs. Mathematically, the production function is denoted as

$$Q = F(K, L)$$

that is, the maximum amount of output that can be produced with K units of capital and L units of labor.

Short-Run versus Long-Run Decisions

As a manager, your job is to use the available production function efficiently; this means that you must determine how much of each input to use to produce output. In the short run, some factors of production are **fixed**, and this limits your choices in making input decisions. For example, it takes several years for automakers to develop and build new assembly lines for producing hybrids. The level of capital is generally fixed in the short run. However, in the short run automakers can adjust their use of inputs such as labor and steel; such inputs are called **variable factors of production**.

fixed factors of production
The inputs a manager cannot adjust in the short run.

variable factors of production
The inputs a manager can adjust to alter production.

The *short run* is defined as the time frame in which there are fixed factors of production. To illustrate, suppose capital and labor are the only two inputs in production and that the level of capital is fixed in the short run. In this case, the only short-run input decision to be made by a manager is how much labor to utilize. The short-run production function is essentially only a function of labor since capital is fixed rather than variable. If K^* is the fixed level of capital, the short-run production function may be written as

$$Q = f(L) = F(K^*, L)$$

Columns 1, 2, and 4 in Table 5-1 give values of the components of a short-run production function where capital is fixed at $K^* = 2$. For this production function, 5 units of labor are needed to produce 1,100 units of output. Given the available technology and the fixed level of capital, if the manager wishes to produce 1,952 units of output, 8 units of labor must be utilized. In the short run, more labor is needed to produce more output because increasing capital is not possible.

The *long run* is defined as the horizon over which the manager can adjust all factors of production. If it takes a company three years to acquire additional capital machines, the long run for its management is three years, and the short run is less than three years.

Table 5–1

The Production Function

(1) K^* Fixed Input (Capital) [Given]	(2) L Variable Input (Labor) [Given]	(3) ΔL Change in Labor [Δ(2)]	(4) Q Output [Given]	(5) $\frac{\Delta Q}{\Delta L} = MP_L$ Marginal Product of Labor [Δ(4)/Δ(2)]	(6) $\frac{Q}{L} = AP_L$ Average Product of Labor [(4)/(2)]
2	0	—	0	—	—
2	1	1	76	76	76
2	2	1	248	172	124
2	3	1	492	244	164
2	4	1	784	292	196
2	5	1	1,100	316	220
2	6	1	1,416	316	236
2	7	1	1,708	292	244
2	8	1	1,952	244	244
2	9	1	2,124	172	236
2	10	1	2,200	76	220
2	11	1	2,156	−44	196

Measures of Productivity

An important component of managerial decision making is the determination of the productivity of inputs used in the production process. As we will see, these measures are useful for evaluating the effectiveness of a production process and for making input decisions that maximize profits. The three most important measures of productivity are total product, average product, and marginal product.

Total Product

total product (*TP*)
The maximum level of output that can be produced with a given amount of inputs.

Total product (*TP*) is simply the maximum level of output that can be produced with a given amount of inputs. For example, the total product of the production process described in Table 5-1 when 5 units of labor are employed is 1,100. Since the production function defines the maximum amount of output that can be produced with a given level of inputs, this is the amount that would be produced if the 5 units of labor put forth maximal effort. Of course, if workers did not put forth maximal effort, output would be lower. Five workers who drink coffee all day cannot produce any output, at least given this production function.

Average Product

average product (*AP*)
A measure of the output produced per unit of input.

In many instances, managerial decision makers are interested in the average productivity of an input. For example, a manager may wish to know, on average, how much each worker contributes to the total output of the firm. This information is summarized in the economic concept of average product. The **average product (*AP*)** of an input is defined as total product divided by the quantity used of the input. In particular, the average product of labor (AP_L) is

$$AP_L = \frac{Q}{L}$$

and the average product of capital (AP_K) is

$$AP_K = \frac{Q}{K}$$

Thus, average product is a measure of the output produced per unit of input. In Table 5-1, for example, five workers can produce 1,100 units of output; this amounts to 220 units of output per worker.

Marginal Product

marginal product (*MP*)
The change in total output attributable to the last unit of an input.

The **marginal product (*MP*)** of an input is the change in total output attributable to the last unit of an input. The marginal product of capital (MP_K) therefore is the change in total output divided by the change in capital:

$$MP_K = \frac{\Delta Q}{\Delta K}$$

The marginal product of labor (MP_L) is the change in total output divided by the change in labor:

$$MP_L = \frac{\Delta Q}{\Delta L}$$

For example, in Table 5-1 the second unit of labor increases output by 172 units, so the marginal product of the second unit of labor is 172.

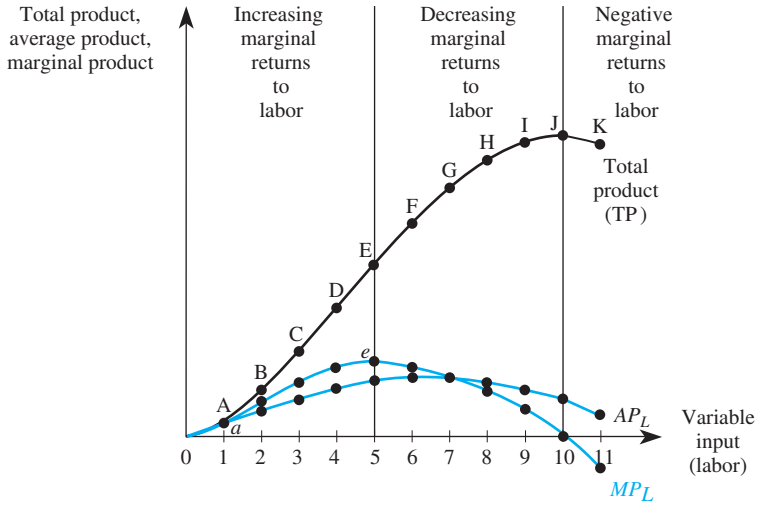


Figure 5-1

Increasing, Decreasing, and Negative Marginal Returns

Table 5-1 illustrates an important characteristic of the marginal product of an input. Notice that as the units of labor are increased from 0 to 5 in column 2, the marginal product of labor increases in column 5. This helps explain why assembly lines are used in so many production processes: By using several workers, each performing potentially different tasks, a manager can avoid inefficiencies associated with stopping one task and starting another. But note in Table 5-1 that after 5 units of labor, the marginal product of each additional unit of labor declines and eventually becomes negative. A negative marginal product means that the last unit of the input actually *reduced* the total product. This is consistent with common sense. If a manager continued to expand the number of workers on an assembly line, he or she would eventually reach a point where workers were packed like sardines along the line, getting in one another's way and resulting in less output than before.

Figure 5-1 shows graphically the relationship among total product, marginal product, and average product. The first thing to notice about the curves is that total product increases and its slope gets steeper as we move from point A to point E along the total product curve. As the use of labor increases between points A and E, the slope of the total product curve increases (becomes steeper); thus, marginal product increases as we move from point *a* to point *e*. The range over which marginal product increases is known as the range of **increasing marginal returns**.

In Figure 5-1, we see that marginal product reaches its maximum at point *e*, where 5 units of labor are employed. As the usage of labor increases from the 5th through the 10th units, total output increases, but at a decreasing rate. This is why marginal product declines between 5 and 10 units of labor but is still positive. The range over which marginal product is positive but declining is known as the range of **decreasing** or **diminishing marginal returns** to the variable input.

In Figure 5-1, marginal product becomes negative when more than 10 units of labor are employed. After a point, using additional units of input actually reduces total product, which is what it means for marginal product to be negative. The range over which marginal product is negative is known as the range of **negative marginal returns**.

increasing marginal returns
Range of input usage over which marginal product increases.

decreasing (diminishing) marginal returns
Range of input usage over which marginal product declines.

negative marginal returns
Range of input usage over which marginal product is negative.

Phases of Marginal Returns

As the usage of an input increases, marginal product initially increases (increasing marginal returns), then begins to decline (decreasing marginal returns), and eventually becomes negative (negative marginal returns).

PRINCIPLE

In studying for an exam, you have very likely experienced various phases of marginal returns. The first few hours spent studying increase your grade much more than the last few hours. For example, suppose you will make a 0 if you do not study but will make a 75 if you study 10 hours. The marginal product of the first 10 hours thus is 75 points. If it takes 20 hours of studying to score 100 on the exam, the marginal product of the second 10 hours is only 25 points. Thus, the marginal improvement in your grade diminishes as you spend additional hours studying. If you have ever pulled an "all-nighter" and ended up sleeping through an exam or performing poorly due to a lack of sleep, you studied in the range of negative marginal returns. Clearly, neither students nor firms should ever employ resources in this range.

The Role of the Manager in the Production Process

The manager's role in guiding the production process described earlier is twofold: (1) to ensure that the firm operates on the production function and (2) to ensure that the firm uses the correct level of inputs. These two aspects ensure that the firm operates at the right point on the production function. These two aspects of production efficiency are discussed next.

Produce on the Production Function

The first managerial role is relatively simple to explain, but it is one of the most difficult for a manager to perform. The production function describes the maximum possible output that can be produced with given inputs. For the case of labor, this means that workers must be putting forth maximal effort. To ensure that workers are in fact working at full potential, the manager must institute an incentive structure that induces them to put forth the desired level of effort. For example, the manager of a restaurant must institute an incentive scheme that ensures that food servers do a good job waiting on tables. Most restaurants pay workers low wages but allow them to collect tips, which effectively provides the workers with an incentive to perform well on the job. More generally, many firms institute profit-sharing plans to provide workers with an incentive to produce on the production function. A more detailed discussion of this role of the manager is presented in Chapter 6.

Use the Right Level of Inputs

The second role of the manager is to ensure that the firm operates at the right point on the production function. For a restaurant manager, this means hiring the "correct" number of servers. To see how this may be accomplished, let us assume that the output produced by a firm can be sold in a market at a price of $3. Furthermore, assume each unit of labor costs $400. How many units of labor should the manager hire to maximize profits? To answer this question, we must first determine the benefit of hiring an additional worker. Each worker increases the firm's output by his or her marginal product, and this increase in output can be sold in the market at a price of $3. Thus, the benefit to the firm from each unit of labor is $\$3 \times MP_L$. This number is called the **value marginal product** of labor. The value marginal product of an input thus is the value of the output produced by the last unit of that input. For example, if each unit of output can be sold at a price of P, the value marginal product of labor is

value marginal product
The value of the output produced by the last unit of an input.

$$VMP_L = P \times MP_L$$

and the value marginal product of capital is

$$VMP_K = P \times MP_K$$

Table 5–2

The Value Marginal Product of Labor

(1) L Variable Input (Labor) [Given]	(2) P Price of Output [Given]	(3) $\frac{\Delta Q}{\Delta L} = MP_L$ Marginal Product of Labor [Column 5 of Table 5-1]	(4) $VMP_L = P \times MP_L$ Value Marginal Product of Labor [(2) × (3)]	(5) W Unit Cost of Labor [Given]
0	$3	—	—	$400
1	3	76	$ 228	400
2	3	172	516	400
3	3	244	732	400
4	3	292	876	400
5	3	316	948	400
6	3	316	948	400
7	3	292	876	400
8	3	244	732	400
9	3	172	516	400
10	3	76	228	400
11	3	−44	−132	400

In our example, the cost to the firm of an additional unit of labor is $400. As Table 5-2 shows, the first unit of labor generates $VMP_L = \$228$ and the VMP_L of the second unit is $516. If the manager were to look only at the first unit of labor and its corresponding VMP_L, no labor would be hired. However, careful inspection of the table shows that the second worker will add $116 in value above her or his cost. If the first worker is not hired, the second will not be hired.

In fact, each worker between the second and the ninth produces additional output whose value exceeds the cost of hiring the worker. It is profitable to hire units of labor so long as the VMP_L is greater than $400. Notice that the VMP_L of the 10th unit of labor is $228, which is less than the cost of the 10th unit of labor. It would not pay for the firm to hire this unit of labor because the cost of hiring it would exceed the benefits. The same is true for additional units of labor. Thus, given the data in Table 5-2, the manager should hire nine workers to maximize profits.

Profit-Maximizing Input Usage

To maximize profits, a manager should use inputs at levels at which the marginal benefit equals the marginal cost. More specifically, when the cost of each additional unit of labor is w, the manager should continue to employ labor up to the point where $VMP_L = w$ in the range of diminishing marginal product.

PRINCIPLE

The *profit-maximizing input usage* rule defines the demand for an input by a profit-maximizing firm. For example, in Figure 5-2 the value marginal product of labor is graphed as a function of the quantity of labor utilized. When the wage rate is w^0, the profit-maximizing quantity of

INSIDE BUSINESS 5–1

Where Does Technology Come From?

In this chapter, we simply assume that the manager knows the underlying technology available for producing goods. How do managers acquire information about technology? Economic research suggests there are seven principal methods.

INDEPENDENT R&D

The most important means of acquiring product and process innovations is independent research and development (R&D). This essentially involves engineers employed by the firm who devise new production processes or products.

LICENSING TECHNOLOGY

The firm that was originally responsible for developing the technology and thus owns the rights to the technology often sells the production function to another firm for a licensing fee. The fee may be fixed, in which case the cost of acquiring the technology is a fixed cost of production. The fee may involve payments based on how much output is produced. In this instance, the cost of the technology is a variable cost of production.

PUBLICATIONS OR TECHNICAL MEETINGS

Trade publications and meetings provide a forum for the dissemination of information about production processes.

REVERSE ENGINEERING

As the term suggests, this involves working backward: taking a product produced by a competitor and devising a method of producing a similar product. The typical result is a product that differs slightly from the existing product and involves a slightly different production function from that used by the original developer.

HIRING EMPLOYEES OF INNOVATING FIRMS

Former employees of other firms often have information about the production process.

PATENT DISCLOSURES

A *patent* gives the holder the exclusive rights to an invention for a specified period of time—17 to 20 years in most countries. However, to obtain a patent an inventor must file detailed information about the invention, which becomes public information. Virtually anyone can look at the information filed, including competitors. In many instances, this information can enable a competitor to "clone" the product in a way that does not infringe on the patent. Interestingly, while a patent is pending, this information is not publicly available. For this reason, stretching out the time in which a patent is pending often provides more protection for an inventor than actually acquiring the patent.

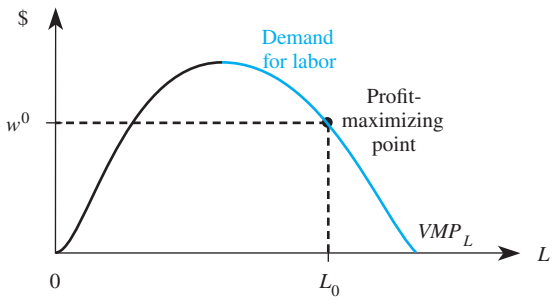
CONVERSATIONS WITH EMPLOYEES OF INNOVATING FIRMS

Despite the obvious benefits of keeping trade secrets "secret," employees inadvertently relay information about the production process to competitors. This is especially common in industries where firms are concentrated in the same geographic region and employees from different firms intermingle in nonbusiness settings.

SOURCES: Wesley M. Cohen, "Fifty Years of Empirical Studies of Innovative Activity and Performance," *Handbook of the Economics of Innovation,* Vol. 1 (2010), pp. 129–213; Richard C. Levin, "Appropriability, R&D Spending, and Technological Performance," *American Economic Review* 78 (May 1988), pp. 424–28.

Figure 5-2

The Demand for Labor



labor is that quantity such that $VMP_L = w_0$ in the range of diminishing marginal returns. In the figure, we see that the profit-maximizing quantity of labor is L_0 units.

The downward-sloping portion of the VMP_L curve defines demand for labor by a profit-maximizing firm; it shows the relationship between the wage rate and the amount of labor a firm will want to hire at that rate. We know the demand for an input slopes downward because of the **law of diminishing marginal returns**, which states that the marginal product of an additional unit of an input will at some point be lower than the marginal product of the previous unit. Since the marginal product of an input declines as more of that input is used, the value of the marginal product also declines as more of the input is used. Since the demand for an input is the value marginal product of the input in the range of diminishing marginal returns, the demand for an input slopes downward. In effect, each additional unit of an input adds less profits than the previous unit. Profit-maximizing firms thus are willing to pay less for each additional unit of an input.

law of diminishing marginal returns
States that the marginal product of an additional unit of an input will at some point be lower than the marginal product of the previous unit.

Algebraic Forms of Production Functions

Up until now, we have relied on tables and graphs to illustrate the concepts underlying production. The underlying notion of a production function can be expressed mathematically, and in fact, it is possible to use statistical techniques like those discussed in Chapter 1 to estimate a particular functional form for a production function. In this section, we highlight some more commonly encountered algebraic forms of production functions. We begin with the most simple production function: a linear function of the inputs.

The **linear production function** is

$$Q = F(K, L) = aK + bL$$

linear production function
A production function that assumes a perfect linear relationship between all inputs and total output.

where a and b are constants. With a linear production function, inputs are perfect substitutes. There is a perfect linear relationship between all the inputs and total output. For instance, suppose it takes workers at a plant four hours to produce what a machine can make in one hour. In this case, the production function is linear with $a = 4$ and $b = 1$:

$$Q = F(K, L) = 4K + L$$

This is the mathematical way of stating that capital is always 4 times as productive as labor. Furthermore, since $F(5,2) = 4(5) + 1(2) = 22$, we know that 5 units of capital and 2 units of labor will produce 22 units of output.

The **Leontief production function** is given by

$$Q = F(K, L) = \min \{aK, bL\}$$

Leontief production function
A production function that assumes that inputs are used in fixed proportions.

where a and b are constants. The Leontief production function is also called the *fixed-proportions production function* because it implies that inputs are used in fixed proportions. To see this, suppose the production function for a car service firm is Leontief, with $a = b = 1$; think of K as the number of cars and L as the number of drivers. The production function then implies that one driver and one car can produce one ride, two drivers and two cars can produce two rides, and so forth. But how many rides can one driver and five cars produce? The answer is only one ride. Additional cars are useful only to the extent that additional drivers are available to use them (at least until they are self driving!). In other words, cars and drivers must be used in the fixed proportion of one driver for every car.

DEMONSTRATION PROBLEM 5–1

The engineers at Morris Industries obtained the following estimate of the firm's production function:

$$Q = F(K, L) = \min\{3K, 4L\}$$

How much output is produced when 2 units of labor and 5 units of capital are employed?

ANSWER:

We simply calculate $F(5, 2)$. But $F(5, 2) = \min\{3(5), 4(2)\} = \min\{15, 8\}$. Since the minimum of the numbers "15" and "8" is 8, we know that 5 units of capital and 2 units of labor produce 8 units of output.

Cobb-Douglas production function
A production function that assumes some degree of substitutability among inputs.

A production function that lies between the extremes of the linear production function and the Leontief production function is the Cobb-Douglas production function. The **Cobb-Douglas production function** is given by

$$Q = F(K, L) = K^a L^b$$

where a and b are constants.

Unlike in the case of the linear production function, the relationship between output and inputs is not linear. Unlike in the Leontief production function, inputs need not be used in fixed proportions. The Cobb-Douglas production function assumes some degree of substitutability between the inputs, albeit not perfect substitutability.

Algebraic Measures of Productivity

Given an algebraic form of a production function, we may calculate various measures of productivity. For example, we learned that the average product of an input is the output produced divided by the number of units used of the input. This concept can easily be extended to production processes that use more than one input.

To be concrete, suppose a consultant provides you with the following estimate of your firm's Cobb-Douglas production function:

$$Q = F(K, L) = K^{1/2} L^{1/2}$$

What is the average product of labor when 4 units of labor and 9 units of capital are employed? Since $F(9, 4) = 9^{1/2}4^{1/2} = (3)(2) = 6$, we know that 9 units of capital and 4 units of labor produce 6 units of output. Thus, the average product of 4 units of labor is $AP_L = 6/4 = 1.5$ units.

Notice that when output is produced with both capital and labor, the average product of labor will depend not only on how many units of labor are used but also on how much capital is used. Since total output (Q) is affected by the levels of both inputs, the corresponding measure of the average product depends on both capital and labor. Likewise, the average product of capital depends not only on the level of capital but also on the level of labor used to produce Q.

Recall that the marginal product of an input is the change in output that results from a given change in the input. When the production function is linear, the marginal product of an input has a very simple representation, as the following formula reveals.

Formula: Marginal Product for a Linear Production Function. If the production function is linear and given by

$$Q = F(K, L) = aK + bL$$

then

$$MP_K = a$$

and

$$MP_L = b$$

A CALCULUS ALTERNATIVE

The marginal product of an input is the derivative of the production function with respect to the input. Thus, the marginal product of labor is

$$MP_L = \frac{\partial Q}{\partial L}$$

and the marginal product of capital is

$$MP_K = \frac{\partial Q}{\partial K}$$

For the case of the linear production function $Q = aK + bL$,

$$MP_K = \frac{\partial Q}{\partial K} = a \qquad \text{and} \qquad MP_L = \frac{\partial Q}{\partial L} = b$$

Thus, for a linear production function, the marginal product of an input is simply the coefficient of the input in the production function. This implies that the marginal product of an input is independent of the quantity of the input used whenever the production function is linear; linear production functions do not obey the law of diminishing marginal product.

In contrast to the linear case, the marginal product of an input for a Cobb-Douglas production function does depend on the amount of the input used, as the following formula reveals.

Formula: Marginal Product for a Cobb-Douglas Production Function. If the production function is Cobb-Douglas and given by

$$Q = F(K, L) = K^a L^b$$

then

$$MP_L = bK^a L^{b-1}$$

and

$$MP_K = aK^{a-1} L^b$$

A CALCULUS ALTERNATIVE

The marginal product of an input is the derivative of the production function with respect to the input. Taking the derivative of the Cobb-Douglas production function yields

$$MP_K = \frac{\partial Q}{\partial K} = aK^{a-1} L^b$$

and

$$MP_L = \frac{\partial Q}{\partial L} = bK^a L^{b-1}$$

which correspond to the equations in the previous formula.

Recall that the profit-maximizing use of an input occurs at the point where the value marginal product of an input equals the price of the input. As the next problem illustrates, we can apply the same principle to algebraic functional forms of production functions to attain the profit-maximizing use of an input.

DEMONSTRATION PROBLEM 5–2

A firm produces output that can be sold at a price of $10. The production function is given by

$$Q = F(K, L) = K^{1/2}L^{1/2}$$

If capital is fixed at 1 unit in the short run, how much labor should the firm employ to maximize profits if the wage rate is $2?

ANSWER:

We simply set the value marginal product of labor equal to the wage rate and solve for L. Since the production function is Cobb-Douglas, we know that $MP_L = bK^aL^{b-1}$. Here $a = 1/2$, $b = 1/2$, and $K = 1$. Hence, $MP_L = .5L^{1/2-1}$. Now, since $P = \$10$, we know that $VMP_L = P \times MP_L = 5L^{-1/2} = 5/\sqrt{L}$. Setting this equal to the wage, which is $2, we get $5/\sqrt{L} = 2$. If we square both sides of this equation, we get $25/L = 4$. Thus, the profit-maximizing quantity of labor is $L = 25/4 = 6.25$ units.

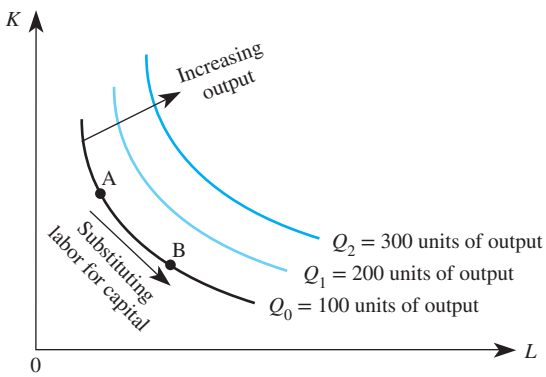
Isoquants

Our next task is to examine the optimal choice of capital and labor in the long run, when both inputs are free to vary. In the presence of multiple variables of production, various combinations of inputs enable the manager to produce the same level of output. For example, an automobile assembly line can produce 1,000 cars per hour by using 10 workers and one robot. It can also produce 1,000 cars by using only two workers and three robots. To minimize the costs of producing 1,000 cars, the manager must determine the efficient combination of inputs to use to produce them. The basic tool for understanding how alternative inputs can be used to produce output is an isoquant. An **isoquant** defines the combinations of inputs (K and L) that yield the producer the same level of output; that is, any combination of capital and labor along an isoquant produces the same level of output.

isoquant
Defines the combinations of inputs that yield the same level of output.

Figure 5-3 depicts a typical set of isoquants. Because input bundles A and B both lie on the same isoquant, each will produce the same level of output, namely, Q_0 units. Input mix A

Figure 5-3
A Family of Isoquants



implies a more capital-intensive plant than does input mix *B*. As more of both inputs are used, a higher isoquant is obtained. Thus, as we move in the northeast direction in the figure, each new isoquant is associated with higher and higher levels of output.

Notice that the isoquants in Figure 5-3 are convex. The reason isoquants are typically drawn with a convex shape is that inputs such as capital and labor typically are not perfectly substitutable. In Figure 5-3, for example, if we start at point A and begin substituting labor for capital, it takes increasing amounts of labor to replace each unit of capital that is taken away. The rate at which labor and capital can substitute for each other is called the **marginal rate of technical substitution (*MRTS*)**. The *MRTS* of capital and labor is the absolute value of the slope of the isoquant and is simply the ratio of the marginal products:

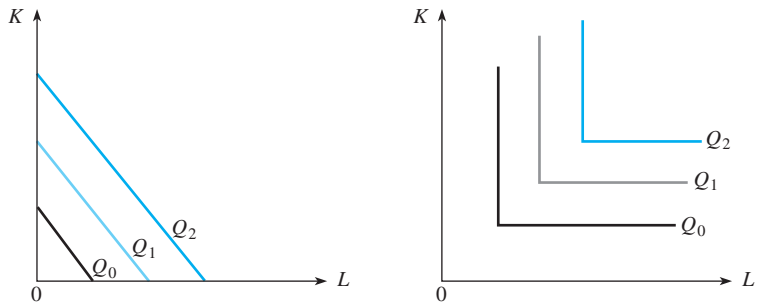
marginal rate of technical substitution (*MRTS*)
The rate at which a producer can substitute between two inputs and maintain the same level of output.

$$MRTS_{KL} = \frac{MP_L}{MP_K}$$

Different production functions will imply different marginal rates of technical substitution. For example, the linear production function implies isoquants that are *linear*, as in Figure 5-4(a). This is because the inputs are perfect substitutes for each other and the rate at which the producer can substitute between the inputs is independent of the level of input usage. Specifically, for the linear production function $Q = aK + bL$, the marginal rate of technical substitution is b/a since $MP_L = b$ and $MP_K = a$. This is independent of the level of inputs utilized.

The Leontief production function, on the other hand, implies isoquants that are *L shaped*, as in Figure 5-4(b). In this case, inputs must be used in fixed proportions; the manager cannot substitute between capital and labor and maintain the same level of output. For the Leontief production function, there is no *MRTS* because there is no substitution among inputs along an isoquant. For most production relations, the isoquants lie somewhere between the perfect-substitute and fixed-proportions cases. In these instances, the inputs are substitutable for one another, but not perfectly, and the rate at which a manager can substitute among inputs will change along an isoquant. For instance, by moving from point A to point B in Figure 5-5, the manager substitutes 1 unit of capital for 1 unit of labor and still produces 100 units of output. But in moving from point C to point D, the manager would have to substitute 3 units of capital for 1 unit of labor to produce 100 units of output. Thus, the production function satisfies the **law of diminishing marginal rate of technical substitution**: As a producer uses less of an input, increasingly more of the other input must be employed to produce the same level of output. It can be shown that the Cobb-Douglas production function implies isoquants that have a diminishing marginal rate of technical substitution. Whenever an isoquant exhibits a diminishing marginal rate of

law of diminishing marginal rate of technical substitution
A property of a production function stating that as less of one input is used, increasing amounts of another input must be employed to produce the same level of output.

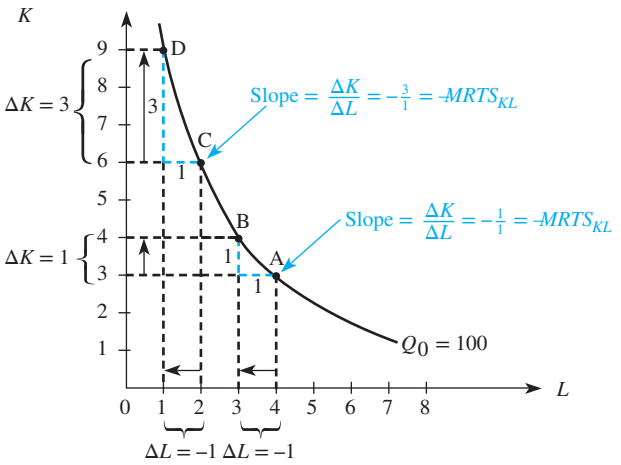


(a) Linear (b) Leontief

Figure 5-4
Linear and Leontief Isoquants

Figure 5-5

The Marginal Rate of Technical Substitution



technical substitution, the corresponding isoquants are convex from the origin; that is, they look like the isoquants in Figure 5-5.

Isocosts

isocost line
A line that represents the combinations of inputs that will cost the producer the same amount of money.

Isoquants describe the combinations of inputs that produce a given level of output. Notice that different combinations of capital and labor end up costing the firm the same amount. The combinations of inputs that will cost the firm the same amount comprise an **isocost line**.

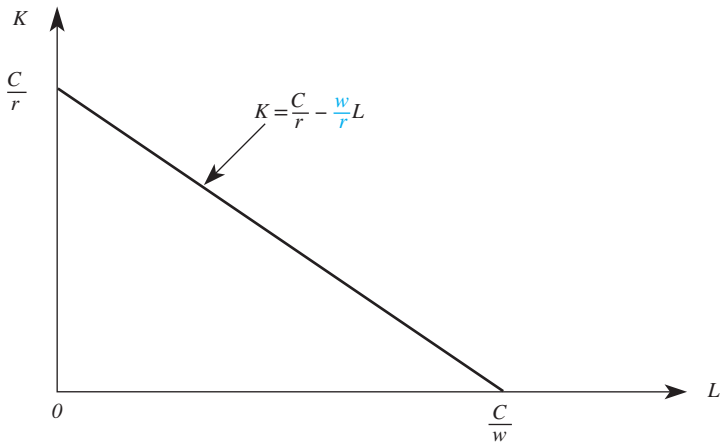
The relation for an isocost line is graphed in Figure 5-6. To understand this concept, suppose the firm spends exactly $\$C$ on inputs. Then the cost of labor plus the cost of capital exactly equals $\$C$:

$$wL + rK = C \tag{5–1}$$

where w is the wage rate (the price of labor) and r is the rental rate (the price of capital). This equation represents the formula for an isocost line.

Figure 5-6

Isocosts



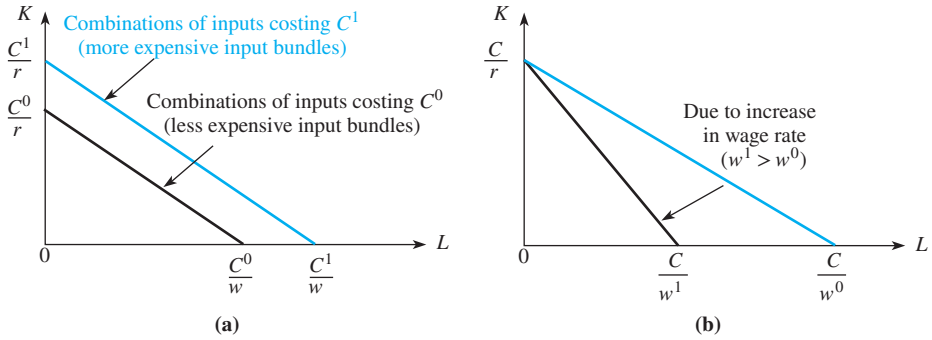


Figure 5-7
Changes in Isocosts

We may obtain a more convenient expression for the slope and intercept of an isocost line as follows. We multiply both sides of Equation 5–1 by $1/r$ and get

$$\frac{w}{r}L + K = \frac{C}{r}$$

or

$$K = \frac{C}{r} - \frac{w}{r}L$$

Thus, along an isocost line, K is a linear function of L with a vertical intercept of C/r and a slope of $-w/r$.

Note that if the producer wishes to use more of both inputs, more money must be spent. Thus, isocosts associated with higher costs lie above those with lower costs. When input prices are constant, the isocost lines will be parallel to one another. Figure 5-7(a) illustrates the isocost lines for cost levels C^0 and C^1, where $C^0 < C^1$.

Similarly, changes in input prices affect the position of the isocost line. An increase in the price of labor makes the isocost curve steeper, while an increase in the price of capital makes it flatter. For instance, Figure 5-7(b) reveals that the isocost line rotates clockwise when the wage rate increases from w^0 to w^1.

Changes in Isocosts
For given input prices, isocosts farther from the origin are associated with higher costs. Changes in input prices change the slopes of isocost lines.

PRINCIPLE

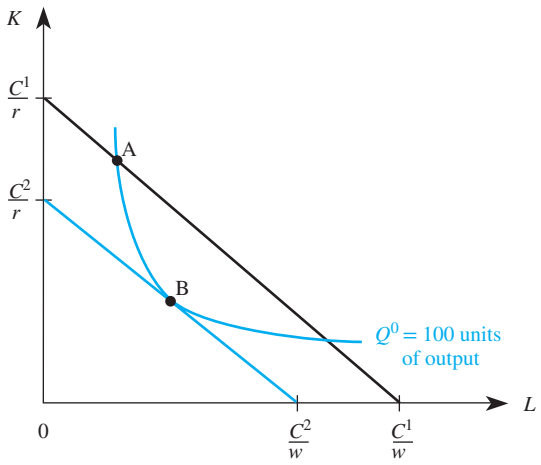
Cost Minimization

The isocosts and isoquants just defined may be used to determine the input usage that minimizes production costs. If there were no scarcity, the producer would not care about production costs. But because scarcity is an economic reality, producers are interested in **cost minimization**—that is, producing output at the lowest possible cost. After all, to maximize profits, the firm must first produce its output in the least-cost manner. Even not-for-profit organizations can achieve their objectives by providing a given level of service at the lowest possible cost. Let us piece together the tools developed thus far to see how to choose the optimal mix of capital and labor.

cost minimization
Producing output at the lowest possible cost.

Figure 5-8

Input Mix B Minimizes the Cost of Producing 100 Units of Output



Consider an input bundle such as that at point A in Figure 5-8. This combination of L and K lies on the isoquant labeled Q_0 and thus produces Q_0 units of output. It also lies on the isocost line through point A. Thus, if the producer uses input mix A, he or she will produce Q_0 units of output at a total cost of C^1. Is this the cost-minimizing way to produce the given level of output? Clearly not, for by using input mix B instead of A, the producer could produce the same amount of output at a lower cost, namely C^2. In short, it is inefficient for the producer to use input mix A because input mix B produces the same output and lies on a lower isocost line.

At the cost-minimizing input mix, the slope of the isoquant is equal to the slope of the isocost line. Recalling that the absolute value of the slope of the isoquant reflects the marginal rate of technical substitution and that the slope of the isocost line is given by $-w/r$, we see that at the cost-minimizing input mix,

$$MRTS_{KL} = w/r$$

If this condition did not hold, the technical rate at which the producer could substitute between L and K would differ from the market rate at which she or he could substitute between the inputs. For example, at point A in Figure 5-8, the slope of the isoquant is steeper than the slope of the isocost line. Consequently, capital is "too expensive"; the producer finds it in his or her interest to use less capital and more labor to produce the given level of output. This substitution continues until ultimately the producer is at a point such as B, where the *MRTS* is equal to the ratio of input prices. The condition for the cost-minimizing use of inputs also can be stated in terms of marginal products.

To see why this condition must hold to be able to minimize the cost of producing a given level of output, suppose $MP_L/w > MP_K/r$. Then, on a last-dollar-spent basis, labor is a better deal than capital, and the firm should use less capital and more labor to minimize costs. In particular, if the firm reduced its expenditures on capital by \$1, it could produce the same level of output if it increased its expenditures on labor by less than \$1. Thus, by substituting away from capital and toward labor, the firm could reduce its costs while producing the same level of output. This substitution clearly would continue until the marginal product per dollar spent on capital exactly equaled the marginal product per dollar spent on labor.

Cost-Minimizing Input Rule

To minimize the cost of producing a given level of output, the marginal product per dollar spent should be equal for all inputs:

$$\frac{MP_L}{w} = \frac{MP_K}{r}$$

PRINCIPLE

Equivalently, to minimize the cost of production, a firm should employ inputs such that the marginal rate of technical substitution is equal to the ratio of input prices:

$$\frac{MP_L}{MP_K} = \frac{w}{r}$$

DEMONSTRATION PROBLEM 5–3

For a video walkthrough of this problem, visit www.mhhe.com/baye10e

Terry's Lawn Service rents five small push mowers and two large riding mowers to cut the lawns of neighborhood households. The marginal product of a small push mower is three lawns per day, and the marginal product of a large riding mower is six lawns per day. The rental price of a small push mower is $10 per day, whereas the rental price of a large riding mower is $25 per day. Is Terry's Lawn Service utilizing small push mowers and large riding mowers in a cost-minimizing manner?

ANSWER:

Let MP_S be the marginal product of a small push mower and MP_L be the marginal product of a large riding mower. If we let P_S and P_L be the rental prices of a small push mower and large riding mower, respectively, cost minimization requires that

$$\frac{MP_S}{P_S} = \frac{MP_L}{P_L}$$

Substituting in the appropriate values, we see that

$$\frac{3}{10} = \frac{MP_S}{P_S} > \frac{MP_L}{P_L} = \frac{6}{25}$$

Thus, the marginal product per dollar spent on small push mowers exceeds the marginal product per dollar spent on large riding mowers. Riding mowers are twice as productive as push mowers, but more than twice as expensive. The firm clearly is not minimizing costs and thus should use fewer riding mowers and more push mowers.

Optimal Input Substitution

A change in the price of an input will lead to a change in the cost-minimizing input bundle. To see this, suppose the initial isocost line in Figure 5-9 is FG and the producer is cost-minimizing at input mix A, producing Q_0 units of output. Now suppose that the wage rate increases so that if the firm spent the same amount on inputs, its isocost line would rotate clockwise to FH in Figure 5-9. Clearly, if the firm spends the amount it spent prior to the increase in the wage rate, it cannot produce the same level of output.

Given the new slope of the isocost line, which reflects a higher relative price of labor, the cost-minimizing way to maintain the output implied by the initial isoquant is at point B, where

INSIDE BUSINESS 5–2

Artificial Intelligence and Cost-Minimizing Inputs

Among other things, artificial intelligence (AI) allows machines to take on tasks formerly completed by humans. For example, well-trained machines are increasingly able to perform medical diagnoses via medical imaging, such as ultrasound and CT scans. An ongoing debate concerns whether AI will generally lead to firms using more or less labor for their production. While we cannot offer the answer to such a broad question, our analysis of cost-minimizing inputs can help a manager think carefully about how the adoption of AI at her firm might affect the optimal number of workers she should hire at a given cost.

To simplify the analysis, suppose AI only affected productivity and not prices for labor and capital. To begin, AI is likely to increase the marginal product of capital. Using our cost-minimization input rule, the manager should then increase capital and decrease labor as a result. However, AI may make labor more productive as well. For example, AI can boost the productivity of software developers, helping them to make higher quality software in less time. If AI does increase the productivity of capital *and* labor, the net effect on the cost-minimizing input bundle is unclear—it could lead to more capital and less labor or more labor and less capital. It all depends on the relative increases in productivity. Consequently, managers seeing opportunities to use AI in their business should not just assume AI utilization will lead to fewer employees; it could lead to a larger, and more productive, labor force.

SOURCES: A. Hosny, C. Parmar, J. Quackenbush, L.H. Schwartz, and H.J.W.L Aerts, "Artificial Intelligence in Radiology," *Nature Reviews Cancer* 18 (August 2018), pp. 500–10; Morgan Frank, David Autor, James Bessen, Erik Brynjolfsson, Manuel Cebrian, David Deming, Maryann Feldman, Matthew Groh, Jose Lobo, Esteban Moro, Dashun Wang, Hyejin Youn, and Ilyad Rahwan, "Toward Understanding the Impact of Artificial Intelligence on Labor," *Proceedings of the National Academy of Sciences of the United States of America* 116 (April 2019), pp. 6531–39.

isocost line IJ is tangent to the isoquant. Due to the increase in the price of labor relative to capital, the producer substitutes away from labor and toward capital and adopts a more capital-intensive mode of production. This suggests the following important result:

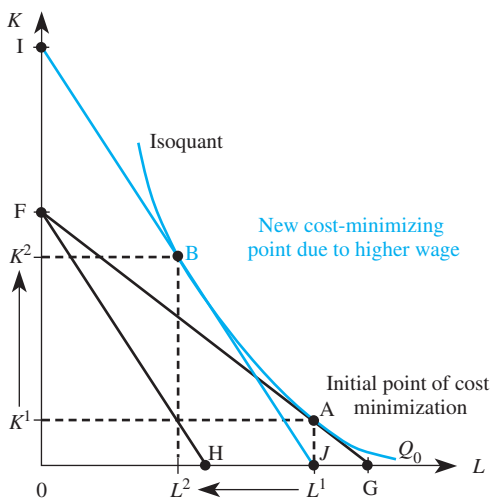
PRINCIPLE

Optimal Input Substitution

To minimize the cost of producing a given level of output, the firm should use less of an input and more of other inputs when that input's price rises.

Figure 5-9

Substituting Capital for Labor Due to Increase in the Wage Rate



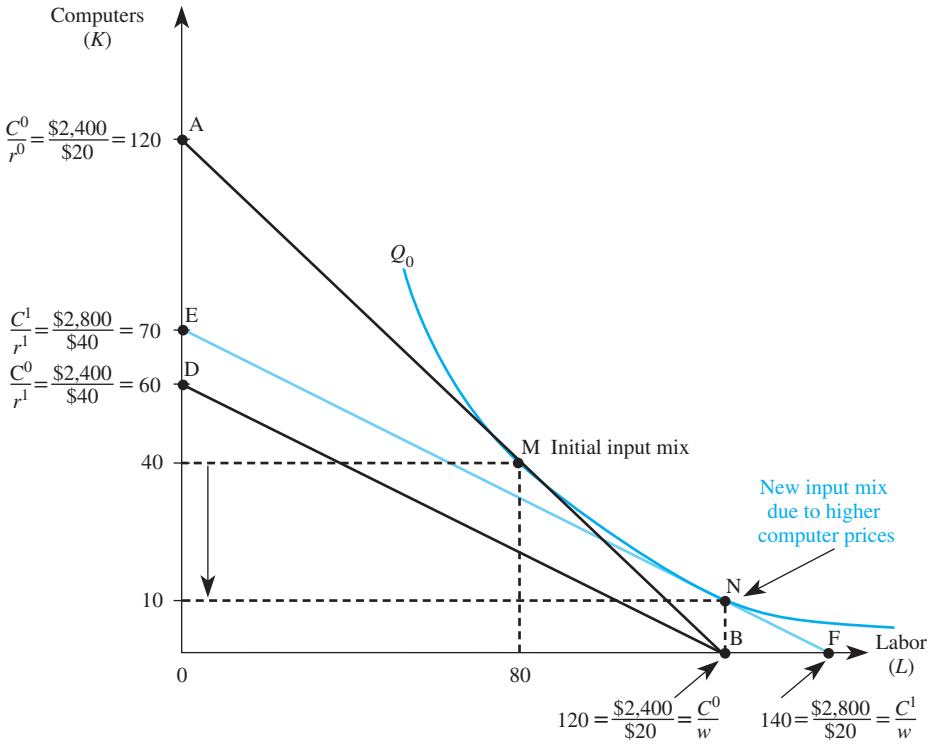


Figure 5-10

Substituting Labor for Computers, Due to Higher Computer Prices

Figure 5-10 shows the isocost line (AB) and isoquant for a firm that produces rugs using computers and labor. The initial point of cost minimization is at point M, where the manager has chosen to use 40 units of capital (computers) and 80 units of labor when the wage rate is $w = \$20$ and the rental rate of computers (capital) is $r^0 = \$20$. This implies that at point M, total costs are $C^0 = (\$20 \times 40) + (\$20 \times 80) = \$2{,}400$. Notice also at point M that the *MRTS* equals the ratio of the wage to the rental rate.

Now assume that due to a decrease in the supply of silicon chips, the rental rate of capital increases to $r^1 = \$40$. What will the manager do to minimize costs? Since the price of capital has increased, the isocost line will rotate counterclockwise from AB to DB. To produce the same amount of output, the manager will have to spend more than $C^0 = \$2{,}400$. The additional expenditures will shift the isocost line out to EF in Figure 5-10. The new point of cost minimization is at point N, where the firm now employs more labor (120 units) and less capital (10 units) to minimize the production costs of rugs. Costs are now $C^1 = (\$40 \times 10) + (\$20 \times 120) = \$2{,}800$, which are higher than C^0.

Data-Driven Production Functions

As we mentioned earlier, it is possible to use statistical techniques such as regression analysis, along with carefully collected data, to estimate a production function. For example, a firm may believe its production function to be Cobb-Douglas, $Q = CK^aL^b$. However, to make cost-minimizing or profit-maximizing input decisions, the manager needs to have values for a and b. The manager can estimate these values using data on output, capital, and labor, perhaps collected through a field experiment.

Table 5–3

Regression Estimates for a Cobb-Douglas Production Function

	Coefficients	Standard Error	*t*-Stat	*P*-value	Lower 95%	Upper 95%
Intercept	2.66	1.129	2.359	0.019	0.436	4.889
ln*K*	0.66	0.210	3.148	0.002	0.247	1.078
ln*L*	0.41	0.192	2.151	0.033	0.034	0.790

Notice that the Cobb-Douglas production function is not linear, but log-linear. That is, we may transform it into an equation suitable for linear regression by taking the log of both sides:

$$\ln Q = \ln C + a \ln K + b \ln L$$

This equation is linear in the logarithms; that is, the manager can obtain estimates of the unknown parameters (a, b and $\ln C$) by regressing the natural log of output ($\ln Q$) on the natural log of capital ($\ln K$) and the natural log of labor ($\ln L$).

In Table 5-3, we present regression estimates along with measures of their significance for such a Cobb-Douglas production function, using a demonstration dataset (*Table05-03.xls*). These results indicate that our estimate for a is 0.66 and our estimate for b is 0.41. Recall from Chapter 1 that the large (in absolute value) t-stats and small P-values for both of these parameter estimates tell us that both are statistically significant.

Using this simple estimated production function, we can now calculate the marginal product of capital and labor. Here, we have $MP_K = 0.66K^{-0.34}L^{0.41}$ and $MP_L = 0.41K^{0.66}L^{-0.59}$. Therefore, for any given price of capital and labor (r and w, respectively), we know the manager will minimize costs by choosing capital and labor such that:

$$\frac{0.41K^{0.66}L^{-0.59}}{0.66K^{-0.34}L^{0.41}} = \frac{0.41K}{0.66L} = \frac{w}{r}$$

For example, if the wage rate is \$25 and the price of capital is \$20, the cost-minimizing choice of inputs uses about twice as much capital as labor, since this equation implies $K/L = (25/20)(0.66/0.41) = 2.01$.

THE COST FUNCTION

For given input prices, different isoquants will entail different production costs, even allowing for optimal substitution between capital and labor. Each isoquant corresponds to a different level of output, and the isocost line tangent to higher isoquants will imply higher costs of production, even assuming the firm uses the cost-minimizing input mix. Since the cost of production increases as higher isoquants are reached, it is useful to let $C(Q)$ denote the cost to the firm of producing isoquant Q in the cost-minimizing fashion. The function C is called the *cost function.*

The cost function is extremely valuable because, as we will see in later chapters, it provides essential information a manager needs to determine the profit-maximizing level of output. In addition, the cost function summarizes information about the production process. The cost function thus reduces the amount of information the manager has to process to make optimal output decisions.

INSIDE BUSINESS 5–3

The Affordable Care Act, Employer Mandate, and Input Substitution

Government regulations often have unintended consequences. In 2010, President Obama signed into law the Affordable Care Act, which marked a significant overhaul of the American health care system. The new law introduced many new regulations, several of which proved highly controversial. One notably controversial new regulation is the employer mandate, which requires every American business with 50 or more full-time employees to "offer affordable health coverage that provides a minimum level of coverage to their full-time employees (and their dependents)." If firms do not comply with the mandate, they must pay a fee of $2,000 per employee for every employee beyond the first 30.

Opponents of the mandate argued it would have a detrimental effect on low-wage workers, presumably one of the groups the law is intended to assist. To see why, consider a company that hires computer programmers and administrative assistants. Suppose the annual wage bill of a computer programmer is $80,000 and that of an administrative assistant is $40,000. Next, suppose the employer mandate forces businesses to offer additional benefits of $4,000 to its employees. Without the employer mandate, the relative price of an administrative assistant to a computer programmer is $40,000/$80,000 = .5. But when the cost of the additional benefits is added in, the relative price of an administrative assistant increases to a little over .52 of that of a computer programmer. Isoquant and isocost analyses suggest that firms should substitute away from the now higher-priced administrative assistants to minimize costs.

Seem far-fetched? Economists Frank Scott, Mark Berger, and Dan Black examined the relationship between health care costs and employment of low-wage workers. They found that industries that offered more generous health care plans employed significantly fewer bookkeepers, keypunch operators, receptionists, secretaries, clerk-typists, janitors, and food service workers than did industries with lower health care costs. Moreover, industries with higher levels of fringe benefits hired more part-time workers than did industries with lower fringe-benefit levels since the government does not require firms to offer pension, health care, and many other fringe benefits to part-time workers.

Lastly, note that firms that choose not to comply with the mandate and instead pay the penalty still have an incentive to substitute away from administrative assistants, as the relative price of an administrative assistant is a little over .51.

SOURCES: https://www.irs.gov/Affordable-Care-Act/Employers/Questions-and-Answers-on-Employer-Shared-Responsibility-Provisions-Under-the-Affordable-Care-Act, accessed October 2015; Frank Scott, Mark Berger, and Dan Black, "Effects of Fringe Benefits on Labor Market Segmentation," *Industrial and Labor Relations Review* 42 (January 1989), pp. 216–19.

Short-Run Costs

Recall that the *short run* is defined as the period over which the amounts of some inputs are fixed. In the short run, the manager is free to alter the use of variable inputs but is "stuck" with existing levels of fixed inputs. Because inputs are costly whether fixed or variable, the **total cost** of producing output in the short run consists of (1) the cost of fixed inputs and (2) the cost of variable inputs. These two components of short-run total cost are called fixed costs and variable costs, respectively. **Fixed costs**, denoted FC, are costs that do not vary with output. Fixed costs include the costs of fixed inputs used in production. **Variable costs**, denoted $VC(Q)$, are costs that change when output is changed. Variable costs include the costs of inputs that vary with output.

Since all costs fall into one category or the other, the sum of fixed and variable costs is the firm's short-run cost function. In the presence of fixed factors of production, the **short-run cost function** summarizes the minimum possible cost of producing each level of output when variable factors are being used in the cost-minimizing way.

Table 5-4 illustrates the costs of producing with the technology used in Table 5-1. Notice that the first three columns comprise a short-run production function because they

total cost
Sum of fixed and variable costs.

fixed costs
Costs that do not change with changes in output; include the costs of fixed inputs used in production.

variable costs
Costs that change with changes in output; include the costs of inputs that vary with output.

short-run cost function
A function that defines the minimum possible cost of producing each output level when variable factors are employed in the cost-minimizing fashion.

Table 5–4

The Cost Function

(1) *K* Fixed Input [Given]	(2) *L* Variable Input [Given]	(3) *Q* Output [Given]	(4) *FC* Fixed Cost [$1,000 × (1)]	(5) *VC* Variable Cost [$400 × (2)]	(6) *TC* Total Cost [(4) + (5)]
2	0	0	$2,000	$ 0	$2,000
2	1	76	2,000	400	2,400
2	2	248	2,000	800	2,800
2	3	492	2,000	1,200	3,200
2	4	784	2,000	1,600	3,600
2	5	1,100	2,000	2,000	4,000
2	6	1,416	2,000	2,400	4,400
2	7	1,708	2,000	2,800	4,800
2	8	1,952	2,000	3,200	5,200
2	9	2,124	2,000	3,600	5,600
2	10	2,200	2,000	4,000	6,000

summarize the maximum amount of output that can be produced with two units of the fixed factor (capital) and alternative units of the variable factor (labor). Assuming capital costs $1,000 per unit and labor costs $400 per unit, we can calculate the fixed and variable costs of production, which are summarized in columns 4 and 5 of Table 5-4. Notice that irrespective of the amount of output produced, the cost of the capital equipment is $1,000 × 2 = $2,000. Thus, every entry in column 4 contains this number, illustrating the principle that fixed costs do not vary with output.

To produce more output, more of the variable factor must be employed. For example, to produce 1,100 units of output, 5 units of labor are needed; to produce 1,708 units of output, 7 units of labor are required. Since labor is the only variable input in this simple example, the variable cost of producing 1,100 units of output is the cost of 5 units of labor, or $400 × 5 = $2,000. Similarly, the variable cost of producing 1,708 units of output is $400 × 7 = $2,800. Total costs, summarized in the last column of Table 5-4, are simply the sum of fixed costs (column 4) and variable costs (column 5) at each level of output.

Figure 5-11 illustrates graphically the relations among total costs (*TC*), variable costs (*VC*), and fixed costs (*FC*). Because fixed costs do not change with output, they are constant for all output levels and must be paid even if zero units of output are produced. Variable costs, on the other hand, are zero if no output is produced but increase as output increases above zero. Total cost is the sum of fixed costs and variable costs. Thus, the distance between the *TC* and *VC* curves in Figure 5-11 is simply fixed costs. Note that the curves look closer together as they get steeper; however, this is due to the fact that, with a fixed vertical difference in the curves, the horizontal difference will get smaller as the curves get steeper, making them look closer on that dimension.

Average and Marginal Costs

One common misconception about costs is that large firms have lower costs than smaller firms because they produce larger quantities of output. One fundamental implication of

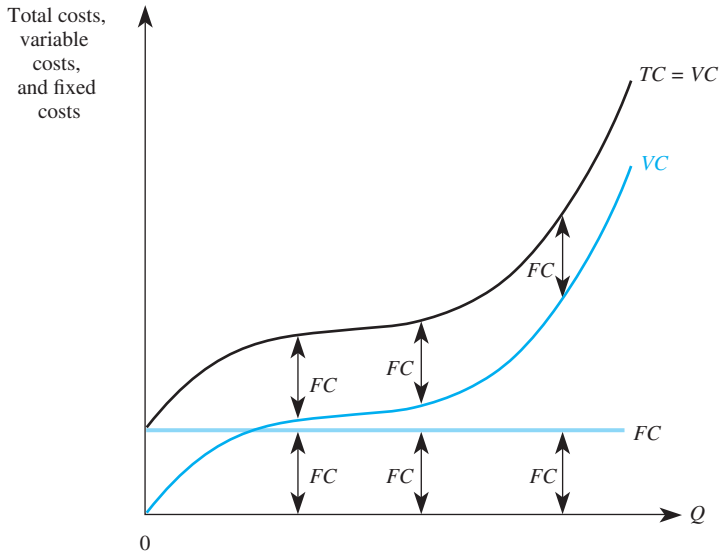


Figure 5-11
The Relationship among Costs

scarcity is that to produce more output, more must be spent. What individuals most likely have in mind when they consider the advantages of producing large quantities of output is that the overhead is spread out over a larger level of output. This idea is intricately related to the economic concept of average fixed cost. **Average fixed cost (*AFC*)** is defined as fixed costs (*FC*) divided by the number of units of output:

average fixed cost (*AFC*)
Fixed costs divided by the number of units of output.

$$AFC = \frac{FC}{Q}$$

Since fixed costs do not vary with output, as more and more output is produced, the fixed costs are allocated over a greater quantity of output. As a consequence, average fixed costs decline continuously as output is expanded. This principle is revealed in column 5 of Table 5-5, where we see that average fixed costs decline as total output increases.

Average variable cost provides a measure of variable costs on a per-unit basis. **Average variable cost (*AVC*)** is defined as variable cost (*VC*) divided by the number of units of output:

average variable cost (*AVC*)
Variable costs divided by the number of units of output.

$$AVC = \frac{VC(Q)}{Q}$$

Column 6 of Table 5-5 provides the average variable cost for the production function in our example. Notice that as output increases, average variable cost initially declines, reaches a minimum between 1,708 and 1,952 units of output, and then begins to increase.

Average total cost is analogous to average variable cost, except that it provides a measure of total costs on a per-unit basis. **Average total cost (*ATC*)** is defined as total cost (*TC*) divided by the number of units of output:

average total cost (*ATC*)
Total cost divided by the number of units of output.

$$ATC = \frac{C(Q)}{Q}$$

Column 7 of Table 5-5 provides the average total cost of various outputs in our example. Notice that average total cost declines as output expands to 2,124 units and then begins to rise.

Table 5–5

Derivation of Average Costs

(1) *Q* Output [Given]	(2) *FC* Fixed Cost [Given]	(3) *VC* Variable Cost [Given]	(4) *TC* Total Cost [(2) + (3)]	(5) *AFC* Average Fixed Cost [(2)/(1)]	(6) *AVC* Average Variable Cost [(3)/(1)]	(7) *ATC* Average Total Cost [(4)/(1)]
0	$2,000	$ 0	$2,000	—	—	—
76	2,000	400	2,400	$26.32	$5.26	$31.58
248	2,000	800	2,800	8.06	3.23	11.29
492	2,000	1,200	3,200	4.07	2.44	6.50
784	2,000	1,600	3,600	2.55	2.04	4.59
1,100	2,000	2,000	4,000	1.82	1.82	3.64
1,416	2,000	2,400	4,400	1.41	1.69	3.11
1,708	2,000	2,800	4,800	1.17	1.64	2.81
1,952	2,000	3,200	5,200	1.02	1.64	2.66
2,124	2,000	3,600	5,600	0.94	1.69	2.64
2,200	2,000	4,000	6,000	0.91	1.82	2.73

Furthermore, note that average total cost is the sum of average fixed costs and average variable costs (the sum of columns 5 and 6) in Table 5-5.

marginal (incremental) cost (MC)
The change in total costs arising from a change in the managerial control variable *Q*.

The most important cost concept is marginal (or incremental) cost. Conceptually, **marginal cost** (***MC***) is the cost of producing an additional unit of output, that is, the change in cost attributable to the last unit of output:

$$MC = \frac{\Delta C}{\Delta Q}$$

To understand this important concept, consider Table 5-6, which summarizes the short-run cost function with which we have been working. Marginal cost, depicted in column 7, is calculated as the change in costs arising from a given change in output. For example, increasing output from 248 to 492 units ($\Delta Q = 244$) increases costs from 2,800 to 3,200 ($\Delta C = \$400$). Thus, the marginal cost of increasing output to 492 units is $\Delta C/\Delta Q = 400/244 = \$1.64$.

When only one input is variable, the marginal cost is the price of that input divided by its marginal product. Remember that marginal product increases initially, reaches a maximum, and then decreases. Because marginal cost is the reciprocal of marginal product times the input's price, it decreases as marginal product increases and increases when marginal product is decreasing.

Relations among Costs

Figure 5-12 graphically depicts average total, average variable, average fixed, and marginal costs under the assumption that output is infinitely divisible (the firm is not restricted to producing only the outputs listed in Tables 5-5 and 5-6 but can produce any outputs). The shapes of the curves indicate the relation between the marginal and average costs presented in those tables. These relations among the cost curves, also depicted in Figure 5-12, are very

Table 5–6

Derivation of Marginal Costs

(1) Q [Given]	(2) ΔQ [Δ(1)]	(3) VC [Given]	(4) ΔVC [Δ(3)]	(5) TC [Given]	(6) ΔTC [Δ(5)]	(7) MC [(6)/(2) or (4)/2)]
0	—	0	—	2,000	—	—
76	76	400	400	2,400	400	400/76 = 5.26
248	172	800	400	2,800	400	400/172 = 2.33
492	244	1,200	400	3,200	400	400/244 = 1.64
784	292	1,600	400	3,600	400	400/292 = 1.37
1,100	316	2,000	400	4,000	400	400/316 = 1.27
1,416	316	2,400	400	4,400	400	400/316 = 1.27
1,708	292	2,800	400	4,800	400	400/292 = 1.37
1,952	244	3,200	400	5,200	400	400/244 = 1.64
2,124	172	3,600	400	5,600	400	400/172 = 2.33
2,200	76	4,000	400	6,000	400	400/76 = 5.26

important. The first thing to notice is that the marginal cost curve intersects the *ATC* and *AVC* curves at their minimum points. This implies that when marginal cost is below an average cost curve, average cost is declining, and when marginal cost is above average cost, average cost is rising.

There is a simple explanation for this relationship among the various cost curves. Again consider your grade in this course. If your grade on an exam is below your average grade, the new grade lowers your average grade. If the grade you score on an exam is above your average grade, the new grade increases your average. In essence, the new grade is the marginal contribution to your total grade. When the marginal is above the average, the average increases; when the marginal is below the average, the average decreases. The same principle applies to marginal and average costs, and this is why the curves in Figure 5-12 look the way they do.

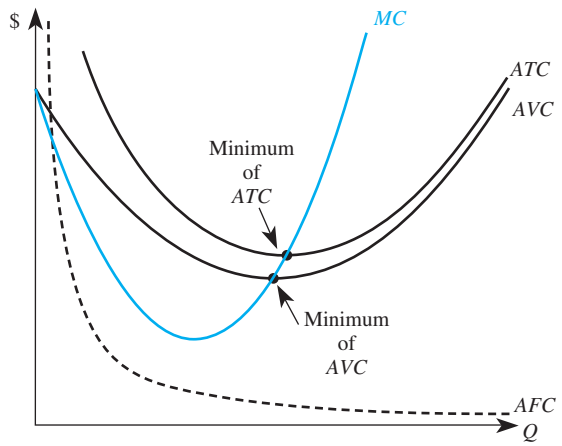


Figure 5-12
The Relationship among Average and Marginal Costs

The second thing to notice in Figure 5-12 is that the *ATC* and *AVC* curves get closer together as output increases. This is because the only difference in *ATC* and *AVC* is *AFC*. To see why, note that total costs consist of variable costs and fixed costs:

$$C(Q) = VC(Q) + FC$$

If we divide both sides of this equation by total output (Q), we get

$$\frac{C(Q)}{Q} = \frac{VC(Q)}{Q} + \frac{FC}{Q}$$

But $C(Q)/Q = ATC$, $VC(Q)/Q = AVC$, and $FC/Q = AFC$. Thus,

$$ATC = AVC + AFC$$

The difference between average total costs and average variable costs is $ATC - AVC = AFC$. Because average fixed costs decline as output is expanded, as in Figure 5-12, this difference between average total and average variable costs diminishes as fixed costs are spread over increasing levels of output.

Fixed and Sunk Costs

sunk cost
A cost that is forever lost after it has been paid.

We now make an important distinction between fixed costs and sunk costs. Recall that a fixed cost is a cost that does not change when output changes. A related concept, called **sunk cost**, is a cost that is lost forever once it has been paid. To be concrete, imagine that you are the manager of a coal company and have just paid $10,000 to lease a railcar for one month. This expense reflects a fixed cost to your firm—the cost is $10,000, regardless of whether you use the railcar to transport 10 tons or 10,000 tons of coal. How much of this $10,000 is a sunk cost depends on the terms of your lease. If the lease does not permit you to recoup any of the $10,000 once it has been paid, the entire $10,000 is a sunk cost—you have already incurred the cost and there is nothing you can do to change it. If the lease states that you will be refunded $6,000 in the event you do not need the railcar, then only $4,000 of the $10,000 in fixed costs is a sunk cost. Sunk costs are thus the amount of these fixed costs that cannot be recouped.

Since sunk costs are lost forever once they have been paid, they are irrelevant to decision making. To illustrate, suppose you paid a nonrefundable amount of $10,000 to lease a railcar for one month, but immediately after signing the lease, you realize that you do not need it—the demand for coal is significantly lower than you expected. A farmer approaches you and offers to sublease the railcar from you for $2,000. If the terms of your lease permit you to sublease the railcar, should you accept the farmer's offer?

You might reason that the answer is no; after all, your firm would appear to lose $8,000 by subleasing a $10,000 railcar for a measly $2,000. *This reasoning is wrong.* Your lease payment is nonrefundable, which means that the $10,000 is an unavoidable cost that has already been lost. Because there is nothing you can do to eliminate this $10,000 cost, the only relevant issue is whether you can do something to enhance your inflow of cash. In this case, your optimal decision is to sublease the railcar because doing so provides you with $2,000 in revenues that you would not get otherwise. Notice that, while sunk costs are irrelevant in making your decision, they do affect your calculation of total profits. If you do not sublease the railcar, you lose $10,000; if you sublease it, you lose only $8,000.

PRINCIPLE

Irrelevance of Sunk Costs

A decision maker should ignore sunk costs to maximize profits or minimize losses.

DEMONSTRATION PROBLEM 5–4

ACME Coal paid $5,000 to lease a railcar from the Reading Railroad. Under the terms of the lease, $1,000 of this payment is refundable if the railcar is returned within two days of signing the lease.

1. Upon signing the lease and paying $5,000, how large are ACME's fixed costs? Its sunk costs?
2. One day after signing the lease, ACME realizes that it has no use for the railcar. A farmer has a bumper crop of corn and has offered to sublease the railcar from ACME at a price of $4,500. Should ACME accept the farmer's offer?

ANSWER:

1. ACME's fixed costs are $5,000. For the first two days, its sunk costs are $4,000 (this is the amount that cannot be recouped). After two days, the entire $5,000 becomes a sunk cost.
2. Yes, ACME should sublease the railcar. Note that ACME's total loss is $500 if it accepts the farmer's offer. If it does not, its losses will equal $4,000 (assuming it returns the railcar by the end of the next business day).

Algebraic Forms of Cost Functions

In practice, cost functions may take many forms, but the cubic cost function is frequently encountered and closely approximates any cost function. The **cubic cost function** is given by

$$C(Q) = f + aQ + bQ^2 + cQ^3$$

where *a, b, c,* and *f* are constants. Note that *f* represents fixed costs.

cubic cost function
Costs are a cubic function of output; provides a reasonable approximation to virtually any cost function.

Given an algebraic form of the cubic cost function, we may directly calculate the marginal cost function.

Formula: Marginal Cost for Cubic Costs. For a cubic cost function,

$$C(Q) = f + aQ + bQ^2 + cQ^3$$

the marginal cost function is

$$MC(Q) = a + 2bQ + 3cQ^2$$

A CALCULUS ALTERNATIVE

Marginal cost is simply the derivative of the cost function with respect to output:

$$MC(Q) = \frac{dC}{dQ}$$

For example, the derivative of the cubic cost function with respect to Q is

$$\frac{dC}{dQ} = a + 2bQ + 3cQ^2$$

which is the equation for marginal cost given in the formula.

DEMONSTRATION PROBLEM 5–5

The cost function for Managerial Enterprises is given by $C(Q) = 20 + 3Q^2$. Determine the marginal cost, average fixed cost, average variable cost, and average total cost when $Q = 10$.

ANSWER:

Using the formula for marginal cost (here $a = c = 0$), we know that $MC = 6Q$. Thus, the marginal cost when $Q = 10$ is \$60.

To find the various average costs, we must first calculate total costs. The total cost of producing 10 units of output is

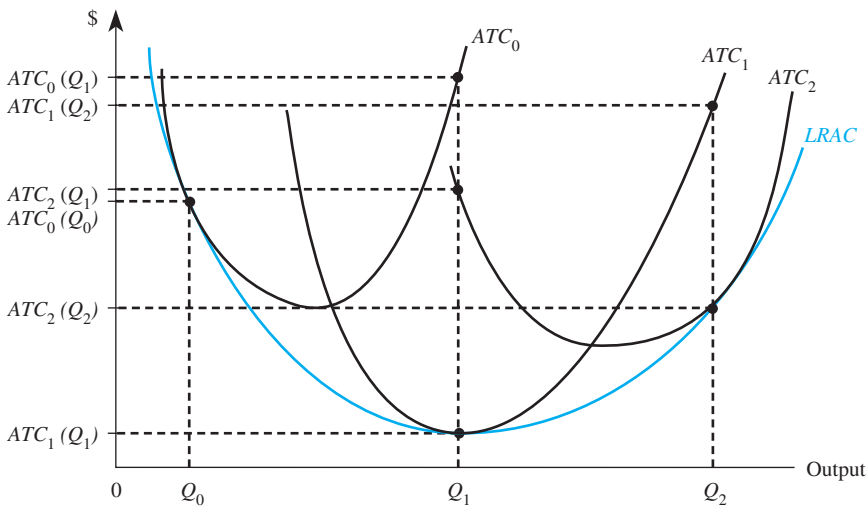
$$C(10) = 20 + 3(10)^2 = \$320$$

Fixed costs are those costs that do not vary with output; thus fixed costs are \$20. Variable costs are the costs that vary with output, namely $VC(Q) = 3Q^2$. Thus, $VC(10) = 3(10)^2 = \$300$. It follows that the average fixed cost of producing 10 units is \$2, the average variable cost is \$30, and the average total cost is \$32.

Long-Run Costs

In the long run, all costs are variable because the manager is free to adjust the levels of all inputs. In Figure 5-13, the short-run average cost curve ATC_0 is drawn under the assumption that there are some fixed factors of production. The average total cost of producing output level Q_0, given the fixed factors of production, is $ATC_0(Q_0)$. In the short run, if the firm increases output to Q_1, it cannot adjust the fixed factors, and thus average costs rise to $ATC_0(Q_1)$. In the long run, however, the firm can adjust the fixed factors. Let ATC_1 be the average cost curve after the firm adjusts the fixed factors in an optimal manner. Now the firm can produce Q_1 with average cost curve ATC_1. If the firm produced Q_1 with average cost curve ATC_0, its average costs would be $ATC_0(Q_1)$. By adjusting the fixed factors in a way that optimizes the scale of operation, the firm economizes in production and can produce Q_1 units of output at a lower average cost, $ATC_1(Q_1)$. Notice that the curve labeled

Figure 5-13
Optimal Plant Size and Long-Run Average Cost



ATC_1 is itself a short-run average cost curve, based on the new levels of fixed inputs that have been selected to minimize the cost of producing Q_1. If the firm wishes to further expand output—say, to Q_2—it would follow curve ATC_1 in the short run to $ATC_1(Q_2)$ until it again changed its fixed factors to incur lower average costs of producing Q_2 units of output, namely $ATC_2(Q_2)$.

The **long-run average cost curve**, denoted *LRAC* in Figure 5-13, defines the minimum average cost of producing alternative levels of output, allowing for optimal selection of all variables of production (both fixed and variable factors). The long-run average cost curve is the lower envelope of all the short-run average cost curves. This means that the long-run average cost curve lies below every point on the short-run average cost curves, except that it equals each short-run average cost curve at the points where the short-run curve uses fixed factors optimally. In essence, we may think of each short-run average cost curve in Figure 5-13 as the average cost of producing in a plant of fixed size. Different short-run average cost curves are associated with different plant sizes. In the long run, the firm's manager is free to choose the optimal plant size for producing the desired level of output, and this determines the long-run average cost of producing that output level.

long-run average cost curve
A curve that defines the minimum average cost of producing alternative levels of output, allowing for optimal selection of both fixed and variable factors of production.

Economies of Scale

Notice that the long-run average cost curve in Figure 5-14(a) is U-shaped. This implies that initially an expansion of output allows the firm to produce at lower long-run average cost, as is shown for outputs between 0 and Q^*. This condition is known as **economies of scale**. When there are economies of scale, increasing the size of the operation decreases the minimum average cost. After a point, such as Q^* in Figure 5-14(a), further increases in output lead to an increase in average costs. This condition is known as **diseconomies of scale**. Sometimes the technology in an industry allows a firm to produce different levels of output at the same minimum average cost, as in Figure 5-14(b). This condition is called **constant returns to scale**.

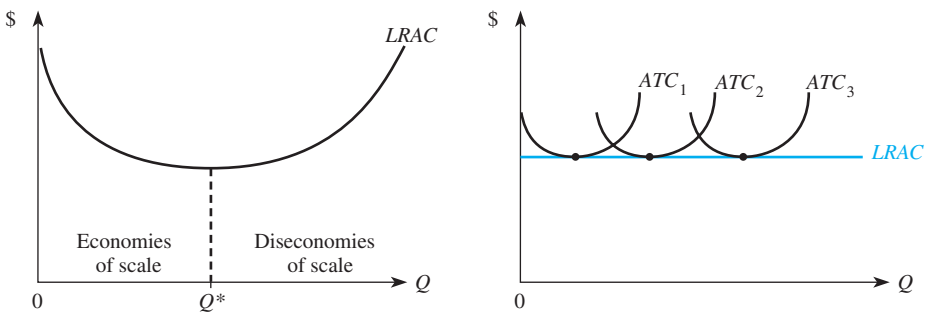
economies of scale
Exist whenever long-run average costs decline as output increases.

diseconomies of scale
Exist whenever long-run average costs increase as output increases.

constant returns to scale
Exist when long-run average costs remain constant as output is increased.

Data-Driven Cost Functions

Just as with the case of production functions, it is also possible to use regression analysis to estimate a cost function. The cubic cost function, written as $C(Q) = f + aQ + bQ^2 + cQ^3$, fits squarely within the multiple regression framework discussed in Chapter 1. In order to determine useful cost metrics such as marginal cost, average total cost, and so forth, a manager needs to have values for f, a, b, and c. Similar to production functions, the manager can estimate these parameters using carefully collected data on quantity and costs.



(a) Economies and diseconomies of scale

(b) Constant returns to scale

Figure 5-14
Scale Economies

Table 5-7

Regression Estimates for a Cubic Cost Function

	Coefficients	Standard Error	*t*-Stat	*P*-value	Lower 95%	Upper 95%
Intercept	1034.419	47.578	21.742	8.6E-49	940.430	1128.409
Quantity	21.670	8.921	2.429	0.016	4.047	39.293
$Quantity^2$	1.093	0.532	2.055	0.042	0.043	2.144
$Quantity^3$	0.087	0.010	8.571	1.0E-14	0.067	0.107

In Table 5-7, we present regression estimates (along with measures of their statistical significance) for a cubic cost function based on a demonstration dataset (*Table05-07.xls*). These results indicate that our estimate for f is 1034, our estimate for a is 21.67, our estimate for b is 1.09, and our estimate for c is 0.09 (rounding to the nearest hundredth). Recall from Chapter 1 that the large (in absolute value) t-stats and small P-values for all of these parameter estimates tell us that all of these parameters are statistically significant.

Using this estimated cost function, we can now calculate useful measures such as marginal cost and average total cost. For example, if the manager is currently producing at $Q = 20$, he can calculate the cost of producing the next unit using the marginal cost formula. Since $MC(Q) = a + 2bQ + 3cQ^2$, marginal cost when $Q = 20$ is approximately $21.67 + 2(1.09)(20) + 3(0.09)(20)^2 = 173.27$. He can also calculate average total cost when producing at $Q = 20$. Since $ATC(Q) = f/Q + a + bQ + cQ^2$, average total cost when $Q = 20$ is approximately $1034.42/20 + 21.67 + 1.09(20) + 0.09(20)^2 = 131.19$. Just from these calculations, the manager knows that producing the 21st unit will raise average total costs, since $MC(20) > ATC(20)$.

A Reminder: Economic Costs versus Accounting Costs

In concluding this section, it is important to recall the difference between economic costs and accounting costs. Accounting costs are the costs most often associated with the costs of

INSIDE BUSINESS 5–4

International Companies Exploit Economies of Scale

In industries with economies of scale, firms that produce greater levels of output produce at lower average costs and thus gain a potential competitive advantage over rivals. Not long ago, two international businesses pursued such strategies to enhance their bottom line.

Japan's Matsushita Plasma Display Panel Company Ltd. invested $835 million to build the world's largest plant for producing plasma display panels. The factory—a joint venture between Panasonic and Toray Industries—had the capacity to produce 250,000 panels per month by the late 2000s. This strategy was implemented in response to rising global demand for plasma display panels, and a desire on the part of the company to gain a competitive advantage over rivals in this increasingly competitive industry.

An automaker in India—Maruti Udyog Ltd.—produced tangible evidence that economies of scale are important in business decisions. It enjoyed a 271 percent increase in net profits in the mid-2000s, thanks to its ability to exploit these economies. The increase was spawned by a 30 percent increase in sales volume that permitted the firm to spread its sizable fixed costs over greater output. Importantly, the company's reduction in average costs due to economies of scale was more than enough to offset the higher costs stemming from increases in the price of steel.

SOURCES: "Matsushita Plans Big Expansion of PDP Manufacturing," *IDG News Service,* May 19, 2004; "MUL Gains from Cost-Saving Measures," *Sify India,* May 18, 2004.

producing. For example, accounting costs include direct payments to labor and capital to produce output. Accounting costs are the costs that appear on the income statements of firms.

These costs are not the only costs of producing a good, however. The firm could use the same resources to produce some other good. By choosing to produce one good, producers give up the opportunity for producing some other good. Thus, the costs of production include not only the accounting costs but also the opportunities forgone by producing a given product.

MULTIPLE-OUTPUT COST FUNCTIONS

Until now, our analysis of the production process has focused on situations where the firm produces a single output. There are also numerous examples of firms that produce multiple outputs. Toyota produces cars, trucks, and SUVs (and many varieties of each); Dell produces many different types of computers and printers. While our analysis for the case of a firm that produces a single output also applies to a multiproduct firm, the latter raises some additional issues. This section will highlight these concepts.

In this section, we will assume that the cost function for a multiproduct firm is given by $C(Q_1, Q_2)$, where Q_1 is the number of units produced of product 1 and Q_2 is the number of units produced of product 2. The **multiproduct cost function** thus defines the cost of producing Q_1 units of product 1 and Q_2 units of product 2 assuming all inputs are used efficiently.

multiproduct cost function
A function that defines the cost of producing given levels of two or more types of outputs assuming all inputs are used efficiently.

Notice that the multiproduct cost function has the same basic interpretation as a single-output cost function. Unlike with a single-product cost function, however, the costs of production depend on how much of each type of output is produced. This gives rise to what economists call economies of scope and cost complementarities, discussed next.

Economies of Scope

Economies of scope exist when the total cost of producing Q_1 and Q_2 together is less than the total cost of producing Q_1 and Q_2 separately, that is, when

$$C(Q_1, 0) + C(0, Q_2) > C(Q_1, Q_2)$$

economies of scope
Exist when the total cost of producing two products within the same firm is lower than when the products are produced by separate firms.

In a restaurant, for example, to produce given quantities of steak and chicken dinners, it generally is cheaper to produce both products in the same restaurant than to have two restaurants, one that sells only chicken and one that sells only steak. The reason is, of course, that producing the dinners separately would require duplication of many common factors of production, such as ovens, refrigerators, tables, the building, and so forth.

Cost Complementarity

Cost complementarities exist in a multiproduct cost function when the marginal cost of producing one output is reduced when the output of another product is increased. Let $C(Q_1, Q_2)$ be the cost function for a multiproduct firm, and let $MC_1(Q_1, Q_2)$ be the marginal cost of producing the first output. The cost function exhibits cost complementarity if

cost complementarity
When the marginal cost of producing one type of output decreases when the output of another good is increased.

$$\frac{\Delta MC_1(Q_1, Q_2)}{\Delta Q_2} < 0$$

that is, if an increase in the output of product 2 decreases the marginal cost of producing product 1.

An example of cost complementarity is the production of doughnuts and doughnut holes. The firm can make these products separately or jointly. But the cost of making additional doughnut holes is lower when workers roll out the dough, punch the holes, and fry both the doughnuts and the holes instead of making the holes separately.

The concepts of economies of scope and cost complementarity can also be examined within the context of an algebraic functional form for a multiproduct cost function. For example, suppose the multiproduct cost function is quadratic:

$$C(Q_1, Q_2) = f + aQ_1Q_2 + (Q_1)^2 + (Q_2)^2$$

For this cost function,

$$MC_1 = aQ_2 + 2Q_1$$

Notice that when $a < 0$, an increase in Q_2 reduces the marginal cost of producing product 1. Thus, if $a < 0$, this cost function exhibits cost complementarity. If $a > 0$, there are no cost complementarities.

Formula: Quadratic Multiproduct Cost Function. The multiproduct cost function

$$C(Q_1, Q_2) = f + aQ_1Q_2 + (Q_1)^2 + (Q_2)^2$$

has corresponding marginal cost functions,

$$MC_1(Q_1, Q_2) = aQ_2 + 2Q_1$$

and

$$MC_2(Q_1, Q_2) = aQ_1 + 2Q_2$$

To examine whether economies of scope exist for a quadratic multiproduct cost function, recall that there are economies of scope if

$$C(Q_1, 0) + C(0, Q_2) > C(Q_1, Q_2)$$

or, rearranging,

$$C(Q_1, 0) + C(0, Q_2) - C(Q_1, Q_2) > 0$$

This condition may be rewritten as

$$f + (Q_1)^2 + f + (Q_2)^2 - [f + aQ_1Q_2 + (Q_1)^2 + (Q_2)^2] > 0$$

which may be simplified to

$$f - aQ_1Q_2 > 0$$

Thus, economies of scope are realized in producing output levels Q_1 and Q_2 if $f > aQ_1Q_2$.

Summary of the Properties of the Quadratic Multiproduct Cost Function. The multiproduct cost function $C(Q_1, Q_2) = f + aQ_1Q_2 + (Q_1)^2 + (Q_2)^2$

1. Exhibits cost complementarity whenever $a < 0$.
2. Exhibits economies of scope whenever $f - aQ_1Q_2 > 0$.

DEMONSTRATION PROBLEM 5–6

Suppose the cost function of firm A, which produces two goods, is given by

$$C = 100 - .5Q_1Q_2 + (Q_1)^2 + (Q_2)^2$$

The firm wishes to produce 5 units of good 1 and 4 units of good 2.

1. Do cost complementarities exist? Do economies of scope exist?
2. Firm A is considering selling the subsidiary that produces good 2 to firm B, in which case it will produce only good 1. What will happen to firm A's costs if it continues to produce 5 units of good 1?

ANSWER:

1. For this cost function, $a = -1/2 < 0$, so indeed there are cost complementarities. To check for economies of scope, we must determine whether $f - aQ_1Q_2 > 0$. This is clearly true since $a < 0$ in this problem. Thus, economies of scope exist in producing 5 units of good 1 and 4 units of good 2.
2. To determine what will happen to firm A's costs if it sells the subsidiary that produces good 2 to firm B, we must calculate costs under the alternative scenarios. By selling the subsidiary, firm A will reduce its production of good 2 from 4 to 0 units; since there are cost complementarities, this will increase the marginal cost of producing good 1. Notice that the total costs to firm A of producing the 5 units of good 1 fall from

$$C(5, 4) = 100 - 10 + 25 + 16 = 131$$

to

$$C(5, 0) = 100 + 25 = 125$$

But the costs to firm B of producing 4 units of good 2 will be

$$C(0, 4) = 100 + 16 = 116$$

Firm A's costs will fall by only \$6 when it stops producing good 2, and the costs to firm B of producing 4 units of good 2 will be \$116. The combined costs to the two firms of producing the output originally produced by a single firm will be \$110 more than the cost of producing by a single firm.

The preceding problem illustrates some important aspects of mergers and sales of subsidiaries. First, when there are economies of scope, two firms producing distinct outputs could merge into a single firm and enjoy a reduction in costs. Second, selling off an unprofitable subsidiary could lead to only minor reductions in costs. In effect, when economies of scope exist, it is difficult to "allocate costs" across product lines.

ANSWERING THE headLINE

In the opening headline, the phrase "wins the battle" refers to the short-run implications of the agreement between Boeing and the IAM, while "wins the war" refers to the agreement's long-run implications. The analyst recognizes that the agreement benefited union workers in the short run, but the agreement also increased Boeing's long-term value by giving it the *flexibility* to substitute away from more costly unionized inputs.

More specifically, Boeing's new union contract provided a number of "short-term" provisions (health and pension benefits, higher wages, and job security for some of the union's more senior workers) that were costly to Boeing but beneficial to the union. In the long run, however, the higher labor costs associated with the agreement provide Boeing with an incentive to substitute away from more expensive union labor, and the agreement provides Boeing the *flexibility* to do so. For instance, the subcontracting provisions Boeing won in the agreement may, in the long run, permit the company to substitute away from its costly and heavily unionized Pacific Northwest inputs toward assembly facilities in less costly areas. In short, the analyst concluded that the long-run flexibility imbedded in the agreement translates into cost-reducing substitution possibilities for Boeing that generate long-run benefits that probably more than offset the short-run costs.

SUMMARY

In this chapter, we introduced the production and cost functions, which summarize important information about converting inputs into outputs sold by a firm. For firms that use several inputs to produce output, isocosts and isoquants provide a convenient way to determine the optimal input mix.

We broke down the cost function into average total cost, average fixed cost, average variable cost, and marginal cost. These concepts help build a foundation for understanding the profit-maximizing input and output decisions that will be covered in greater detail in later chapters.

Given a desired level of output, isoquants and isocosts provide the information needed to determine the cost-minimizing level of inputs. The cost-minimizing level of inputs is determined by the point at which the ratio of input prices equals the ratio of marginal products for the various inputs.

Finally, we showed how economies of scale, economies of scope, and cost complementarities influence the level and mix of outputs produced by single- and multiproduct firms. In the next chapter, we will look at the acquisition of inputs. We will see how managers can use spot markets, contracts, or vertical integration to efficiently obtain the inputs needed to produce their desired mix of outputs.

KEY TERMS AND CONCEPTS

average fixed cost (*AFC*)
average product (*AP*)
average total cost (*ATC*)
average variable cost (*AVC*)
capital
Cobb-Douglas production function
constant returns to scale
cost complementarity
cost function
cost minimization
cubic cost function
decreasing (or diminishing) marginal returns
diseconomies of scale
economies of scale
economies of scope
fixed costs
fixed factors of production
increasing marginal returns
isocost line
isoquant
labor
law of diminishing marginal rate of technical substitution
law of diminishing marginal returns
Leontief (or fixed proportions) production function
linear production function
long run
long-run average cost curve
marginal (incremental) cost (*MC*)
marginal product (*MP*)
marginal rate of technical substitution (*MRTS*)
multiproduct cost function
negative marginal returns
optimal input substitution
patent
production function
profit-maximizing input usage
short run
short-run cost function
sunk costs
total cost
total product (*TP*)
value marginal product
variable costs
variable factors of production

CONCEPTUAL AND COMPUTATIONAL QUESTIONS

1. A firm's analysts estimate that the firm can manufacture a product according to the production function *(LO1, LO2, LO5, LO6)*

$$Q = F(K, L) = K^{3/4}L^{1/4}$$

   a. Calculate the average product of labor, AP_L, when the level of capital is fixed at 81 units and the firm uses 16 units of labor. How does the average product of labor change when the firm uses 256 units of labor?
   b. Find an expression for the marginal product of labor, MP_L, when the amount of capital is fixed at 81 units. Then, illustrate that the marginal product of labor depends on the amount of labor hired by calculating the marginal product of labor for 16 and 81 units of labor.
   c. Suppose capital is fixed at 81 units. If the firm can sell its output at a price of $200 per unit of output and can hire labor at $50 per unit of labor, how many units of labor should the firm hire in order to maximize profits?

2. A firm's product sells for $4 per unit in a highly competitive market. The firm produces output using capital (which it rents at $25 per hour) and labor (which is paid a wage of $30 per hour under a contract for 20 hours of labor services). Complete the following table and use that information to answer these questions. *(LO1, LO2, LO5, LO6)*
   a. Identify the fixed and variable inputs.
   b. What are the firm's fixed costs?
   c. What is the variable cost of producing 475 units of output?
   d. How many units of the variable input should be used to maximize profits?
   e. What are the maximum profits this firm can earn?
   f. Over what range of the variable input usage do increasing marginal returns exist?
   g. Over what range of the variable input usage do decreasing marginal returns exist?
   h. Over what range of input usage do negative marginal returns exist?

K	L	Q	MP_K	AP_K	AP_L	VMP_K
0	20	0				
1	20	50				
2	20	150				
3	20	300				
4	20	400				
5	20	450				
6	20	475				
7	20	475				
8	20	450				
9	20	400				
10	20	300				
11	20	150				

3. Explain the difference between the law of diminishing marginal returns and the law of diminishing marginal rate of technical substitution. *(LO2, LO5)*
4. An economist estimated that the cost function of a single-product firm is

$$C(Q) = 90 + 35Q + 25Q^2 + 10Q^3$$

Based on this information, determine: *(LO4, LO5)*

a. The fixed cost of producing 10 units of output.
b. The variable cost of producing 10 units of output.
c. The total cost of producing 10 units of output.
d. The average fixed cost of producing 10 units of output.
e. The average variable cost of producing 10 units of output.
f. The average total cost of producing 10 units of output.
g. The marginal cost when $Q = 10$.

5. A manager hires labor and rents capital equipment in a very competitive market. Currently the wage rate is \$9 per hour and capital is rented at \$10 per hour. If the marginal product of labor is 50 units of output per hour and the marginal product of capital is 60 units of output per hour, is the firm using the cost-minimizing combination of labor and capital? If not, should the firm increase or decrease the amount of capital used in its production process? *(LO2)*
6. A firm's fixed costs for 0 units of output and its average total cost of producing different output levels are summarized in the following table. Complete the table to find the fixed cost, variable cost, total cost, average fixed cost, average variable cost, and marginal cost at all relevant levels of output. *(LO5, LO6)*

Q	FC	VC	TC	AFC	AVC	ATC	MC
0	\$15,000					—	
100						300	
200						200	
300						175	
400						225	
500						325	
600						400	

7. A multiproduct firm's cost function was recently estimated as *(LO7)*

$$C(Q_1, Q_2) = 90 - 0.5\,Q_1Q_2 + 0.4\,Q_1^2 + 0.3\,Q_2^2$$

a. Are there economies of scope in producing 10 units of product 1 and 10 units of product 2?
b. Are there cost complementarities in producing products 1 and 2?
c. Suppose the division selling product 2 is floundering and another company has made an offer to buy the exclusive rights to produce product 2. How would the sale of the rights to produce product 2 change the firm's marginal cost of producing product 1?

8. Explain the difference between fixed costs, sunk costs, and variable costs. Provide an example that illustrates that these costs are, in general, different. *(LO4)*
9. A firm produces output according to a production function $Q = F(K, L) = \min\{4K, 4L\}$. *(LO1, LO2)*

a. How much output is produced when $K = 2$ and $L = 3$?
b. If the wage rate is \$60 per hour and the rental rate on capital is \$40 per hour, what is the cost-minimizing input mix for producing 8 units of output?
c. How does your answer to part b change if the wage rate decreases to \$40 per hour but the rental rate on capital remains at \$40 per hour?

10. A firm produces output according to the production function $Q = F(K, L) = 4K + 8L$. *(LO1, LO2)*
    a. How much output is produced when $K = 2$ and $L = 3$?
    b. If the wage rate is \$60 per hour and the rental rate on capital is \$20 per hour, what is the cost-minimizing input mix for producing 32 units of output?
    c. How does your answer to part b change if the wage rate decreases to \$20 per hour but the rental rate on capital remains at \$20 per hour?

PROBLEMS AND APPLICATIONS



11. In an effort to stop the migration of many of the automobile manufacturing facilities from the Detroit area, Detroit's city council is considering passing a statute that would give investment tax credits to auto manufacturers. Effectively, this would reduce auto manufacturers' costs of using capital and high-tech equipment in their production processes. On the evening of the vote, local union officials voiced serious objections to this statute. Outline the basis of the argument most likely used by union officials. (*Hint:* Consider the impact that the statute would have on auto manufacturers' capital-to-labor ratio.) As a representative for one of the automakers, how would you counter the union officials' argument? *(LO1, LO2)*
12. You were recently hired to replace the manager of the Roller Division at a major conveyor-manufacturing firm, despite the manager's strong external sales record. Roller manufacturing is relatively simple, requiring only labor and a machine that cuts and crimps rollers. As you begin reviewing the company's production information, you learn that labor is paid \$9 per hour and the last worker hired produced 110 rollers per hour. The company rents roller cutters and crimping machines for \$14 per hour, and the marginal product of capital is 120 rollers per hour. What do you think the previous manager could have done to keep his job? *(LO1, LO2)*
13. You are a manager for Herman Miller, a major manufacturer of office furniture. You recently hired an economist to work with engineering and operations experts to estimate the production function for a particular line of office chairs. The report from these experts indicates that the relevant production function is

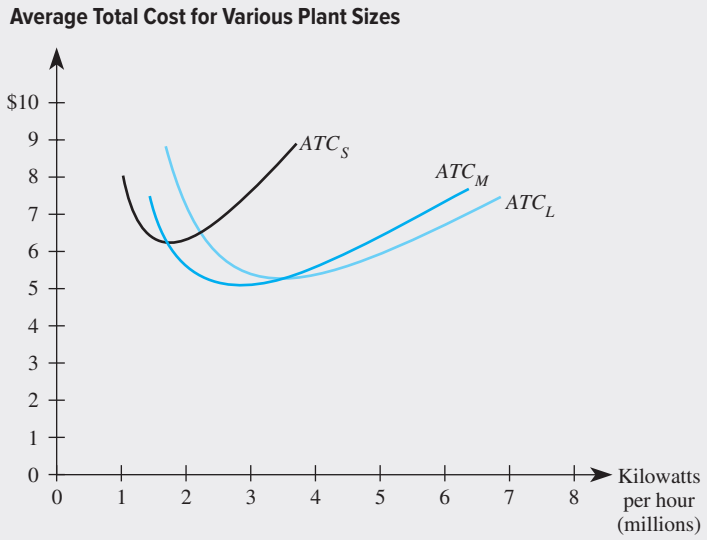
$$Q = 2(K)^{1/2}(L)^{1/2}$$

    where K represents capital equipment and L is labor. Your company has already spent a total of \$11,000 on the 5 units of capital equipment it owns. Due to current economic conditions, the company does not have the flexibility needed to acquire additional equipment. If workers at the firm are paid a competitive wage of \$80 per day and chairs can be sold for \$500 each, what is your profit-maximizing level of output and labor usage? What is your maximum profit? *(LO1, LO2)*
14. Recently, the Boeing Commercial Airline Group (BCAG) recorded orders for more than 15,000 jetliners and delivered more than 13,000 airplanes. To maintain its output volume, this Boeing division combines efforts of capital and more than 90,000 workers. Suppose the European company Airbus enjoys a similar production technology and produces a similar number of aircraft but that labor costs (including fringe benefits) are higher in Europe than in the United States. Would you expect workers at Airbus to have the same marginal product as workers at Boeing? Explain carefully. *(LO1, LO2)*
15. You are a manager at Glass Inc.—a mirror and window supplier. Recently, you conducted a study of the production process for your single-side encapsulated window. The results from the study are summarized in the following table, and are based on the eight units of capital currently available at your plant. Each unit of labor costs \$60, each unit of capital is \$20, and your encapsulated windows sell for \$12 each. Given this

information, optimize your human resource and production decisions. Do you anticipate earning a profit or a loss? Explain carefully. *(LO1, LO2, LO3)*

Labor	Output
0	0
1	10
2	30
3	60
4	80
5	90
6	95
7	95
8	90
9	80
10	60
11	30

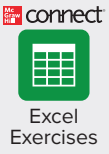
16. A Nike women's-only store in California offers women's running, training, and sportswear products and also contains an in-store fitness studio for group and personal fitness training sessions. The store consistently earns profits in excess of $500,000 per year and is located on prime real estate in the center of town. The store owner pays $15,000 per month in rent for the building. A real estate agent approached the owner and informed her that she could add $8,000 per month to her firm's profits by renting out the portion of her store that she uses as a fitness studio. While the prospect of acquiring this rental income was enticing, the owner believed the use of that space as a fitness studio was an important contributor to her store's profits. What is the opportunity cost of continuing to operate the fitness studio within the store? *(LO3)*
17. A local restaurateur who had been running a profitable business for many years recently purchased a three-way liquor license. This license gives the owner the legal right to sell beer, wine, and spirits in her restaurant. The cost of obtaining the three-way license was about $90,000 since only 300 such licenses are issued by the state. While the license is transferable, only $75,000 is refundable if the owner chooses not to use the license. After selling alcoholic beverages for about one year, the restaurateur came to the realization that she was losing dinner customers and that her profitable restaurant was turning into a noisy, unprofitable bar. Subsequently, she spent about $8,000 placing advertisements in various newspapers and restaurant magazines across the state offering to sell the license for $80,000. After a long wait, she finally received one offer to purchase her license for $77,000. What is your opinion of the restaurateur's decisions? Would you recommend that she accept the $77,000 offer? *(LO4)*
18. In the wake of the energy crisis in California in 2000 and 2001, many electricity-generating facilities across the nation periodically reassess their projections of future demand and capacity for electricity in their respective markets. As a manager at Florida Power & Light Company, you are in charge of determining the optimal size of two electricity generating facilities. The accompanying figure illustrates the short-run average total cost curves associated with different facility sizes. Demand projections indicate that 6 million kilowatts must be produced at your South Florida facility and 2 million kilowatts must be produced at your facility in the Panhandle. Determine the optimal facility size (*S*, *M*, or *L*) for these two regions, and indicate whether there will be economies of scale, diseconomies of scale, or constant returns to scale if the facilities are built optimally. *(LO6)*



19. The A-1 Corporation supplies airplane manufacturers with preformed sheet metal panels that are used on the exterior of aircraft. Manufacturing these panels requires only five sheet metal–forming machines, which cost $500 each, and workers. These workers can be hired on an as-needed basis in the labor market at $9,000 each. Given the simplicity of the manufacturing process, the preformed sheet metal panel market is highly competitive. Therefore, the market price for one of A-1's panels is $80. Based on the production data in the accompanying table, how many workers should A-1 hire to maximize its profits? *(LO1, LO2)*

Sheet Metal-Forming Machines	Workers	Number of Panels Produced
5	0	0
5	1	600
5	2	1,000
5	3	1,290
5	4	1,480
5	5	1,600
5	6	1,680

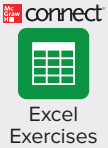
20. According to *The Wall Street Journal,* Mitsubishi Motors announced a major restructuring plan in an attempt to reverse declining global sales. Suppose that as part of the restructuring plan Mitsubishi conducts an analysis of how labor and capital are used in its production process. Prior to restructuring, Mitsubishi's marginal rate of technical substitution is 0.12 (in absolute value). To hire workers, suppose that Mitsubishi must pay the competitive hourly wage of ¥1,800. In the study of its production process and markets where capital is procured, suppose that Mitsubishi determines that its marginal productivity of capital is 0.8 small cars per hour at its new targeted level of output and that capital is procured in a highly competitive market. The same study indicates that the average selling price of Mitsubishi's smallest car is ¥1,200,000. Determine the rate at which Mitsubishi can rent capital and the marginal productivity of labor at its new targeted level of output. To minimize costs Mitsubishi should hire capital and labor until the marginal rate of technical substitution reaches what proportion? *(LO1, LO2)*



21. Hyundai Heavy Industries Co. is one of Korea's largest industrial producers. According to an article in *Bloomberg BusinessWeek Online,* the company not only is the world's largest shipbuilder, but also manufactures other industrial goods ranging from construction equipment and marine engines to building power plants and oil refineries worldwide. Despite being a major industrial force in Korea, several of the company's divisions are unprofitable, or "bleeding red ink" in the words of the article. Indeed, last year the power plant and oil refineries building division recorded a $105 million loss, or 19 percent of its sales. Hyundai Heavy Industries recently hired a new CEO who is charged with the mission of bringing the unprofitable divisions back to profitability. According to *Bloomberg BusinessWeek,* Hyundai's profit-driven CEO has provided division heads with the following ultimatum: ". . . hive off money-losing businesses and deliver profits within a year—or else resign." Suppose you are the head of the marine engine division and that it has been unprofitable for 7 of the last 10 years. While you build and sell in the competitive marine engines industry, your primary customer is Hyundai's profitable ship-building division. This tight relationship is due, in large part, to the technical specifications of building ships around engines. Suppose that in your end-of-year report to the CEO you must disclose that while your division reduced costs by 10 percent, it still remains unprofitable. Make an argument to the CEO explaining why your division should not be shut down. What conditions must hold for your argument to withstand the CEO's criticism? *(LO7)*

22. In the aftermath of a hurricane, an entrepreneur took a one-month leave of absence (without pay) from her $5,000-per-month job in order to operate a kiosk that sold fresh drinking water. During the month she operated this venture, the entrepreneur paid the government $2,500 in kiosk rent and purchased water from a local wholesaler at a price of $1.34 per gallon. Write an equation that summarizes the cost function for her operation, as well as equations that summarize the marginal, average variable, average fixed, and average total costs of selling fresh drinking water at the kiosk. If consumers were willing to pay $2.25 to purchase each gallon of fresh drinking water, how many units did she have to sell in order to turn a profit? Explain carefully. *(LO1, LO3)*

23. You are the manager of a large but privately held online retailer that currently uses 17 unskilled workers and 6 semiskilled workers at its warehouse to box and ship the products it sells online. Your company pays its unskilled workers the minimum wage but pays the semiskilled workers $12.75 per hour. Thanks to government legislation, the minimum wage in your state will increase from $10.25 per hour to $10.75 per hour on July 24, 2021. Discuss the implications of this legislation for your company's operations and in particular the implications for your optimal mix of inputs and long-run investment decisions. *(LO1, LO2, LO6)*



24. As a member of the Analysts Inc. consulting firm, you have carefully collected data on a manufacturing firm's output, capital and labor. The data are contained in the file called *Q05-24.xls* available online at www.mhhe.com/baye10e. You believe the firm's production function to be Cobb-Douglas, $Q = CK^aL^b$.
    a. Use regression analysis to get estimates for the parameters C, a, and b from the Cobb-Douglas production function. Report your estimates and determine whether each is statistically significant.
    b. Suppose capital is fixed at 400 and the price of output is $100. If labor costs $95 per unit, how many units of labor should the firm hire to maximize profits?
    c. If labor costs $75 per unit and capital costs $125 per unit, what is the cost-minimizing input mix for producing 4,000 units of output?

25. As another matter with Analysts Inc., your team has carefully collected data on output and costs for a software servicing firm. The data are contained in the file called *Q05-25.xls* available online at www.mhhe.com/baye10e. You've decided to model the firm's costs as a cubic cost function.

a. Use regression analysis to get estimates for the parameters of the firm's cubic cost function. Report your estimates and determine whether each is statistically significant.
b. What are the fixed costs for this firm?
c. What is the average total cost when $Q = 140$?
d. What is the marginal cost when $Q = 140$?

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APPENDIX

THE CALCULUS OF PRODUCTION AND COSTS

THE PROFIT-MAXIMIZING USAGE OF INPUTS

In this section, we use calculus to show that the profit-maximizing level of an input is the level at which the value marginal product of the input equals the input's price. Let P denote the price of the output, Q, which is produced with the production function $F(K, L)$. The profits of the firm are

$$\pi = PQ - wL - rK$$

PQ is the revenue of the firm, and wL and rK are labor costs and capital costs, respectively. Since $Q = F(K, L)$, the objective of the manager is to choose K and L so as to maximize

$$\pi = PF(K, L) - wL - rK$$

The first-order condition for maximizing this function requires that we set the first derivatives equal to zero:

$$\frac{\partial \pi}{\partial K} = P\frac{\partial F(K, L)}{\partial K} - r = 0$$

and

$$\frac{\partial \pi}{\partial L} = P\frac{\partial F(K, L)}{\partial L} - w = 0$$

But since

$$\partial F(K, L)/\partial L = MP_L$$

and

$$\partial F(K, L)/\partial K = MP_K$$

this implies that to maximize profits, $P \times MP_L = w$ and $P \times MP_K = r$; that is, each input must be used up to the point where its value marginal product equals its price.

THE SLOPE OF AN ISOQUANT

In this section, we use calculus to show that the slope of an isoquant is the negative of the ratio of the marginal products of two inputs.

Let the production function be $Q = F(K, L)$. If we take the total derivative of this relation, we have

$$dQ = \frac{\partial F(K, L)}{\partial K} dK + \frac{\partial F(K, L)}{\partial L} dL$$

Since output does not change along an isoquant, then $dQ = 0$. Thus,

$$0 = \frac{\partial F(K, L)}{\partial K} dK + \frac{\partial F(K, L)}{\partial L} dL$$

Solving this relation for dK/dL yields

$$\frac{dK}{dL} = \frac{\partial F(K, L)/\partial L}{\partial F(K, L)/\partial K}$$

Since

$$\partial F(K, L)/\partial L = MP_L$$

and

$$\partial F(K, L)/\partial K = MP_K$$

we have shown that the slope of an isoquant (dK/dL) is

$$\frac{dK}{dL} = -\frac{MP_L}{MP_K}$$

THE OPTIMAL MIX OF INPUTS

In this section, we use calculus to show that to minimize the cost of production, the manager chooses inputs such that the slope of the isocost line equals the *MRTS*.

To choose K and L so as to minimize

$$wL + rK \text{ subject to } F(K, L) = Q$$

we form the Lagrangian

$$H = wL + rK + \mu[Q - F(K, L)]$$

where μ is the Lagrange multiplier. The first-order conditions for a minimum are

$$\frac{\partial H}{\partial L} = w - \mu \frac{\partial F(K, L)}{\partial L} = 0 \qquad \text{(A–1)}$$

$$\frac{\partial H}{\partial K} = r - \mu \frac{\partial F(K, L)}{\partial K} = 0 \qquad \text{(A–2)}$$

and

$$\frac{\partial H}{\partial \mu} = Q - F(K, L) = 0$$

Taking the ratio of Equations (A–1) and (A–2) gives us

$$\frac{w}{r} = \frac{\partial F(K, L)/\partial L}{\partial F(K, L)/\partial K}$$

which is

$$\frac{w}{r} = \frac{MP_L}{MP_K} = MRTS$$

THE RELATION BETWEEN AVERAGE AND MARGINAL COSTS

Finally, we will use calculus to show that the relation between average and marginal costs in the diagrams in this chapter is indeed correct. If $C(Q)$ is the cost function (the analysis that follows is valid for both variable and total costs, so we do not distinguish between them here), average cost is $AC(Q) = C(Q)/Q$. The change in average cost due to a change in output is simply the derivative of average cost with respect to output. Taking the derivative of $AC(Q)$ with respect to Q and using the quotient rule, we see that

$$\frac{dAC(Q)}{dQ} = \frac{Q(dC/dQ) - C(Q)}{Q^2} = \frac{1}{Q}[MC(Q) - AC(Q)]$$

since $dC(Q)/dQ = MC(Q)$. Thus, when $MC(Q) < AC(Q)$, average cost declines as output increases. When $MC(Q) > AC(Q)$, average cost rises as output increases. Finally, when $MC(Q) = AC(Q)$, average cost is at its minimum.

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6 The Organization of the Firm

LEARNING OBJECTIVES

After completing this chapter, you will be able to:

- **LO1** Discuss the economic trade-offs associated with obtaining inputs through spot exchange, contract, or vertical integration.
- **LO2** Identify four types of specialized investments, and explain how each can lead to costly bargaining, underinvestment, and/or a "hold-up problem."
- **LO3** Explain the optimal manner of procuring different types of inputs.
- **LO4** Describe the principal–agent problem as it relates to owners and managers.
- **LO5** Discuss three forces that owners can use to discipline managers.
- **LO6** Describe the principal–agent problem as it relates to managers and workers.
- **LO7** Discuss four tools the manager can use to mitigate incentive problems in the workplace.

headLINE

AT&T Finalizes Acquisition of Time Warner Inc.

In a bold move, AT&T shelled out $85 billion to purchase Time Warner Inc. This move marks an attempt by AT&T to vertically integrate into what it deems premium content, acquiring Time Warner's vast portfolio, which includes HBO, TNT, CNN, and Warner Bros. Industry experts note that the purchase will allow AT&T to collect usage data on viewership of the content, opening the possibility for the firm to compete in digital advertising. AT&T also claims the merger promises economic efficiencies, which not only would benefit the firm, but would lead to lower consumer prices.

If you were a decision maker at AT&T, would you have recommended vertical integration?

SOURCES: "AT&T Completes Acquisition of Time Warner, Inc.," AT&T News Release, June 15, 2018; "AT&T and Time Warner Merger Case: What You Need to Know," *Investopedia*, December 7, 2018.

INTRODUCTION

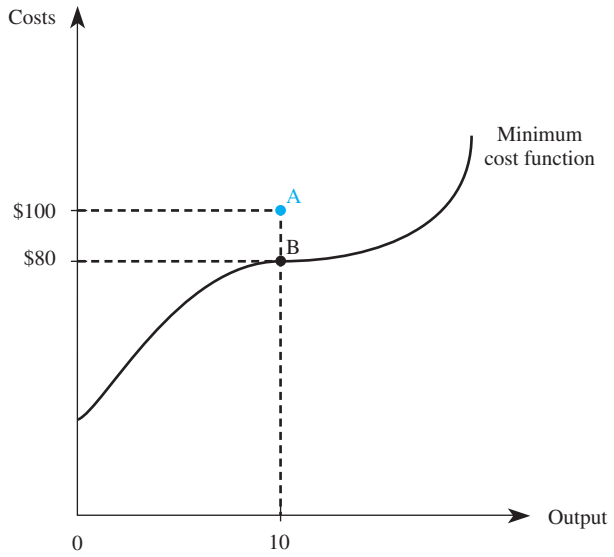
In Chapter 5 we saw how a manager can select the mix of inputs that minimizes the cost of production. However, our analysis in that chapter left unresolved two important questions. First, what is the optimal way to acquire this efficient mix of inputs? Second, how can the owners of a firm ensure that workers put forth the maximum effort consistent with their capabilities? In this chapter, we address these two issues.[1]

Figure 6–1 illustrates why it is important to resolve these two questions. The cost function defines the minimum possible cost of producing each level of output. Point A corresponds to the situation where a firm has costs in excess of the minimum costs necessary to produce a given level of output. At point A, 10 units of output are being produced for a total cost of $100. Notice that this cost is greater than $80, which is the minimum cost necessary to produce 10 units of output. Even if the firm has the right mix of inputs, if it did not obtain them efficiently or if workers are not expending the maximum effort consistent with their capabilities, the firm's costs will be higher than the minimum possible costs.

In this chapter we consider techniques a firm can use to ensure that it is operating on the cost function (point B in Figure 6–1) and not above it (point A). We begin by discussing three methods managers can use to obtain inputs needed in production: spot exchange, contracts, and vertical integration. To minimize costs, a firm must not only use all inputs efficiently (the $MRTS_{KL} = w/r$ rule discussed in Chapter 5); it must use the least-cost method of obtaining the inputs. We will explain when it is optimal to acquire inputs (1) via spot exchange, (2) by writing contracts with input suppliers, or (3) by producing the inputs within the firm (vertical integration). Thus, the first part of this chapter provides managers with the information needed to acquire a given set of inputs in the optimal manner.

The second part of the chapter examines how a firm can ensure that labor inputs, including both managers and workers, put forth the maximum effort consistent with their capabilities. This is an important consideration because conflicts of interest often arise among workers, managers, and the firm's owners. For example, the manager may wish to spend the

Figure 6–1
Producing at Minimum Cost



[1]Other questions that remain include how much output to produce and how to price the product. These important questions will be answered in the remaining chapters of this book.

firm's resources on plush office carpeting or corporate jets, while the owners prefer that the funds be invested to increase profits, which accrue to them by virtue of their status as owners. Or workers may wish to spend most of their day gossiping in the lunchroom instead of working. When employees and owners have conflicting interests, a *principal–agent problem* is said to exist. We will see how manager and worker compensation plans can be constructed to ensure that all employees put forth their highest levels of effort.

METHODS OF PROCURING INPUTS

A manager can use several approaches to obtain the inputs needed to produce a final product. Consider the manager of a car rental company. One input needed to produce output (rental cars) is automobile servicing (tune-ups, oil changes, lube jobs, and the like). The manager has three options: (1) simply take the cars to a firm that services automobiles and pay the market price for the services; (2) sign a contract with a firm that services automobiles and, when service is needed, pay the price negotiated in the contract for that particular service; or (3) create within the firm a division that services automobiles. Each of these methods of servicing automobiles generally will imply different cost functions for producing car rental services. The manager's job is to choose the method that minimizes costs. Before we examine how to determine the best method of acquiring a given type of input, it is useful to provide a broad overview of these three methods of acquiring inputs.

Purchase the Inputs Using Spot Exchange

One method of acquiring inputs is to use spot exchange. **Spot exchange** occurs when the buyer and the seller of an input meet, exchange, and then go their separate ways. If the manager of a car rental company simply takes a car to one of many firms that provide automobile servicing and pays for the services, the manager has used spot exchange to obtain automobile servicing. With the spot exchange, buyers and sellers essentially are "anonymous"; the parties may make an exchange without even knowing each other's names, and there is no formal (legal) relationship between buyer and seller.

spot exchange
An informal relationship between a buyer and seller in which neither party is obligated to adhere to specific terms for exchange.

A key advantage of acquiring inputs with spot exchange is that the firm gets to specialize in doing what it does best: converting the inputs into output. The input manufacturer specializes in what it does best: producing inputs. Spot exchange often is used when inputs are "standardized." In that case, one simply purchases the desired input from one of many suppliers that will sell the input.

Acquire Inputs Under a Contract

A **contract** is a legal document that creates an extended relationship between a particular buyer and seller of an input. It specifies the terms under which they agree to exchange over a given time horizon, say, three years. For example, the manager of a car rental firm might choose to formalize her relationship with a particular firm that services automobiles by signing a contract. Such a contract specifies the range of services covered, the price of each service, and the hours during which the cars will be serviced. As long as the service requirements for the automobiles are understood beforehand, the parties can address all the important issues in the written contract. However, if the number of services needed during the term of the contract is very large, or if some types of unanticipated breakdowns occur, the contract may be incomplete. A contract is incomplete if, for example, a car needs a new transmission and the contract does not specify the price at which the servicing firm will provide this service. Of course, this opens the door to a dispute between the two parties regarding the price of the service needed but not spelled out in the contract.

contract
A formal relationship between a buyer and seller that obligates the buyer and seller to exchange at terms specified in a legal document.

By acquiring inputs with contracts, the purchasing firm enjoys the benefits of specializing in what it does best because the other firm actually produces the inputs the purchasing firm needs. Contracts also allow the purchasing firm a greater ability to purchase "nonstandard" inputs for which there may not be many suppliers. This method of obtaining inputs works well when it is relatively easy to write a contract that describes the characteristics of the inputs needed. One key disadvantage of contracts is that they are costly to write; it takes time, and often legal fees, to draw up a contract that specifies precisely the obligations of both parties. Also, it can be extremely difficult to cover all the contingencies that could occur in the future. Thus, in complex contracting environments, contracts will necessarily be incomplete.

Produce the Inputs Internally

Finally, a manager may choose to produce the inputs needed for production within the firm. In this situation the manager of the car rental company dispenses with outside service firms entirely. She sets up a facility to service the automobile fleet with her own employees as service personnel. The firm thus bypasses the service market completely and does the work itself. When a firm shuns other suppliers and chooses to produce an input internally, it has engaged in **vertical integration**.

vertical integration
A situation where a firm produces the inputs required to make its final product.

With vertical integration, however, a firm loses the gains in specialization it would realize were the inputs purchased from an independent supplier. Moreover, the firm now has to manage the production of inputs as well as the production of the final product produced with those inputs. This leads to the bureaucratic costs associated with a larger organization. On the other hand, by producing the inputs it needs internally, the firm no longer has to rely on other firms to provide the desired inputs. This allows the firm to utilize highly "nonstandard" inputs, even those for which writing a contract with an outside supplier would be difficult.

DEMONSTRATION PROBLEM 6–1

Determine whether the following transactions involve spot exchange, a contract, or vertical integration:

1. Clone 1 PC is legally obligated to purchase 300 computer chips each year for the next three years from AMI. The price paid in the first year is $200 per chip, and the price rises during the second and third years by the same percentage by which the wholesale price index rises during those years.
2. Clone 2 PC purchased 300 computer chips from a firm that ran an advertisement in the back of a computer magazine.
3. Clone 3 PC manufactures its own motherboards and computer chips for its personal computers.

ANSWER:

1. Clone 1 PC is using a contract to purchase its computer chips.
2. Clone 2 PC used spot exchange to acquire its chips.
3. Clone 3 PC uses vertical integration to obtain its chips and motherboards.

TRANSACTION COSTS

transaction costs
Costs associated with acquiring an input that are in excess of the amount paid to the input supplier.

When a firm acquires an input, it may incur costs in excess of the actual amount paid to the input supplier. These costs are known as **transaction costs** and play a crucial role in determining optimal input procurement.

The transaction costs of acquiring an input are the costs of locating a seller of the input, negotiating a price at which the input will be purchased, and putting the input to use. Transaction costs include:

1. The cost of searching for a supplier willing to sell a given input.
2. The costs of negotiating a price at which the input will be purchased. These costs may be in terms of the opportunity cost of time, legal fees, and so forth.
3. Other investments and expenditures required to facilitate exchange.

Many transaction costs are obvious. For example, if an input supplier charges a price of $10 per unit but requires you to furnish your own trucks and drivers to pick up the input, the transaction costs to your firm include the cost of the trucks and the personnel needed to "deliver" the input to your plant. Clearly, the relevant price of the input to your firm includes not only the $10 per unit but also the transaction costs of getting the input to your plant.

Some important transaction costs, however, are less obvious. To understand these "hidden" transaction costs, we must distinguish between transaction costs that are specific to a particular trading relationship and those that are general in nature. The key to this distinction is the notion of a specialized investment. A **specialized investment** is simply an investment in a particular exchange that cannot be recovered in another trading relationship. For example, suppose that to ascertain the quality of bolts, it is necessary to spend $100 on a machine that tests the bolts' strength. If the machine is useful only for testing a particular manufacturer's bolts and the investment in the machine is a sunk (and therefore nonrecoverable) cost, it is a specialized investment. In contrast, if the machine can be resold at its purchase price or used to test the quality of bolts produced by other firms, it does not represent a specialized investment.

specialized investment
An expenditure that must be made to allow two parties to exchange but has little or no value in any alternative use.

When specialized investments are required to facilitate an exchange, the resulting relationship between the parties is known as a **relationship-specific exchange**. The distinguishing feature of relationship-specific exchange is that the two parties are "tied together" because of the specific investments made to facilitate exchange between them. As we will see, this feature often creates transaction costs due to the sunk nature of the specific investments.

relationship-specific exchange
A type of exchange that occurs when the parties to a transaction have made specialized investments.

Types of Specialized Investments

Before we examine how specialized investments affect transaction costs and the optimal method of acquiring inputs, it is important to recognize that specialized investments occur in many forms. Common examples of different types of specialized investments are provided next.

Site Specificity

Site specificity occurs when the buyer and the seller of an input must locate their plants close to each other to be able to engage in exchange. For example, electric power plants often locate close to a particular coal mine to minimize the transportation costs of obtaining coal; the output (electricity) is less expensive to ship than the input (coal). The cost of building the two plants close to each other represents a specialized investment that would have little value if the parties were not involved in exchange.

Physical-Asset Specificity

Physical-asset specificity refers to a situation where the capital equipment needed to produce an input is designed to meet the needs of a particular buyer and cannot be readily adapted to produce inputs needed by other buyers. For example, if producing a lawn mower engine

requires a special machine that is useful only for producing engines for a particular buyer, the machine is a specific physical asset for producing the engines.

Dedicated Assets

Dedicated assets are general investments made by a firm that allow it to exchange with a particular buyer. For example, suppose that a computer manufacturer opens a new assembly line to enable it to produce enough computers for a large government purchaser. If opening the new assembly line is profitable only if the government actually purchases the firm's computers, the investment represents a dedicated asset.

Human Capital

A fourth type of specialized investment is *human capital*. In many employment relationships, workers must learn specific skills to work for a particular firm. If these skills are not useful or transferable to other employers, they represent a specialized investment.

Implications of Specialized Investments

Now that you have a broad understanding of specialized investments and relationship-specific exchange, we will consider how the presence of specialized investments can affect the transaction costs of acquiring inputs. Specialized investments increase transaction costs because they lead to (1) costly bargaining, (2) underinvestment, and (3) opportunism.

Costly Bargaining

In situations where transaction costs are low and the desired input is of uniform quality and sold by many firms, the price of the input is determined by the forces of supply and demand. When specialized investments are not required to facilitate exchange, very little time is expended negotiating a price. The scenario differs, however, if specialized investments are required to obtain the input.

Specialized investments imply that only a few parties are prepared for a trading relationship. There is no other supplier capable of providing the desired input at a moment's notice; obtaining the input the buyer needs requires making a specialized investment before the input becomes available. Consequently, there generally is no "market price" for the input; the two parties in the relationship-specific exchange bargain with each other over a price at which the input will be bought and sold. The bargaining process generally is costly, as each side employs negotiators to obtain a more favorable price. The parties may also behave strategically to enhance their bargaining positions. For example, the buyer may refuse to accept delivery to force the seller to accept a lower price. Ultimatums may be given. The supplier may reduce the quality of the input and the buyer may complain about the input's quality through company attorneys. All of these factors generate transaction costs as the two firms negotiate a price for the input.

Underinvestment

When specialized investments are required to facilitate exchange, the level of the specialized investment often is lower than the optimal level. To see this, suppose the specialized investment is human capital. To work for a particular firm, a worker must first invest his own time in learning how to perform some task. If the worker perceives that he may not work at the firm for very long (due to being laid off or accepting another job), he will not invest as heavily in

learning the task as he otherwise would. For example, if you plan to transfer to another university at the end of the semester, you will not invest very heavily in learning how to use the library facilities at your present university. The investment in learning about the library facilities is an investment in human capital specific to your present university and will have little value at another university with a completely different library setup.

Similar problems exist with other types of specialized investments. For example, if an input supplier must invest in a specific machine to produce an input used by a particular buyer (physical-asset specificity), the supplier may invest in a cheaper machine that produces an input of inferior quality. This is because the supplier recognizes that the machine will not be useful if the buyer decides to purchase from another firm, in which case the supplier will be "stuck" with an expensive machine it cannot use. Thus, specialized investments may be lower than optimal, resulting in higher transaction costs because the input produced is of inferior quality.

Opportunism and the "Hold-Up Problem"

When a specialized investment must be made to acquire an input, the buyer or seller may attempt to capitalize on the "sunk" nature of the investment by engaging in *opportunism*. To be concrete, suppose the buyer of an input must make a specific investment of $10—say, the cost of verifying the quality of a particular supplier's input. The manager knows there are many firms willing to sell the input at a price of $100, so she goes to one of them at random and spends $10 inspecting the input. Once she has paid this $10, the supplier attempts to take advantage of the specialized investment and behave in an opportunistic manner: It attempts to "hold up" the manager by asking for a price of $109—$9 more than the price charged by all other suppliers. Since the manager has already spent $10 inspecting this firm's input, she is better off paying the $109 than spending an additional $10 inspecting another supplier's input. After all, even if the other supplier did not engage in opportunistic behavior, it would cost the firm $10 + $100 = $110 to inspect and purchase another supplier's input. This is the "hold-up problem": Once a firm makes a specialized investment, the other party may attempt to "rob" it of its investment by taking advantage of the investment's sunk nature. This behavior, of course, would make firms reluctant to engage in relationship-specific investments in the first place unless they can structure contracts to mitigate the hold-up problem.

In many instances, both sides in a trading relationship are required to make specialized investments, in which case both parties may engage in opportunism. For example, suppose an automaker needs crankshafts as an input for making engines. The crankshafts are a specialized input designed for use by that particular automobile manufacturer and require an investment by the producer in highly specialized capital equipment to produce them. If the crankshaft manufacturer does not sell the crankshafts to the automaker, the automaker's investment in continuing production of the engine will be effectively worthless. Similarly, if the automobile manufacturer does not buy the crankshafts, the supplier's investment in the capital equipment is likely to be wasted as well since the equipment is not designed to serve the needs of other automobile makers. The investments made by both parties have tied them together in a relationship-specific exchange, giving each firm a potential incentive to engage in opportunistic behavior. Once the supplier has invested in the equipment to make crankshafts, the automaker may attempt to capitalize on the sunk nature of the investment by asking for a lower price. On the other hand, once the automaker reaches the stage of production where it must have crankshafts to finish the cars, the crankshaft supplier may ask for a higher price to capitalize on the sunk investment made by the automaker. The result is that the two parties spend considerable time negotiating over precisely how much will be paid for the crankshafts, thus increasing the transaction costs of acquiring the input.

INSIDE BUSINESS 6–1

The Cost of Using an Inefficient Method of Procuring Inputs

In a classic study, Scott Masten, James Meehan, and Edward Snyder not only quantify the transaction costs of acquiring inputs, but point out the high cost to managers of using an inappropriate method to acquire an input.

Based on the procurement decisions of a naval construction firm, the study reveals that transaction costs account for roughly 14 percent of the total costs of ship construction. Thus, transaction costs are an important component of costs; managers must consider them when they make decisions.

What is the cost of not carefully considering transaction costs when deciding which method to use to acquire an input? The authors of the study report that mistaken integration—that is, producing internally a component that should have been purchased from another firm—increased transaction costs by an average of 70 percent. Subcontracting work that would have been more efficiently performed within the firm, on the other hand, raised transaction costs by almost 300 percent. The potential cost savings to a firm that chooses the best method of acquiring inputs are thus substantial.

Assessing the costs of input procurement methods isn't just for naval construction; it is pertinent for just about every industry. Subsequent research has analyzed these costs in industries ranging from coffee production in Brazil to luxury hotels in Germany.

SOURCES: Gustavo Magalhaes de Oliveira and Decio Zylbersztajn, "Make or Buy: The Case of Harvesting Mechanization in Coffee Crop in Brazil," *International Food and Agribusiness Management Review* 21 (2018), pp. 895–914; Matteo Pedrini and Chiara de Bernardi, "To Affiliate, or Not To Affiliate. Transaction Costs and Governance Choices in Luxury Hotels in Germany," *Tourism and Hospitality Research,* May 2019; Scott Masten, James Meehan, and Edward Snyder, "The Costs of Organization," *Journal of Law, Economics and Organization* 7 (Spring 1991), pp. 1–25.

OPTIMAL INPUT PROCUREMENT

Now we will examine how the manager should acquire inputs in such a way as to minimize costs. The cost-minimizing method will depend on the extent to which there is relationship-specific exchange.

Spot Exchange

The most straightforward way for a firm to obtain inputs for a production process is to use spot exchange. If there are no transaction costs and there are many buyers and sellers in the input market, the market price (say, p^*) is determined by the intersection of the supply and demand curves for the input. The manager can easily obtain the input from a supplier chosen at random by paying a price of p^* per unit of input. If any supplier attempted to charge a price greater than p^*, the manager could simply decline and purchase the input from another supplier at a price of p^*.

Why, then, would a manager ever wish to bear the expense of drafting a contract or have the firm expend resources to integrate vertically and manufacture the inputs itself? The reason is that in the presence of specialized investments, spot exchange does not insulate a buyer from opportunism, and the parties may end up spending considerable time bargaining over the price and incur substantial costs if negotiations break down. These problems will occur each time the buyer attempts to obtain additional units of the input. Also, as we noted earlier, the input purchased may be of inferior quality due to underinvestment in specialized investments needed to facilitate the exchange.

DEMONSTRATION PROBLEM 6–2

Jiffyburger, a fast-food outlet, sells approximately 8,000 quarter-pound hamburgers in a given week. To meet that demand, Jiffyburger needs 2,000 pounds of ground beef delivered to its premises every Monday morning by 8:00 AM sharp.

1. As the manager of a Jiffyburger franchise, what problems would you anticipate if you acquired ground beef using spot exchange?
2. As the manager of a firm that sells ground beef, what problems would you anticipate if you were to supply meat to Jiffyburger through spot exchange?

ANSWER:

1. While ground beef for hamburgers is a relatively standardized product, the delivery of one ton of meat to a particular store involves specialized investments (in the form of dedicated assets) on the part of both Jiffyburger and the supplier. In particular, Jiffyburger would face a hold-up problem if the supplier showed up at 8:00 AM and threatened not to unload the meat unless Jiffyburger paid it "ransom"; it would be difficult to find another supplier that could supply the desired quantity of meat on such short notice. The supplier may even attempt to unload meat of inferior quality. Thus, Jiffyburger is not protected from opportunism, bargaining, and underinvestment in quality when it uses spot exchange to acquire such a large quantity of ground beef.
2. By showing up at Jiffyburger at 8:00 AM with one ton of meat, the supplier makes a specific investment in selling to Jiffyburger. Consequently, the supplier also is subject to a potential hold-up problem. Suppose Jiffyburger behaves opportunistically by asking 10 other suppliers to show up with a ton of meat at 8:00 AM too. Since each supplier would rather unload its meat at a low price than let it spoil, Jiffyburger can bargain with the suppliers to get a great deal on the meat. In this case, each supplier risks selling meat at a low price, or not at all, since it is not protected from opportunism by using spot exchange.

When the acquisition of an input requires substantial specialized investments, spot exchange is likely to result in high transaction costs due to opportunism, bargaining costs, and underinvestment. Clearly, managers must consider alternatives to spot exchange when inputs require substantial specialized investments.

Contracts

Given the prospect of the hold-up problem and a need to bargain over price each time an input is to be purchased, an alternative strategy is to acquire an input from a particular supplier under an appropriately structured contract. While a contract often requires substantial up-front expenditures in terms of negotiations, attorneys' fees, and the like, it offers several advantages. First, a contract can specify prices of the input before the parties make specialized investments. This feature reduces the magnitude of costly opportunism down the road. For example, if the manager in Demonstration Problem 6–2 had written a contract that specified a price and a quantity of ground beef before the specialized investments were made, there would not have been a hold-up problem. Both parties would have been legally obligated to honor the contracted price and quantity.

Second, by guaranteeing an acceptable price for both parties for an extended time horizon, a contract reduces the incentive for either the buyer or the seller to skimp on the specialized investments required for the exchange. For example, a worker who has a contract that guarantees employment with a particular firm for three years will have a greater incentive to

invest in human capital specific to that firm. Similarly, if the firm knows the worker will be around for three years, it will be willing to invest in more training for the worker.

DEMONSTRATION PROBLEM 6–3

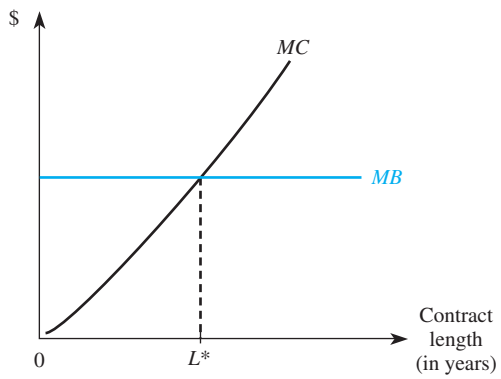
In the real world, virtually all purchases involve some type of specialized investment. For instance, by driving to a particular supermarket, you invest time (and gasoline) that is valuable to you only if you purchase groceries at that supermarket. Why, then, don't consumers sign contracts with supermarkets to prevent the supermarkets from engaging in opportunism once they are inside the store?

ANSWER:

The cost of driving to another supermarket if you are "held up" is relatively low: The cashier may be able to extract an extra few cents on a can of beans, but not much more. Thus, when specialized investments involve only small sums of money, the potential cost of being held up is very low compared to the cost of writing a contract to protect against such opportunism. It doesn't make sense to pay an attorney $200 to write a contract that would potentially save you only a few cents. Moreover, when only a small gain can be realized by engaging in opportunistic behavior, the supermarket will likely not find it in its interest to hold up customers. If a supermarket attempts to take advantage of a customer's minuscule specialized investment, the customer can threaten to tell others not to ever shop at that store. In this instance, the extra few cents extracted from the customer would not be worth the lost future business. In essence, there is an implicit agreement between the two parties—not an agreement that is enforceable in a court of law, but one that is enforceable by consumers' future actions. Thus, when the gains from opportunistic behavior are small compared to the costs of writing contracts, formal contracts will not emerge. However, when the gains from opportunism are sufficiently large, formal contracts are needed to prevent opportunistic behavior.

Once the decision is made to use a contract to acquire an input, how long should the contract last? The "optimal" contract length reflects a fundamental economic trade-off between the marginal costs and marginal benefits of extending the length of a contract. The marginal cost (*MC*) of extending contract length increases as contracts become longer, as illustrated in Figure 6–2. This is because as a contract gets longer, more time and money must be spent writing into the contract a larger number of increasingly hypothetical contingencies (for example, "If an Ice Age begins, the price will be . . . "). It may be easy to specify a mutually acceptable price for a contract that is to be executed tomorrow, but with a 10-year agreement it is difficult (and expensive) to write clauses that include contingencies and prices for each year of the contract. Furthermore, the longer the contract, the more locked in the buyer is to a particular seller and the greater the likelihood that some other supplier can provide the input

Figure 6–2
Optimal Contract Length



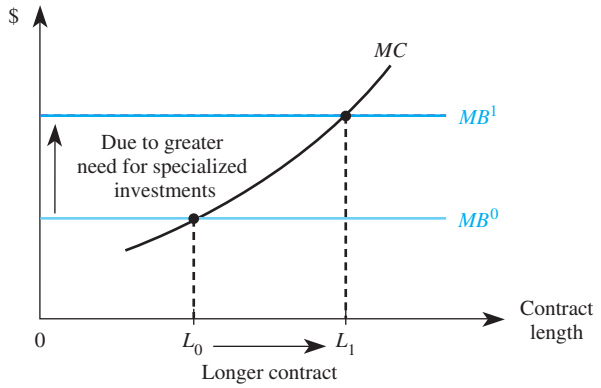


Figure 6–3

Specialized Investments and Contract Length

at a lower cost in the future. In other words, the longer the contract, the less flexibility the firm has in choosing an input supplier. For these reasons, the marginal cost of contract length in Figure 6–2 is upward sloping.

The marginal benefit (*MB*) of extending a contract for another year is the avoided transaction costs of opportunism and bargaining. These benefits may vary with the length of the contract, but for simplicity we have drawn a flat *MB* curve in Figure 6–2. The optimal contract length, L^*, is the point at which the marginal costs and marginal benefits of longer contracts are equal.

The optimal contract length will increase when the level of specialized investment required to facilitate an exchange increases. To see this, note that as specialized investments become more important, the parties face higher transaction costs once the contract expires. Since these costs can be avoided by writing longer contracts, higher levels of specialized investments increase the marginal benefit of writing longer contracts from MB^0 to MB^1 in Figure 6–3. The result is an increase in the length of the optimal contract from L_0 to L_1.

The optimal contract length also depends on factors that affect the marginal cost of writing longer contracts. As an input becomes more standardized and the future economic environment becomes more certain, the marginal cost of writing longer contracts in Figure 6–4 decreases from MC^0 to MC^1. This decrease in the complexity of the contracting environment leads to longer optimal contracts (from L_0 to L_1). In contrast, as the input becomes more complex and the future economic environment becomes more uncertain, contracts must be made more detailed. This increase in the complexity of the contracting environment increases the marginal cost of writing longer contracts from MC^0 to MC^2 in Figure 6–4. Optimal contracts, in this case, will be shorter in duration.

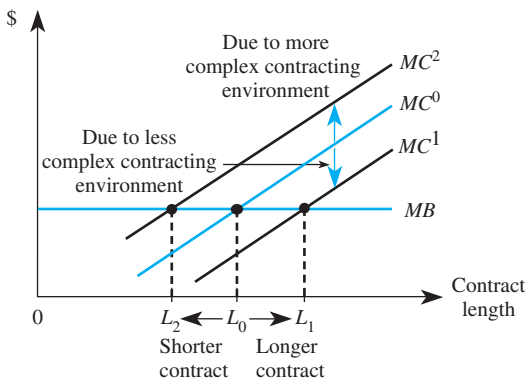


Figure 6–4

Contracting Environment and Contract Length

INSIDE BUSINESS 6–2

What Determines Contract Length in Franchising?

Want to open a McDonald's or Starbucks as a franchisee? To do so, you'll need to sign a contract with a franchisor. The contract you sign will spell out details of the relationship, including the royalty, advertising, sales quotas, etc. You will also have to agree on a contract length.

Virtually any franchisee must make some specific investments, including equipment, marketing, employee training, and often offsite training provided by the franchisor. In the text, we explain how, all else equal, franchises requiring relatively more specialized investments will have longer contracts. An alternative theory—sometimes called the naïve franchisee view—proposes that relatively powerful franchises will "bully" naïve franchisees into short-term contracts, making them more susceptible to hold-up.

Which theory do the data support? Researchers James A. Brickley, Sanjog Misra, and R. Lawrence Van Horn tested these theories using data on contracting by nearly 2,000 franchisors. Their analysis strongly shows that contract duration is increasing in physical and human capital investments, which are often firm specific. In contrast, they find no evidence supporting the naïve franchisee view, as more experienced franchisors actually tend to offer longer-term contracts compared to newer franchisors.

SOURCE: James A. Brickley, Sanjog Misra, and R. Lawrence Van Horn, "Contract Duration: Evidence from Franchising," *Journal of Law and Economics* 49 (April 2006), pp. 173–96.

As the contract length shortens due to the complexity of the contracting environment, firms must continually write new contracts as existing ones expire. Considerable resources are spent on attorneys' fees and bargaining over contract terms, and because of the complex contracting environment, it is not efficient to write longer contracts to reduce these costs. Faced with such a prospect, a manager may wish to use yet another method to procure a necessary input: have the firm integrate vertically and make the input itself.

Vertical Integration

When specialized investments generate transaction costs (due to opportunism, bargaining costs, or underinvestment), and when the product being purchased is extremely complex or the economic environment is plagued by uncertainty, complete contracts will be extremely costly or even impossible to write. The only choice left is for the firm to set up a facility to produce the input internally. This process is referred to as *vertical integration* because it entails the firm moving farther up the production stream toward increasingly basic inputs. For example, most automobile manufacturers make their own fenders from sheet steel and plastics, having vertically integrated up the production stream from automobile assembly to the fabrication of body parts.

The advantage of vertical integration is that the firm "skips the middleman" by producing its own inputs. This reduces opportunism by uniting previously distinct firms into divisions of a single, integrated firm. While this strategy might seem desirable in general because it mitigates transaction costs by eliminating the market, this approach has some disadvantages as well. Managers must replace the discipline of the market with an internal regulatory mechanism, a formidable task to anyone familiar with the failure of central planning often encountered in nonmarket economies. In addition, the firm must bear the cost of setting up production facilities for producing a product that, at best, may be tangentially related to the firm's main line of business; the firm no longer specializes in doing what it does best. Because of these difficulties, vertical integration should be viewed as a last resort, undertaken only when spot exchange or contracts have failed.

INSIDE BUSINESS 6–3

The Role and Growth of Outsourcing

In an increasingly connected and global economy, firms have an expanding number of options for procuring inputs externally through contracts or spot exchange. Along with these increasing procurement options has come an increase in the practice of *outsourcing*.

While firms' use of external suppliers dates back many decades, outsourcing was not formally acknowledged as a business strategy until 1989. The distinguishing feature of outsourcing—in contrast to external procurement in general—is that it involves moving activities traditionally performed within the firm to an external, and often international, provider. Typically, the expectation is that the external firm can produce the input at lower cost.

A common example of outsourcing involves information technology (IT). Instead of performing IT operations in-house, firms outsource to IT specialists, a task made even easier with the advent of cloud computing.

The decision to outsource, just as with input procurement decisions in general, must weigh the economic trade-offs. In fact, some firms have reversed course on outsourcing after reevaluating the trade-offs. For example, outsourcing offshore often requires additional staff and substantial documentation, which can nontrivially impact the anticipated cost savings. Recently it was estimated that up to 30 percent of IT services historically outsourced would be brought back in-house.

SOURCES: Anna Frazzetto, "Outsourcing in the New Normal: Three Trends Reshaping the Global Industry," Forbes.com, March 21, 2018; Sherry Jackson, "Reversing Outsourcing Trend, Many U.S. Companies Bring IT Back Home," *Upstate Business Journal,* 2014; Rick Mullin, "Managing the Outsourced Enterprise," *Journal of Business Strategy*, 17 (1996), pp. 28–36.

The Economic Trade-Off

The cost-minimizing method of acquiring an input depends on the characteristics of the input. Whether a manager chooses spot exchange or an alternative method such as a contract or vertical integration depends on the importance of the specialized investments that lead to relationship-specific exchange. The basic questions involved are illustrated in Figure 6–5.

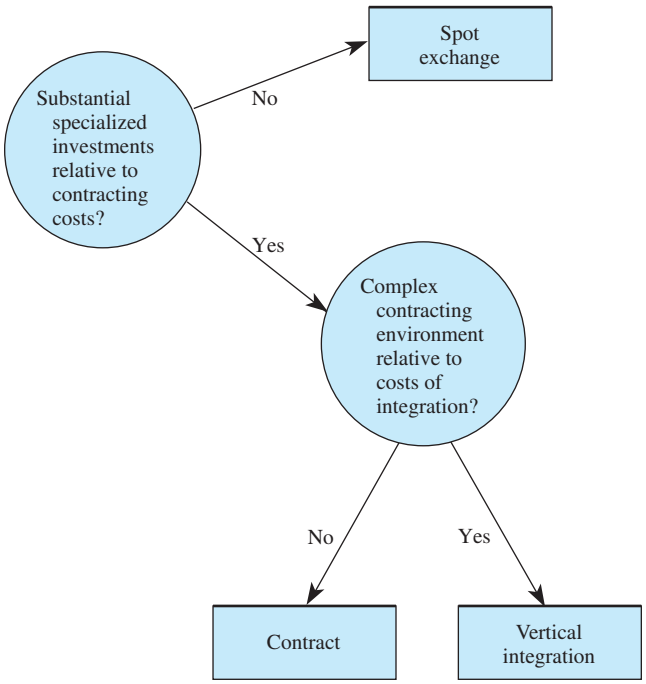


Figure 6–5
Optimal Procurement of Inputs

When the desired input does not involve specialized investments, the firm can use spot exchange to obtain the input without concern for opportunism and bargaining costs. By purchasing the input from a supplier, the firm can specialize in doing what it does best rather than spending money writing contracts or engaging in vertical integration.

When substantial specialized investments are required to facilitate exchange, managers should think twice about using spot exchange to purchase inputs. Specialized investments lead to opportunism, bargaining costs, and underinvestment, and these transaction costs of using spot exchange often can be reduced by using some other method to acquire an input. When the contracting environment is simple and the cost of writing a contract is less than the transaction costs associated with spot exchange, it is optimal to acquire the input through a contract. In this case, the optimal contract length is determined by the intersection of the marginal cost and marginal benefits of writing a longer contract, as we illustrated previously in Figure 6–2.

Finally, when substantial specialized investments are required and the desired input has complex characteristics that are difficult to specify in a contract, or when it is very costly to write into the contract all the clauses needed to protect the parties from changes in future conditions, the manager should integrate vertically to minimize the cost of acquiring inputs needed for production—provided the costs of integration are not too high. In this instance, the firm produces the input internally. The firm no longer specializes in doing what it does best, but the elimination of opportunism, bargaining, and underinvestment more than makes up for lack of specialization.

DEMONSTRATION PROBLEM 6–4

Big Bird Air is legally obligated to purchase 50 jet engines from ERUS at the end of two years at a price of $200,000 per engine. Confident that it is protected from opportunism with this contract, Big Bird begins making aircraft bodies designed to fit ERUS's engines. Due to unforeseen events in the aerospace industry, in the second year of the contract ERUS is on the brink of bankruptcy. It tells Big Bird that unless it increases the engine price to $300,000, it will go bankrupt.

1. What should the manager of Big Bird Air do?
2. How could this problem have been avoided?
3. Did the manager of Big Bird Air use the wrong method of acquiring inputs?

ANSWER:

1. Big Bird is experiencing a hold-up problem because of an incomplete contract; the contract did not specify what would happen if ERUS went belly-up. ERUS claims it will go bankrupt if Big Bird does not pay a price of $300,000 for the engines, in which case Big Bird will lose its specialized investment in aircraft bodies. The manager should verify that ERUS is indeed on the brink of bankruptcy. If not, Big Bird can take ERUS to court if ERUS does not honor the contract price. If ERUS is on the verge of bankruptcy, the manager should determine how much it would cost to obtain engines from another supplier versus making them within the firm. Once the manager knows the cost of each alternative, Big Bird may wish to bargain with ERUS over how much more it will pay for the engines. This could be risky, however; the lower the price negotiated, the greater the chance ERUS will go bankrupt. New clauses must be put into the contract to protect Big Bird against ERUS's bankruptcy. The manager should especially guard against attempts by ERUS to reduce the quality of the engines in an attempt to save money. In any event, Big Bird should not spend more money drawing up a new contract and paying for ERUS's engines than it would cost to obtain them from the best alternative source.
2. This problem illustrates that when contracts are incomplete, unanticipated events can occur that lead to costly bargaining and opportunism. The problem could have been avoided had Big Bird written clauses into the contract that protected it against ERUS's going bankrupt. If this was not possible, it could have vertically integrated and produced its own engines.

3. Big Bird's manager did not necessarily choose the wrong method of acquiring engines. If it was not possible (or would have been extremely costly) to write into the initial contract protection against ERUS's going bankrupt, and if the costs of vertically integrating would exceed the likely costs of opportunism due to an incomplete contract, the manager made the correct decision at the time. Sometimes bad things happen even when managers make good decisions. If this was not the case, either a more complete contract should have been written or Big Bird should have decided to make its own engines.

MANAGERIAL COMPENSATION AND THE PRINCIPAL–AGENT PROBLEM

You now know the principal factors in selecting the best method of acquiring inputs. Our remaining task in this chapter is to explain how to compensate labor inputs to ensure that they put forth their "best" effort. After completing this section, you will better understand why restaurants rely on tips to compensate employees, why secretaries usually are paid an hourly wage, and even why textbook authors are paid royalties. We will begin, however, by examining managerial compensation.

One characteristic of many large firms is the separation of ownership and control: The owners of the firm often are distantly located stockholders, and the firm is run on a day-to-day basis by a manager. The fact that the firm's owners are not physically present to monitor the manager creates a fundamental incentive problem. Suppose the owners pay the manager a salary of $50,000 per year to manage the firm. Since the owners cannot monitor the manager's effort, if the firm has lost $1 million by year's end, they will not know whether the fault lies with the manager or with bad luck. Uncertainty regarding whether low profits are due to low demand or to low effort by the manager makes it difficult for the owners to determine precisely why profits are low. Even if the fault lies with the manager—perhaps he or she never showed up at the plant but instead took an extended fishing trip—the manager can claim it was just a "bad year." The manager might say, "You should be very glad you hired me as your manager. Had I not worked 18-hour days, your company would have lost twice the amount it did. I was lucky to keep our loss to its current level, but I am confident things will improve next year when our new product line hits the market." Since the owners are not present at the firm, they will not know the true reason for the low profits.

By creating a firm, an owner enjoys the benefits of reduced transaction costs. But when ownership is separated from control, the *principal–agent problem* emerges: If the owner is not present to monitor the manager, how can she get the manager to do what is in her best interest?

The essence of the problem is that the manager likes to earn income, but he also likes to consume leisure. Clearly, if the manager spent every waking hour on the job, he would be unable to consume any leisure. But the less time he spends on the job, the more time he has for ball games, fishing trips, and other activities that he values. The job description indicates that the manager is supposed to spend eight hours per day on the job. The important question, from the owner's point of view, is how much leisure (shirking) the manager will consume while on the job. Shirking may take the form of excessive coffee breaks, long lunch hours, leaving work early, or, in the extreme case, not showing up on the job at all. Note that while the manager enjoys shirking, the owner wants the manager to work hard to enhance profits.

When the manager is offered a fixed salary of $50,000 and the owner is not physically present at the workplace, he will receive the same $50,000 regardless of whether he works a full eight hours (hence, doesn't shirk) or spends the entire day at home (shirks eight hours).

Table 6–1

Managerial Earnings and Firm Profits under a Fixed Salary

Manager's Earnings	Hours Worked by Manager	Hours Shirked by Manager	Profits of Firm
$50,000	8	0	$3,000,000
50,000	7	1	2,950,000
50,000	6	2	2,800,000
50,000	5	3	2,500,000
50,000	4	4	2,000,000
50,000	3	5	1,800,000
50,000	2	6	1,300,000
50,000	1	7	700,000
50,000	0	8	0

This situation is illustrated in Table 6–1. From the point of view of the owner, the fixed salary does not give the manager a strong incentive to monitor the other employees, and this has an adverse effect on the firm's profits. For example, as Table 6–1 shows, if the manager spends the entire day on the job monitoring the other employees (i.e., making sure that they put out maximum effort), shirking is zero and the firm's profits are $3 million. If the manager spends the entire day shirking, profits are zero. If the manager shirks two hours and thus works six hours, the firm's profits are $2.8 million. Since the fixed salary of $50,000 provides the manager with the same income regardless of his effort level, he has a strong incentive to shirk eight hours. In this case the profits of the firm are zero, but the manager still earns $50,000.

How can the owner of the firm get the manager to spend time monitoring the production process? You might think if she paid the manager a higher salary, the manager would work harder. But this will not work when the owner cannot observe the manager's effort; the employment contract is such that there is absolutely no cost to the manager of shirking. Many managers would prefer to earn money without having to work for it, and such a contract allows this manager to do just that.

Suppose the owner of the firm offers the manager the following *incentive contract*: The manager is to receive 10 percent of profits (gross of managerial compensation) earned by the firm. Table 6–2 summarizes the implications of such a contract. Note that if the manager spends eight hours shirking, profits are zero and the manager earns nothing. But if the manager does not shirk at all, the firm earns $3 million in gross profits and the manager receives compensation equal to 10 percent of those profits: $300,000.

Exactly what the manager does under the profit-sharing compensation scheme depends on his preferences for leisure and money. But one thing is clear: If the manager wants to earn income, he cannot shirk the entire day. The manager faces a trade-off: He can consume more leisure on the job, but at a cost of lower compensation. For example, suppose the manager has carefully evaluated the trade-off between leisure on the job and income in Table 6–2 and wishes to earn $250,000. He can achieve this by working five hours instead of shirking all day. What is the impact of the profit-sharing plan on the owner of the firm? The manager has decided to work five hours to earn $250,000 in compensation. The five hours of managerial effort generate $2.5 million in gross profits for the firm. Thus, by making managerial compensation dependent on performance, the gross profits for the owner rise from zero (under the fixed-salary arrangement) to $2.5 million. Note that even after deducting the manager's compensation, the

Table 6–2

Managerial Earnings and Firm Profits with Profit Sharing

Hours Worked by Manager	Hours Shirked by Manager	Gross Profits for Firm (π)	Manager's Share of Profits (.10 × π)
8	0	$3,000,000	$300,000
7	1	2,950,000	295,000
6	2	2,800,000	280,000
5	3	2,500,000	250,000
4	4	2,000,000	200,000
3	5	1,800,000	180,000
2	6	1,300,000	130,000
1	7	700,000	70,000
0	8	0	0

owner ends up with a hefty $2,500,000 − $250,000 = $2.25 million in profits. The performance bonus has increased not only the manager's earnings but also the owner's net profits.

FORCES THAT DISCIPLINE MANAGERS

Incentive Contracts

Typically the chief executive officer of a corporation receives stock options and other bonuses directly related to profits. It may be tempting to argue that a CEO who earns over $1 million per year is receiving excessive compensation. What is important, however, is *how* the executive earns the $1 million. If the earnings are due largely to a performance bonus, it could be a big mistake to reduce the executive's compensation. This point is important because the media often imply that it is unfair to heavily reward CEOs of major corporations. Remember, however, that performance-based rewards benefit stockholders as well as CEOs, and reducing such rewards may result in declining profits for the firm.

DEMONSTRATION PROBLEM 6–5

You are attending the annual stockholders' meeting of PIC Company. A fellow shareholder points out that the manager of PIC earned $100,000 last year, while the manager of a rival firm, CUP Enterprises, earned only $50,000. A motion is made to lower the salary of PIC's manager. Given only this information, what should you do?

ANSWER:

There is not enough information to make an informed decision about the appropriate way to vote; you should ask for additional information. If none is forthcoming, you should move to table the motion until shareholders can obtain additional information about such things as the profits and sales of the two firms, how much of each manager's earnings is due to profit sharing and performance bonuses, and the like. Explain to the other shareholders that the optimal contract will reward the manager for high profits; if PIC's manager's high earnings are due to a huge performance bonus paid because of high profits, eliminating the bonus would not be prudent. On the other hand, if CUP's manager has generated larger profits for that firm than your manager has for PIC, you may wish to adjust your manager's contract to reflect incentives similar to those of the rival firm or even attempt to hire CUP's manager to work for PIC.

External Incentives

The preceding analysis focused on factors within the firm that provide the manager with an incentive to maximize profits. In addition, forces outside the firm often provide managers with an incentive to maximize profits.

Reputation

Managers have increased job mobility when they can demonstrate to other firms that they have the managerial skills needed to maximize profits. It is costly to be an effective manager; many hours must be spent supervising workers and planning production outlays. These costs represent an investment by the manager in a reputation for being an excellent manager. In the long run, this reputation can be sold at a premium in the market for managers, where other firms compete for the right to hire the best managers. Thus, even when the employment contract does not explicitly include a performance bonus, a manager may choose to do a good job of running the firm if he or she wishes to work for another firm at some future date.

Takeovers

Another external force that provides managers with an incentive to maximize profits is the threat of a takeover. If a manager is not operating the firm in a profit-maximizing manner, investors will attempt to buy the firm and replace management with new managers who will. By installing a better manager, the firm's profits will rise and the value of the firm's stock will increase. Thus, one cost to a manager of doing a poor job of running the firm is the increased likelihood of a takeover. To avoid paying this cost, managers will work harder than they otherwise would, even if they are paid only a fixed salary.

THE MANAGER–WORKER PRINCIPAL–AGENT PROBLEM

When we introduced the principal–agent problem, the owner of the firm was viewed as having different objectives from the manager. There is nothing special about the owner–manager relationship that gives rise to the principal–agent problem; indeed, there is a similar problem between the manager and the employees she or he supervises.

To see this, suppose the manager is being paid a fraction of profits and thus has an incentive to increase the firm's profits. The manager cannot be in several places at the same time and thus cannot monitor every worker even if he or she wanted to. The workers, on the other hand, would just as soon gossip and drink coffee as work. How can the manager (the principal) induce the workers (the agents) not to shirk?

profit sharing
Mechanism used to enhance workers' efforts that involves tying compensation to the underlying profitability of the firm.

revenue sharing
Mechanism used to enhance workers' efforts that involves linking compensation to the underlying revenues of the firm.

Solutions to the Manager–Worker Principal–Agent Problem

Profit Sharing

One mechanism the manager can use to enhance workers' efforts is **profit sharing**—making the workers' compensation dependent on the underlying profitability of the firm. Offering workers compensation that is tied to underlying profitability provides an incentive for workers to put forth more effort.

Revenue Sharing

Another mechanism for inducing greater effort by workers is **revenue sharing**—linking compensation to the underlying revenues of the firm. Examples of this type of incentive scheme

include tips and sales commissions. Food servers usually receive a very low wage, plus tips. Tips are simply a commission paid by the person being served. If the server does a terrible job, the tip is low; if the server does an excellent job, the tip usually is higher. Similarly, car salespeople and insurance agents usually receive a percentage of the sales they generate. The idea behind all these compensation schemes is that it is difficult, if not impossible, for the manager to monitor these people's efforts, and there is uncertainty regarding what final sales will be. By making these workers' incomes dependent on their performance, the manager gives workers an incentive to work harder than they otherwise would. By working harder, they benefit both the firm and themselves.

Revenue sharing is particularly effective when worker productivity is related to revenues rather than costs. For example, a restaurant manager can design a contract whereby servers get some fraction of a tip; the tip is presumed to be an increasing function of the servers' quality (productivity). The manager of a sales firm can provide incentives to employees by paying them a percentage of the sales they generate. In contrast, a retail store that hires a security guard to prevent shoplifting will likely find revenue sharing with the security guard to be ineffective; his productivity is much more strongly related to the store's costs compared to its revenues.

One problem with revenue-based incentive schemes is that they do not provide an incentive for workers to minimize costs. For example, a food server may attempt to collect a big tip by offering the customer larger portions, free drinks, and the like, which will enhance the tip at the expense of the restaurant's costs.

Piece Rates

An alternative compensation method is to pay workers based on a *piece rate* rather than on a fixed hourly wage. For example, by paying a data entry clerk a fixed amount per word entered into the firm's database, the payment to the clerk depends on the output produced. To earn more money, the clerk must enter more words into the firm's database during a given time period.

A potential problem with paying workers based on a piece rate is that effort must be expended in quality control; otherwise, workers may attempt to produce quantity at the expense of quality. One advantage of revenue or profit sharing is that it reduces the incentive to produce low-quality products. Lower quality reduces sales, thus reducing compensation to those receiving revenue- or profit-sharing incentives.

DEMONSTRATION PROBLEM 6–6

For a video walkthrough of this problem, visit www.mhhe.com/baye10e

Your boss, who just earned an MBA, finished reading Chapter 6 of a noted economics textbook. She asks you why the firm pays its secretaries an hourly wage instead of a piece rate or a percentage of the firm's profits. How do you answer her?

ANSWER:

Incentive contracts such as piece rates and profit sharing are designed to solve principal–agent problems when effort is not observable. There is little need to provide "incentive contracts" to secretaries given the presence of bosses in the workplace. In particular, it is very easy to monitor the secretaries' effort; they usually are within the boss's eyesight and there are numerous opportunities to observe the quality of their work (e.g., letters for the boss's signature). Thus, there is no real separation between the "principal" (the boss) and the "agent" (the secretary); the secretary's "boss" knows when the secretary "messes up" and can fire him or her if performance is consistently low. In most instances, this provides secretaries with a stronger incentive to work hard than would paying them a fraction of the profits generated by the effort of all employees in the firm.

Paying secretaries piece rates would be an administrative nightmare and involve significant transaction costs; it would be extremely costly to keep track of all of the pages typed and tasks performed during the course of a week. Piece rates may also encourage secretaries to worry more about the quantity instead of the quality of the work done. All things considered, hourly wages are a reasonable way to compensate most secretaries—provided their bosses are given an incentive to monitor them.

Time Clocks and Spot Checks

Many firms use time clocks to assist managers in monitoring workers. However, time clocks are generally not useful in addressing the principal–agent problem. Time clocks essentially are designed to verify when an employee arrives and departs from the job. They do not monitor effort; rather, they simply measure presence at the workplace at the beginning and end of the workday.

A more useful mechanism for monitoring workers is for a manager to engage in spot checks of the workplace. In this case, the manager enters the workplace from time to time to monitor workers. Spot checks allow the manager to verify not only that workers are physically present but also that worker effort and the quality of the work are satisfactory.

The advantage of spot checks is that they reduce the cost of monitoring workers. With spot checks, the manager needn't be in several places at the same time. Because workers do not know when the manager will show up, they will put forth more effort than they would otherwise since getting caught "goofing off" may lead to dismissal or a reduction in pay.

INSIDE BUSINESS 6–4

Incentives Matter for Performance

Research has shown time and again that employee incentives play a significant role in firm performance. For example, Edward Lazear examined the importance of incentives for the Safelite Glass Corporation. His analysis showed average output per worker increased by almost 50 percent when it changed compensation from an hourly wage to a piece-rate system. Moreover, the average worker's pay increased by more than 10 percent under piece-rate compensation.

As another example of the importance of incentives, a group of researchers performed a field experiment where field managers on a fruit farm in the United Kingdom were given a performance bonus, based on their team's productivity, midway through the season. Even with their subordinates already being paid a piece rate, the introduction of the bonus for the managers led to increased overall productivity of the manager's teams by about 25 percent.

Pay-for-performance contracts are most effective in environments where a worker's responsibilities are clearly identified and each worker's output is objectively measured. They are least effective when the measurement of individual effort is garbled or when it is not possible to write a contract to control important aspects of worker behavior. For instance, the usual benefits of pay-for-performance are mitigated when the production process requires a team of workers. In this case, workers may "shirk" in anticipation of being able to "piggyback" on other employees' hard work (this behavior is called "free riding" in the economics literature). However, as was seen in the U.K. fruit farm experiment, pay-for-performance incentives for the team manager can help mitigate these concerns via strategic work assignment and better hiring, for example. Lastly, note that when contracts are incomplete, high-powered contracts may lead to dysfunctional behavior. For example, workers may focus exclusively on those aspects of their jobs where performance is rewarded.

For these reasons, the optimality and prevalence of high-powered incentive schemes like piece-rate systems vary across different types of occupations. In general, piece-rate pay is more common in occupations where output is clearly measurable and quality is relatively unimportant (such as farm labor). It is much less common when quality is important or difficult to objectively measure.

SOURCE: Edward Lazear, "Compensation and Incentives in the Workforce," *Journal of Economic Perspectives*, 32 (Summer 2018), pp. 195–214.

Thus, to be effective, spot checks need to be random; that is, workers should not be able to predict when the manager will be monitoring the workplace.

A disadvantage of spot checks is that they must occur frequently enough to induce workers not to risk getting caught shirking and they must entail some penalty for workers caught shirking. Spot checks work, in effect, through threat. Performance bonuses, on the other hand, work through a promise of reward. These characteristics can have different psychological effects on workers.

ANSWERING THE headLINE

As AT&T vertically integrates its content distribution network into content creation, the wisdom of this move from the firm's perspective will crucially depend on the existence and nature of specialized investments by both firms. For example, if AT&T intends to enter into digital advertising, it may seek specialized investments from content providers in their data collection and analysis to facilitate the process. Absent vertical integration, the need for such specialized investments could present the risk of hold-up or other sources of increased transaction costs for AT&T. Consequently, there may be sound economic rationale for vertical integration, but before making such a recommendation, you should verify that the expected benefits of avoided hold-up problems and other transaction costs due to specialized investments justify the costs of vertical integration.

SUMMARY

In this chapter, we examined the optimal institutional choice for input procurement and the principal–agent problem as it relates to managerial compensation and worker incentives. The manager must decide which inputs will be purchased from other firms and which inputs the firm will manufacture itself. Spot exchange generally is the most desirable alternative when there are many buyers and sellers and low transaction costs. It becomes less attractive when substantial specialized investments generate opportunism, resulting in transaction costs associated with using a market.

When market transaction costs are high, the manager may wish to purchase inputs from a specific supplier using a contract or, alternatively, forgo the market entirely and have the firm set up a subsidiary to produce the required input internally. In a fairly simple contracting environment, a contract may be the most effective solution. But as the contracting environment becomes more complex and uncertain, internal production through vertical integration becomes an attractive managerial strategy.

The chapter also demonstrated a solution to the principal–agent problem: Rewards must be constructed so as to induce the activities desired of workers. For example, if all a manager wants from a worker is for the worker to show up at the workplace, an hourly wage rate and a time clock form an excellent incentive scheme. If it is desirable to produce a high level of output with very little emphasis on quality, piece-rate pay schemes work well. However, if both quantity and quality of output are concerns, profit sharing is an excellent motivator.

KEY TERMS AND CONCEPTS

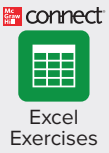
contract
dedicated assets
human capital
incentive contracts
opportunism
outsourcing
physical-asset specificity
piece-rate system
principal–agent problem
profit sharing
relationship-specific exchange
revenue sharing
site specificity
specialized investment
spot exchange
transaction costs
vertical integration

CONCEPTUAL AND COMPUTATIONAL QUESTIONS



1. Discuss the optimal method for procuring inputs that have well-defined and measurable quality specifications and require highly specialized investments. What are the primary advantages and disadvantages of acquiring inputs through this means? Give an example not used in the textbook that uses this method of procurement. *(LO1, LO3)*
2. Discuss the optimal method for procuring a modest number of standardized inputs that are sold by many firms in the marketplace. What are the primary advantages and disadvantages of using this method to acquire inputs? Give an example not used in the text that uses this method of procurement. *(LO1, LO3)*
3. Identify whether each of the following transactions involves spot exchange, contract, or vertical integration. *(LO1)*
   a. Barnacle Inc. has a legal obligation to purchase 2 tons of structural steel per week to manufacture conveyor frames.
   b. ExxonMobil uses the oil extracted from its wells to produce raw polypropylene, a type of plastic.
   c. Boat Lifts R Us purchases generic AC motors from a local distributor.
   d. Kaspar Construction—a home-building contractor—purchases 50 pounds of nails from the local Home Depot.
4. Explain why automobile manufacturers produce their own engines but purchase mirrors from independent suppliers. *(LO1, LO2)*
5. Identify the type of specialized investment that each of the following situations requires. *(LO2)*
   a. You hire an employee to operate a machine that only your company uses.
   b. An aerosol canning company designs a filling line that can be used only for a particular firm's product.
   c. A company builds a manufacturing facility across the street from its primary buyer.
6. Describe how a manager who derives satisfaction from both income and shirking allocates a 10-hour day between these activities when paid an annual, fixed salary of $110,000. When this same manager is given an annual, fixed salary of $110,000 and 6 percent of the firm's profits—amounting to $145,000 per year—the manager chooses to work six hours and shirks for four hours. Explain which of the compensation schemes the manager prefers. *(LO4, LO5)*
7. Compare the advantages and disadvantages of using spot checks/hidden video cameras in the workplace and pay-for-performance pay schemes as means to influence worker performance. *(LO6, LO7)*
8. Discuss the impact of the following factors on the optimal method of procuring an input. *(LO1, LO3)*
   a. Benefits from specialization.
   b. Bureaucracy costs.
   c. Opportunism on either side of the transaction.
   d. Specialized investments.
   e. Unspecifiable events.
   f. Bargaining costs.
9. Suppose the marginal benefit of writing a contract is $100, independent of its length. Find the optimal contract length when the marginal cost of writing a contract of length L is: *(LO3)*
   a. $MC(L) = 30 + 4L$.
   b. $MC(L) = 40 + 5L$.
   c. What happens to the optimal contract length when the marginal cost of writing a contract declines?

10. Suppose the marginal cost of writing a contract of length L is $MC(L) = 40 + 3L$. Find the optimal contract length when the marginal benefit of writing a contract is: *(LO3)*
    a. $MB(L) = 130$.
    b. $MB(L) = 170$.
    c. What happens to the optimal contract length when the marginal benefit of writing a contract increases?



PROBLEMS AND APPLICATIONS



11. During the beginning of the twenty-first century, the growth in computer sales declined for the first time in almost two decades. As a result, PC makers dramatically reduced their orders of computer chips from Intel and other vendors. Explain why computer manufacturers such as Dell are likely to write relatively short contracts for computer chips. *(LO2, LO3)*
12. DonutVille caters to its retirement population by selling over 10,000 donuts each week. To produce that many donuts weekly, DonutVille uses 1,000 pounds of flour, which must be delivered by 5:00 AM every Friday morning. How should the manager of DonutVille acquire flour? Explain. *(LO1, LO3)*
13. The manager of your company's pension fund is compensated based entirely on fund performance; he earned over $1.2 million last year. As a result, the fund is contemplating a proposal to cap the compensation of fund managers at $100,000. Provide an argument against the proposal. *(LO4, LO5)*
14. The division of a large office services company that makes high-end copiers recently signed a five-year, $25 million contract for IT services from CGI Group, a Canadian information technology company. If you were the manager of the division, how would you justify the long-term nature of your contract with CGI Group? *(LO2, LO3)*
15. *The Wall Street Journal* reported that Juniper Networks Inc.—a maker of company network equipment—plans to offer its more than 1,000 employees the opportunity to reprice their stock options. Juniper's announcement came at a time when its stock price is down 90 percent, leaving many employees' stock options worthless. How do you think Juniper's CEO justified repricing the employees' stock options to the shareholders? *(LO4, LO5)*
16. Suppose that Honda is on the verge of signing a 15-year contract with TRW to supply airbags. The terms of the contract include providing Honda with 85 percent of the airbags used in new automobiles. Just prior to signing the contract, a manager reads that one of TRW's competitors has introduced a comparable airbag using a new technology that reduces the cost by 30 percent. How would this information affect Honda's optimal contract length with TRW? *(LO3)*
17. EFI—a material handling company—pays each of its salespersons a base salary plus a percentage of revenues generated. To reduce overhead, EFI has switched from giving each salesperson a company car to reimbursing them $0.35 for each business-related mile driven. Accounting records show that, on average, each salesperson drives 100 business-related miles per day, 240 days per year. Can you think of an alternative way to restructure the compensation of EFI's sales force that could potentially enhance profits? Explain. *(LO6, LO7)*
18. Teletronics reported record profits of $100,000 last year and is on track to exceed those profits this year. Teletronics competes in a very competitive market where many of the firms are merging in an attempt to gain competitive advantages. Currently, the company's top manager is compensated with a fixed salary that does not include any performance bonuses. Explain why this manager might nonetheless have a strong incentive to maximize the firm's profits. *(LO4, LO5)*

19. Recently, Air Liquide signed a long-term contract with Yan'an Energy and Chemical Co., a subsidiary of Yanchang Petroleum Group—one of China's largest firms engaged in oil and natural gas exploration and production as well as oil refining. The new contract specifies that Air Liquide invest approximately 80 million euros in two air separation units (ASUs), which will supply air gases for Yan'an's production of plastics. Air Liquide is a French multinational firm that supplies industrial gases to a wide range of industries, including chemical manufacturers. Why is a long-term contract preferable to a spot exchange or vertical integration between Yan'an and Air Liquide? *(LO1, LO2, LO3)*

20. A few years ago, the *Boston Globe* reported that the city of Boston planned to spend $14 million to convert the FleetCenter sports arena and entertainment center into an appropriate venue for the Democratic National Convention (DNC). The city engaged Shawmut Design and Construction in a contractual relationship to complete the work, which was supposed to start 48 days prior to the commencement of the DNC on July 26. However, when negotiations between Boston's mayor and the police union broke down, the Boston Police Patrolmen's Association took to the picket lines surrounding the FleetCenter and prevented construction crews from beginning the work. The *Globe* reported that "a truck attempting to deliver steel turned around after a crowd of union members stood at a chain-link gate in front of the arena, shouting 'back it up,' and 'respect the line, buddy.'" Moreover, the *Globe* reported that "On-duty police officers, who had been instructed to prevent pickets from restricting access, did not intervene." Given the tight construction schedule, construction delays reportedly cost about $100,000 per day. Identify the principal–agent problem in this situation. Did the mayor and the city of Boston face the classical "hold-up problem" or another problem? Explain. *(LO2, LO6)*

21. Business-process outsourcing (BPO) is a type of outsourcing that consists of contracting operations and responsibilities of a specific business process (e.g., human resources) to a third-party service provider. Such outsourcing generally began with manufacturing firms outsourcing their supply chain but has grown into a much wider range of processes, including marketing, finance, sales, and accounting. Competition among firms in the BPO market is strong. Companies based in the United States include HP Enterprise Services, Affiliated Computer Services, and Automated Data Processing (ADP). A number of Indian companies, however, also provide worldwide BPO services, such as Infosys, Wipro, and Genpact. An article in *Bloomberg BusinessWeek* suggested that BPO can save end users anywhere from 15 to 85 percent. International BPO service providers are particularly attractive since offshore labor offers an additional 25 to 30 percent cost savings. Furthermore, approximately 25 percent of the cost savings results from BPO firms' proprietary products. The remaining 10 to 30 percent in cost reduction accrues from consolidated operations. Suppose you are the manager of a U.S.-based company and must decide whether to outsource your human resources department. Outline arguments supporting and opposing a decision to outsource this function of your business. From a purely business standpoint, do any issues arise from contracting with an international-based versus U.S.-based BPO service firm? Explain. *(LO1, LO3)*

22. You are a management consultant for a 30-year-old partner in a large law firm. In a meeting, your client says: "According to an article in *The New York Times*, 57 percent of large law firms have a mandatory retirement age for partners in the firm. Before they retire, partners are paid directly for the work that they do, and, as owners, they are entitled to a share of the profits of the firm. Once they retire, partners do not receive either form of compensation. In light of this, I think we should eliminate mandatory retirement in order to gain a 'competitive advantage' in attracting high-quality lawyers

to work for our firm. Of course, you are the expert." What do you recommend? Explain. *(LO4, LO5)*

23. Automated Data Processing (ADP) provides computer software and services to a host of companies, including automobile dealerships. ADP charges dealerships a monthly lease for hardware, software, and support services but does not charge for training the dealerships' employees. Dealerships need only pay for their employees' time and travel to ADP headquarters, where they attend "Software U" at no additional charge. Discuss the specialized investments (if any) made by an automobile dealership, its employees, and ADP—and identify two potential vulnerabilities that a dealership faces under this arrangement. *(LO2)*
24. Andrew has decided to open an online store that sells home and garden products. After searching around, he chooses the software company Initech to provide the software for his website since its product required the least amount of specialized investments for him to use it. They agreed upon a price of $2,000. To use Initech's software, Andrew makes $1,200 in sunk capital investments and spends 55 hours learning how to use Initech's software, which is very different from other software packages. Both Andrew and Initech view Andrew's time as worth $26 per hour, and Initech is fully aware of the investments Andrew must make to use its product. After Andrew's investments were made, Initech came to Andrew and asked for more money. How much do you think its asked for and why? *(LO2)*
25. HomeGrown is a small restaurant that specializes in serving local fruits, vegetables, and meats. The company has chosen to enter into a long-term relationship with Family Farms, a local farming operation. The two parties have decided to enter into a long-term contract, where Family Farms will supply produce to HomeGrown at specified prices and volume each year. Before signing a contract, HomeGrown is trying to decide how long the contract should be. It estimates that each year the contract covers saves the restaurant $1,000 in bargaining and opportunism costs. However, each year the contract covers also requires more legal fees. HomeGrown estimates that the number of hours required from lawyers, L, has a quadratic relationship with the number of years on the contract, so that $L = Y^2$, where Y is the number of years for the contract. If HomeGrown's lawyers charge $100 per hour, how long should the contract be? *(LO3)*
26. Jim's diner is just about to open in Memphis, Tennessee. However, Jim is trying to decide whether he wants to offer Coke or Pepsi soda products. He determines that, to offer either product, he will have to spend $1,800 in sunk costs to purchase and install the appropriate paraphernalia, e.g., a large Coca-Cola or Pepsi sign out front. Ultimately, he chooses to offer Coke products and agrees to pay Coke 5 cents per ounce of Coke sold for the right to use its product. After Jim makes the investments specific to his soda choice, Coke returns and asks for a fixed (one-time) fee in addition to the 5 cents per ounce. What is the least Jim should be willing to pay? Explain. *(LO2)*
27. Recently, the owner of a Trader Joe's franchise decided to change how she compensated her top manager. Last year, she paid him a fixed salary of $65,000, and her store made $120,000 in profits (not counting payment to her top manager). She suspected the store could do much better and feared the fixed salary was causing her top manager to shirk on the job. Therefore, this year she decided to offer him a fixed salary of $30,000 plus 15 percent of the store's profits. Since the change, the store is performing much better, and she forecasts profits this year to be $280,000 (again, not counting the payment to her top manager). Assuming the change in compensation is the reason for the increased profits, and that the forecast is accurate, how much more money will the owner make (net of payment to her top manager) because of this change? Does the manager make more money under the new payment scheme? *(LO4, LO5)*

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APPENDIX

AN INDIFFERENCE CURVE APPROACH TO MANAGERIAL INCENTIVES

The essence of the problem with compensation payments that are not tied to performance is depicted graphically in Figure 6–6. The manager views both leisure and income to be goods. Moreover, the manager is willing to substitute between leisure on the job (shirking) and income. This is why his indifference curve has the usual shape in Figure 6–6, where we measure the quantity of leisure consumed at the workplace on the horizontal axis and income on the vertical axis. Note that while the manager enjoys shirking, the owner does not want the manager to shirk.

When the manager is offered a fixed salary of $50,000, his opportunity set becomes the shaded area in Figure 6–6. The reason is simple: Since the owner is not physically present at the workplace, the manager will receive the same $50,000 regardless of whether he works a full eight hours (and hence doesn't shirk) or spends the entire day at home (and shirks eight hours). If profits are low, the owner will not know whether this is due to poor managerial effort or simply bad luck. The manager can take advantage of the separation of ownership from control by pushing his indifference curve as far to the northeast as possible until he is in equilibrium at point A, where he shirks the entire day every day of the year but still collects the $50,000.

From the viewpoint of the firm's owner, the fixed salary has an adverse effect on profits because it does not provide the manager with an incentive to monitor other employees. To see this, suppose the profits of the firm are a simple linear function of the amount of shirking done by the manager during each eight-hour period. Such a relationship is graphed in Figure 6–7. The line through point C defines the level of firm profits, which depends on the manager's degree of shirking. For example, if the manager

Figure 6–6

Impact of a Fixed Salary on Managerial Behavior

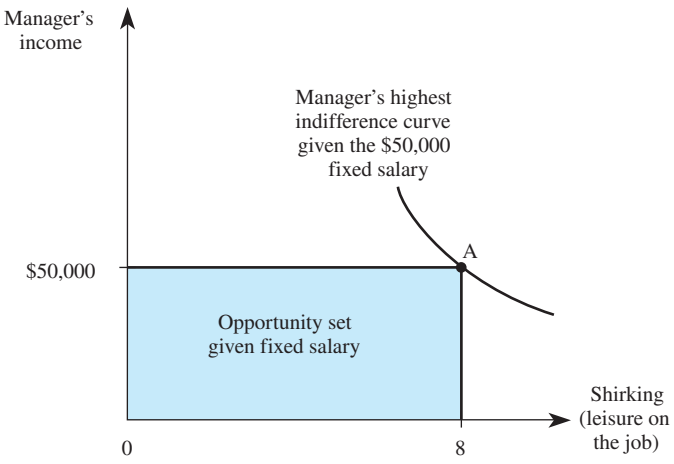


Figure 6–7

A Profit-Sharing Incentive Bonus

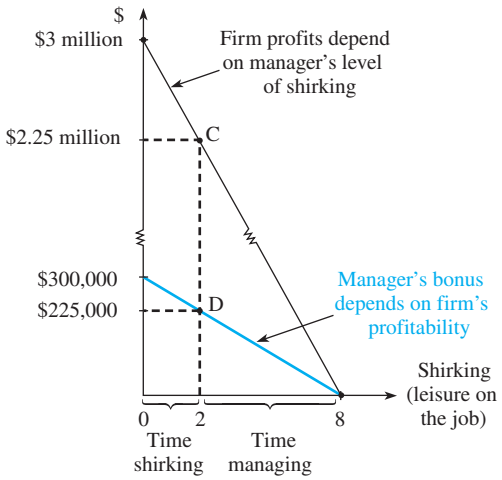
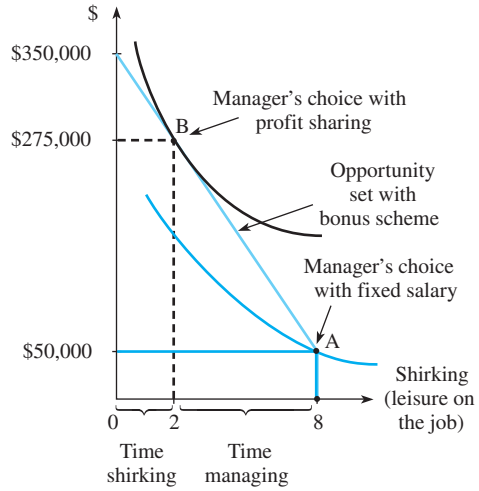


Figure 6–8

A Profit-Sharing Incentive Scheme Increases Managerial Effort



spends the entire day on the job monitoring other employees, shirking is zero and firm profits are $3 million. If the manager spends the entire day shirking, profits are zero. If the manager shirks two hours and thus works six hours, the profits of the firm are $2.25 million. Since the fixed salary of $50,000 provides the manager with an incentive to shirk eight hours, the profits of the firm will be zero if it uses that compensation plan.

How can the owner get the manager to spend time monitoring the production process? You might think that if she paid the manager a bigger salary, the manager would work harder. But this is not correct; a larger salary would simply shift the vertical intercept of the opportunity set in Figure 6–6 above $50,000, but the equilibrium would still imply eight hours of shirking. In essence, the employment contract is such that there is absolutely no cost to the manager of shirking.

Suppose the owner offers the manager the following type of employment contract: a fixed salary of $50,000, plus a bonus of 10 percent of the profits. In this instance, if the manager spends eight hours shirking, profits are zero and the manager gets only $50,000. If the manager does not shirk at all, the firm earns $3 million in profits and the manager gets a bonus equal to 10 percent of those profits. In this instance, the bonus is $300,000. The bonus to the manager, as a function of his level of shirking, is depicted in Figure 6–7 as the line through point D. Note that when the manager shirks for two hours each day, the firm earns $2.25 million in gross profits and the manager's bonus is $225,000.

The effect of a salary-plus-bonus compensation plan on managerial behavior is illustrated in Figure 6–8. The manager's opportunity set is now given by the line through points A and B. For example, if the manager shirks eight hours, profits are zero and he receives no bonus; therefore, his income is $50,000. If the manager does not shirk at all, a bonus of $300,000 is added to his fixed salary; thus, the manager can earn $350,000 if he does not shirk.

Exactly what the manager does under the salary-plus-bonus plan depends on his preferences. But as we see in Figure 6–8, this manager can attain a higher indifference curve by shirking less and moving from point A to point B. At point B, the manager earns $275,000 in income—$225,000 in the form of a bonus payment and $50,000 as a fixed salary. The manager clearly prefers this compensation scheme. Note also that the manager still shirks two hours each day, but this is considerably less than under the fixed-salary/no-bonus plan.

What is the impact of the bonus on the owner of the firm? In Figure 6–7, we see that when the manager shirks two hours each day, the firm earns $2.25 million in gross profits. Thus, the salary plus bonus increases the owner's gross profits from zero (under the fixed salary) to $2.25 million. The bonus has increased the welfare not only of the manager but of the owner; profits, net of managerial compensation, are

$$\$2{,}250{,}000 - \$275{,}000 = \$1{,}975{,}000$$

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7 The Nature of Industry

LEARNING OBJECTIVES

After completing this chapter, you will be able to:

- **LO1** Calculate alternative measures of industry structure, conduct, and performance, and discuss their limitations.
- **LO2** Describe examples of vertical, horizontal, and conglomerate mergers, and explain the economic basis for each type of merger.
- **LO3** Explain the relevance of the Herfindahl-Hirschman index for antitrust policy under the horizontal merger guidelines.
- **LO4** Describe the structure–conduct–performance paradigm, the feedback critique, and their relation to the five forces framework.
- **LO5** Identify whether an industry is best described as perfectly competitive, a monopoly, monopolistically competitive, or an oligopoly.

headLINE

T-Mobile and Sprint Finalize Merger

Recently, T-Mobile and Sprint finalized their merger—estimated to be a $26 billion deal. Reports placed T-Mobile's estimated share of the wireless subscription market at 16 percent, while Sprint's share was estimated at 14 percent. This market had two other major competitors: Verizon, with a 30 percent share, and AT&T, with a 38 percent share. The finalized merger comes after nearly two years of scrutiny and challenges by federal and state agencies.

Explain why management at both merging firms should have expected and prepared for scrutiny of the merger by government agencies.

INTRODUCTION

Managers of firms do not make decisions in a vacuum. Numerous factors affect decisions such as how much output to produce, what price to charge, and how much to spend on research and development, advertising, and so on. Unfortunately, no single theory or methodology provides managers with the answers to these questions. The optimal pricing strategy for an automobile manufacturer generally will differ from that of a computer firm; the level of research and development will differ for food manufacturers and defense contractors. In this chapter, we highlight important differences that exist among industries. In subsequent chapters, we will see why these differences arise and examine how they affect managerial decisions.

Much of the material in this chapter is factual and is intended to acquaint you with aspects of the "real world" that are relevant for managers. You will be exposed to statistics for numerous industries. Some of these statistics summarize how many firms exist in various industries; others indicate which firms and industries are the largest and which industries tend to charge the highest markups.

The numbers presented in this chapter will change over time; the largest firm today is unlikely to be the largest firm in 40 years. Consequently, the most important thing for you to grasp in this chapter is that industries differ substantially in nature; not all industries are created equal. Our task in the remaining chapters of this book is to determine what it is about firms and industries that gives rise to systematic differences in price–cost margins, advertising expenditures, and other managerial decision variables. This will be particularly valuable to you as a manager since you do not know in which industry you will work during the next 40 years of your career. An effective manager is able to adapt to the nature of the industry in which his or her firm competes. As the nature of the industry changes, so will the manager's optimal decisions.

MARKET STRUCTURE

Market structure refers to factors such as the number of firms that compete in a market, the relative size of the firms (concentration), technological and cost conditions, demand conditions, and the ease with which firms can enter or exit the industry. Different industries have different structures, and these structures affect the decisions the prudent manager will make. The following subsections provide an overview of the major structural variables that affect managerial decisions.

market structure
Factors that affect managerial decisions, including the number of firms competing in a market, the relative size of firms, technological and cost considerations, demand conditions, and the ease with which firms can enter or exit the industry.

Firm Size

It will come as no surprise to you that some firms are larger than others. Consider Table 7–1, which provides a snapshot of the sales of companies in a variety of different industries. Notice that there are considerable differences in the size of the largest firm in each industry. In 2020, for instance, Walmart was the largest general merchandiser with sales of approximately $524 billion. In contrast, International Paper was the largest producer of packaging and containers, but it had sales of only $22 billion.

Industries are also dynamic. Over time, changes in competitors' strategies or changes in market conditions can change a firm's relative position within an industry—or potentially change the viability of the industry itself. For instance, Verizon Communications had the

Table 7–1

Largest Firms in Selected Industries

Industry	Largest Company	Sales (millions)
Advertising/marketing	Omnicon Group	$ 14,954
Aerospace and defense	Raytheon Technologies	77,046
Airlines	Delta Air Lines	47,007
Apparel	TJX	41,717
Beverages	Coca-Cola	37,266
Chemicals	Dow Chemical	42,951
Computer software	Microsoft	125,843
Computers, office equipment	Apple	260,174
Electronics, electrical equipment	Honeywell International	36,709
Entertainment	Disney	69,570
General merchandisers	Walmart	523,964
Household and personal products	Procter & Gamble	67,684
Industrial machinery	General Electric	95,214
Information technology services	IBM	77,147
Internet services and retailing	Amazon	280,522
Motor vehicles and parts	Ford Motor	155,900
Packaging, containers	International Paper	22,376
Real estate	CBRE Group	23,894
Telecommunications	AT&T	181,193
Tobacco	Philip Morris International	29,805
Transportation and logistics	XPO Logistics	16,684

SOURCE: *Fortune* 500 List, June 17, 2020; authors' calculations.

largest sales of any telecommunications firm in 2006, but by 2012, AT&T was the industry leader, and continued to lead with sales of $181 billion in 2020. Also, in 2008 Google was the leader in Internet services and retailing, but it had been overtaken by Amazon by 2012.

What drives these differences in sales across industries, and why do firms' relative positions tend to change over time? Are they driven by differences or changes in market structure? Did firms become "large" by combining activities through mergers? To what extent do they stem from differences (or changes) in research and development (R&D) or advertising expenditures? The remainder of this chapter, and indeed the remainder of this book, takes a deeper look at these and other questions.

Industry Concentration

The data in Table 7–1 reveal considerable variation in the size of the largest firm in various industries. Another factor that affects managerial decisions is the size distribution of firms within an industry; that is, are there many small firms within an industry or only a few large firms? This question is important because, as we will see in later chapters, the optimal decisions of a manager who faces little competition from other firms in the industry will differ from those of a manager who works in an industry in which there are many firms.

Some industries are dominated by a few large firms, while others are composed of many small firms. Before presenting concentration data for various U.S. industries, we examine two measures that economists use to gauge the degree of concentration in an industry.

Measures of Industry Concentration

Concentration ratios measure how much of the total output in an industry is produced by the largest firms in that industry. The most common concentration ratio is the four-firm concentration ratio (C_4). The **four-firm concentration ratio** is the fraction of total industry sales produced by the four largest firms in the industry.

four-firm concentration ratio
The fraction of total industry sales generated by the four largest firms in the industry.

Let S_1, S_2, S_3, and S_4 denote the sales of the four largest firms in an industry, and let S_T denote the total sales of all firms in the industry. The four-firm concentration ratio is given by

$$C_4 = \frac{S_1 + S_2 + S_3 + S_4}{S_T}$$

Equivalently, the four-firm concentration ratio is the sum of the market shares of the top four firms:

$$C_4 = w_1 + w_2 + w_3 + w_4$$

where

$w_1 = S_1/S_T$,
$w_2 = S_2/S_T$,
$w_3 = S_3/S_T$, and
$w_4 = S_4/S_T$

When an industry is composed of a very large number of firms, each of which is very small, the four-firm concentration ratio is close to zero. When four or fewer firms produce all of an industry's output, the four-firm concentration ratio is 1. The closer the four-firm concentration ratio is to zero, the less concentrated is the industry; the closer the ratio is to 1, the more concentrated is the industry.

DEMONSTRATION PROBLEM 7–1

Suppose an industry is composed of six firms. Four firms have sales of \$10 each, and two firms have sales of \$5 each. What is the four-firm concentration ratio for this industry?

ANSWER:

Total industry sales are $S_T = \$50$. The sales of the four largest firms are

$$S_1 + S_2 + S_3 + S_4 = \$40$$

Therefore, the four-firm concentration ratio is

$$C_4 = \frac{40}{50} = .80$$

This means that the four largest firms in the industry account for 80 percent of total industry output.

Concentration ratios provide a very crude measure of the size structure of an industry. Four-firm concentration ratios that are close to zero indicate markets in which there are many sellers, giving rise to much competition among producers for the right to sell to consumers. Industries with four-firm concentration ratios close to 1 indicate markets in which there is little competition among producers for sales to consumers.

Herfindahl-Hirschman index (HHI)
The sum of the squared market shares of firms in a given industry multiplied by 10,000.

Another measure of concentration is the Herfindahl-Hirschman index. The **Herfindahl-Hirschman index (HHI)** is the sum of the squared market shares of firms in a given industry, multiplied by 10,000 to eliminate the need for decimals. By squaring the market shares before adding them up, the index weights firms with high market shares more heavily.

Suppose firm i's share of the total market output is $w_i = S_i/S_T$, where S_i is firm i's sales and S_T is total sales in the industry. Then the Herfindahl-Hirschman index is

$$\text{HHI} = 10{,}000\ \Sigma w_i^2$$

The value of the Herfindahl-Hirschman index lies between 0 and 10,000. A value of 10,000 arises when a single firm (with a market share of $w_1 = 1$) exists in the industry. A value of 0 results when there are numerous infinitesimally small firms.

DEMONSTRATION PROBLEM 7–2

Suppose an industry consists of three firms. Two firms have sales of \$10 each, and one firm has sales of \$30. What is the Herfindahl-Hirschman index for this industry? What is the four-firm concentration ratio?

ANSWER:

Since total industry sales are $S_T = \$50$, the largest firm has a market share of $w_1 = 30/50$ and the other two firms have a market share of $10/50$ each. Thus, the Herfindahl-Hirschman index for this industry is

$$\text{HHI} = 10{,}000\left[\left(\frac{30}{50}\right)^2 + \left(\frac{10}{50}\right)^2 + \left(\frac{10}{50}\right)^2\right] = 4{,}400$$

The four-firm concentration ratio is 1 since the top three firms account for all industry sales.

The Concentration of U.S. Industry

Now that you understand the algebra of industry concentration and Herfindahl-Hirschman indexes, we may use these indexes to examine the concentration of representative industries within the United States. Table 7–2 provides concentration ratios (in percentages) and Herfindahl-Hirschman indexes for selected U.S. industries. Notice that there is considerable variation among industries in the degree of concentration. The top four producers of electronic computers account for 87 percent of the industry's total output, suggesting considerable concentration. Distilleries, as well as the industry that makes motor vehicles, also have high four-firm concentration ratios. In contrast, the four-firm concentration ratios for the jewelry, ready-mix concrete, and women's and girls' apparel industries are low, suggesting greater competition among sellers. For example, the four largest producers of ready-mix concrete account for only 23 percent of the total market.

On balance, the Herfindahl-Hirschman indexes reported in Table 7–2 reveal a similar pattern: The industries with high four-firm concentration ratios tend to have higher Herfindahl-Hirschman indexes. There are exceptions, however. Notice that according to the four-firm concentration ratio, the motor vehicle industry is more concentrated than the snack food industry. However, the Herfindahl-Hirschman index for the snack food industry is higher than that for the motor vehicle industry.

There are several reasons that inferences drawn about an industry's level of concentration may differ, depending on whether one uses the four-firm concentration or Herfindahl-Hirschman index. First, the four-firm concentration ratio is based on the market shares of only the four largest firms in an industry, while the Herfindahl-Hirschman index is based on the

Table 7–2

Four-Firm Concentration Ratios and Herfindahl-Hirschman Indexes for Selected U.S. Manufacturing Industries

Industry	C_4 (percentage)	HHI
Breweries	90	NA
Distilleries	70	1,519
Electronic computers	87	NA
Fluid milk	46	1,075
Furniture and related products	11	62
Jewelry (excluding costume)	29	347
Men's and boys' cut and sew apparel	27	324
Motor vehicles	68	1,744
Ready-mix concrete	23	313
Semiconductor and other electronic components	34	476
Snack foods	53	1,984
Soap and cleaning compound	47	848
Soft drinks	52	891
Women's and girls' cut and sew apparel	20	174

SOURCE: U.S. Bureau of the Census, accessed June 2020.

NOTE: The U.S. Bureau of the Census approximates the HHI by using only data on the top 50 firms in the industry

market shares of all firms in an industry. In other words, the four-firm concentration ratio does not take into account the fifth largest firm, whereas the Herfindahl-Hirschman index does. Second, the HHI is based on squared market shares, while the four-firm concentration ratio is not. Consequently, the Herfindahl-Hirschman index places a greater weight on firms with large market shares than does the four-firm concentration ratio. These two factors can lead to differences in the ranking of firms by the C_4 and the HHI.

Limitations of Concentration Measures

Statistics and other data should always be interpreted with caution, and the preceding measures of concentration are no exception. For instance, the HHI indexes reported in Table 7–2 are only approximations because the Census Bureau uses data on only the top 50 firms in the industry rather than data on all firms in the industry. Additionally, the Bureau of Census reports concentration indexes and HHI's based on lagged rather than current data (the most recent data are based on sales in 2007). The data in Table 7-2, therefore, may not reflect current industry structure. For example, Table 7-2 shows that the four-firm concentration ratio for electronic computers was 87 percent in 2007, but our own research suggests that it declined to about 70 percent in 2020. In concluding our discussion of the concentration of U.S. industries, it is important to point out three additional limitations of the numbers reported in Table 7–2.

Global Markets. The four-firm concentration ratios and Herfindahl-Hirschman indexes reported in Table 7–2 are based on a definition of the product market that excludes foreign imports. That is, in calculating C_4 and HHI, the Bureau of the Census does not take into account the penetration by foreign firms into U.S. markets. This tends to overstate the true level of concentration in industries in which a significant number of foreign producers serve the market.

For example, consider the four-firm concentration ratio for the brewery industry. Based on Table 7–2, the top four U.S. firms account for 90 percent of industry sales. However, this figure ignores beer produced by the many well-known breweries in Mexico, Canada, Europe, Australia, and Asia. The four-firm concentration ratio based on both domestic and imported beer would be considerably lower.

National, Regional, and Local Markets. A second deficiency in the numbers reported in Table 7–2 is that they are based on figures for the entire United States. In many industries, the relevant markets are local and may be composed of only a few firms. When the relevant markets are local, the use of national data tends to understate the actual level of concentration in the local markets.

For example, suppose that each of the 50 states had only one gasoline station. If all gasoline stations were the same size, each firm would have a market share of only 1/50. The four-firm concentration ratio, based on national data, would be 4/50, or 8 percent. This would suggest that the market for gasoline services is not very concentrated. However, it does a consumer in central Texas little good to have gas stations in 49 other states since the relevant market for buying gasoline for this consumer is his or her local market. Thus, geographical differences among markets can lead to biases in concentration measures.

In summary, indexes of market structure based on national data tend to understate the degree of concentration when the relevant markets are local.

Industry Definitions and Product Classes. We already emphasized that the geographic definition of the relevant market (local or national) can lead to a bias in concentration ratios. Similarly, the definition of product classes used to define an industry also affects indexes.

Specifically, in constructing indexes of market structure, there is considerable aggregation across product classes. Consider the four-firm concentration ratio for soft drinks, which is 52 percent in Table 7–2. This number may seem surprisingly low when one considers how Coca-Cola and Pepsi dominate the market for cola. However, the concentration ratio of 52 percent is based on a much more broadly defined notion of soft drinks. In fact, the product classes the Bureau of the Census uses to define the industry include many more types of bottled and canned drinks, including birch beer, root beer, fruit drinks, ginger ale, iced tea, and lemonade.

How does one determine which products belong in which industry? As a general rule, products that are close substitutes (have large, positive cross-price elasticities) are considered to belong to a given industry class. Indeed, one might view other soft drinks to be close substitutes for cola drinks, thus justifying their inclusion into the industry before calculating concentration ratios.

Technology

Industries also differ with regard to the technologies used to produce goods and services. Some industries are very labor intensive, requiring much labor to produce goods and services. Other industries are very capital intensive, requiring large investments in plant, equipment, and machines to be able to produce goods or services. These differences in technology give rise to differences in production techniques across industries. In the petroleum-refining industry, for example, firms utilize approximately one employee for each $5 million in sales. In contrast, the beverage industry utilizes roughly 15 workers for each $5 million in sales.

Technology is also important within a given industry. In some industries, firms have access to identical technologies and therefore have similar cost structures. In other industries,

INSIDE BUSINESS 7–1

The 2017 North American Industry Classification System (NAICS)

Industry classification systems provide information about different businesses in the U.S. economy. For instance, if you were interested in starting a business that sells tablets, you might want to know how many companies were already in that business. Or you might want to know about the number of people employed in the industry and the total value of shipments. The answers to these and other questions can be found by using classification systems such as the North American Industry Classification System (NAICS).

The NAICS is a standardized classification system for Canada, Mexico, and the United States. It uses a six-digit code to classify industries into 20 different sectors. Because the first five digits of the NAICS code are the same for Canada, Mexico, and the United States, you can compare industry trends across the three countries. The sixth digit of the NAICS code is country-specific; it varies to accommodate special identification needs in different countries.

The six-digit NAICS code contains varying levels of specificity about a classification. The first two digits comprise the economic sector code, the third digit comprises the subsector, the fourth the industry group, the fifth the NAICS industry, and the sixth digit designates the national industry. The broadest classification is the two-digit code, which simply classifies firms into one of 20 possible sectors. The six-digit code provides the most specific information about a firm's classification: It places firms into a country-specific industry.

To illustrate, suppose a U.S. firm is assigned an NAICS code of 512131. As shown in the accompanying table, the first two digits (51) of this code tell us that the firm belongs to the sector called *Information (51)*. This is a very broad classification that includes publishing industries (newspapers, periodicals, books, and software); motion pictures and sound recording industries; TV and radio broadcasting; telecommunications; and data processing, hosting, and related services. The first three digits provide a more specific classification: The firm belongs to a subsector called *Motion Picture and Sound Recording (512)*. Looking at the first four digits further refines the nature of the firm's product: The firm belongs to an industry group called *Motion Picture and Video Industries (5121)*. Moving to the five-digit code, we see that the firm belongs to the NAICS industry called *Motion Picture and Video Exhibition (51213)*. All digits together tell us that the firm belongs to the national industry that the United States calls *Motion Picture Theaters except Drive-Ins (512131)*.

Interpreting NAICS Code

NAICS Level	NAICS Code	Description
Sector	51	Information
Subsector	512	Motion Picture and Sound Recording
Industry Group	5121	Motion Picture and Video Industries
NAICS Industry	51213	Motion Picture and Video Exhibition
National Industry	512131	Motion Picture Theaters (except Drive-Ins)

one or two firms have access to a technology that is not available to other firms. In these instances, the firms with superior technology will have an advantage over other firms. When this technological advantage is significant, the technologically superior firm (or firms) will completely dominate the industry. In the remaining chapters, we will see how such differences in technologies affect managerial decisions.

Demand and Market Conditions

Industries also differ with regard to the underlying demand and market conditions. In industries with relatively low demand, the market may be able to sustain only a few firms. In

industries where demand is great, the market may require many firms to produce the quantity demanded. One of our tasks in the remaining chapters is to explain how the degree of market demand affects the decisions of managers.

The information accessible to consumers also tends to vary across markets. It is very easy for a consumer to find the lowest airfare on a flight from Washington to Los Angeles; all one has to do is call a travel agent or surf the Internet to obtain price quotes. In contrast, it is much more difficult for consumers to obtain information about the best deal on a used car. The consumer not only has to bargain with potential sellers over the price but also must attempt to ascertain the quality of the used car. As we will learn in subsequent chapters, the optimal decisions of managers will vary depending on the amount of information available in the market.

Finally, the elasticity of demand for products tends to vary from industry to industry. Moreover, the elasticity of demand for an individual firm's product generally will differ from the market elasticity of demand for the product. In some industries, there is a large discrepancy between an individual firm's elasticity of demand and the market elasticity. The reason for this can be easily explained.

In Chapter 3 we learned that the demand for a specific product depends on the number of close substitutes available for the product. As a consequence, the demand for a particular brand of product (e.g., 7Up) will be more elastic than the demand for the product group in general (soft drinks). In markets where there are no close substitutes for a given firm's product, the elasticity of demand for that product will coincide with the market elasticity of demand for the product group (since there is only one product in the market). In industries where many firms produce substitutes for a given firm's product, the demand for the individual firm's product will be more elastic than the overall industry demand.

Rothschild index
A measure of the sensitivity to price of a product group as a whole relative to the sensitivity of the quantity demanded of a single firm to a change in its price.

One measure of the elasticity of industry demand for a product relative to that of an individual firm is the Rothschild index. The **Rothschild index** provides a measure of the sensitivity to price of the product group as a whole relative to the sensitivity of the quantity demanded of a single firm to a change in its price.

The Rothschild index is given by

$$R = \frac{E_T}{E_F}$$

where E_T is the elasticity of demand for the total market and E_F is the elasticity of demand for the product of an individual firm.

The Rothschild index takes on a value between 0 and 1. When the index is 1, the individual firm faces a demand curve that has the same sensitivity to price as the market demand curve. In contrast, when the elasticity of demand for an individual firm's product is much greater (in absolute value) than the elasticity of the market demand, the Rothschild index is close to zero. In this instance, an individual firm's quantity demanded is more sensitive to a price increase than is the industry as a whole. In other words, when the Rothschild index is less than 1, a 10 percent increase in one firm's price will decrease that firm's quantity demanded by more than the total industry quantity would fall if all firms in the industry increased their prices by 10 percent. The Rothschild index therefore provides a measure of how price sensitive an individual firm's demand is relative to the entire market. When an industry is composed of many firms, each producing similar products, the Rothschild index will be close to zero. Historically, markets such as food and textiles have had a rather low Rothschild index, while markets such as chemicals and tobacco have had a Rothschild index closer to unity. This suggests individual firms in the food and textiles markets face a substantial number of substitutes, while individual firms in chemicals and tobacco have fewer substitutes within their markets.

DEMONSTRATION PROBLEM 7–3

Economic analysts estimate the demand curve for an individual airline to be $\ln Q_i = 5 - 4\ln P_i$, where Q_i is the firm's quantity of seats sold and P_i is the firm's price. Analysts estimate demand for air travel to be $\ln Q_M = 8 - 3\ln P_M$, where Q_M is total quantity of airline seats sold and P_M is the market-level price for airline seats. What is the Rothschild index for this industry?

ANSWER:

Recall that, for log-linear demand equations, the coefficient on the log of price equals the price elasticity of demand. Consequently, the Rothschild index is

$$R = \frac{-3}{-4} = 0.75$$

Potential for Entry

The final structure variable we discuss in this chapter is the potential for entry into an industry. In some industries, it is relatively easy for new firms to enter the market; in others, it is more difficult. The optimal decisions by firms in an industry will depend on the ease with which new firms can enter the market.

Numerous factors can create a *barrier to entry*, making it difficult for other firms to enter an industry. One potential barrier to entry is the explicit cost of entering an industry, such as capital requirements. Another is patents, which give owners of patents the exclusive right to sell their products for a specified period of time.

Economies of scale also can create a barrier to entry. In some markets, only one or two firms exist because of economies of scale. If additional firms attempted to enter, they would be unable to generate the volume necessary to enjoy the reduced average costs associated with economies of scale. As we will learn in subsequent chapters, barriers to entry have important implications for the long-run profits a firm will earn in a market.

INSIDE BUSINESS 7–2

The Elasticity of Demand at the Firm and Market Levels

The Rothschild index provides a succinct measure of the relative price sensitivity of a firm's potential customers compared to the price sensitivity of customers for the market in general. When an individual firm raises its price, it risks some of its customers leaving to purchase from other firms or leaving the market altogether by not purchasing from any firm. If the collection of firms in a market all raise their prices together, the primary risk just consists of customers leaving the market altogether. Cast in this light, the Rothschild index essentially captures the closeness of an individual firm's substitutes within its market.

Managers in a given market that want to utilize the Rothschild index need some measure of own price elasticity of market demand and a measure of own price elasticity for the demand of a representative product in their market. For example, the legalization of marijuana in Washington State resulted in a wave of small entrepreneurs selling their own product. Each seller may wonder whether their competitors' products are generally substitutes for their own or if theirs is unique enough (in composition, location, etc.) that customers do not perceive there to be good substitutes. A recent study by researchers Benjamin Hansen, Keaton Miller, and Caroline Weber sheds some light on that question. Their analyses of demand at the firm level and market level for marijuana in Washington State shows that firm-level demand is more elastic than market level demand. With just this information, managers in this market can conclude the Rothschild index is less than 1, and so there are at least some substitutes for their product.

SOURCE: Benjamin Hansen, Keaton Miller, and Caroline Weber, "The Legal Market for Marijuana: Evidence on Tax Incidence, and the Elasticity of Demand from Washington State," University of Oregon working paper, 2017.

CONDUCT

In addition to structural differences across industries, the *conduct*, or behavior, of firms also tends to differ across industries. Some industries charge higher markups than other industries. Some industries are more susceptible to mergers or takeovers than others. In addition, the amount spent on advertising and research and development tends to vary across industries. The following subsections describe important differences in conduct that exist across industries.

Pricing Behavior

Lerner index
A measure of the difference between price and marginal cost as a fraction of the product's price.

Firms in some industries charge higher markups than firms in other industries. To illustrate this fact, we introduce what economists refer to as the Lerner index. The **Lerner index** is given by

$$L = \frac{P - MC}{P}$$

where P is price and MC is marginal cost. Thus, the Lerner index measures the difference between price and marginal cost as a fraction of the price of the product.

When a firm sets its price equal to the marginal cost of production, the Lerner index is zero; consumers pay a price for the product that exactly equals the cost to the firm of producing another unit of the good. When a firm charges a price that is higher than marginal cost, the Lerner index takes on a value greater than zero, with the maximum possible value being unity. The Lerner index therefore provides a measure of how much firms in an industry mark up their prices over marginal cost. The higher the Lerner index, the greater the firm's markup. In industries in which firms rigorously compete for consumer sales by attempting to charge the lowest price in the market, the Lerner index is close to zero. When firms do not rigorously compete for consumers through price competition, the Lerner index is closer to 1.

The Lerner index is related to the markup charged by a firm. In particular, we can rearrange the formula for the Lerner index to obtain

$$P = \left(\frac{1}{1 - L}\right) MC$$

In this equation, $1/(1 - L)$ is the markup factor. It defines the factor by which marginal cost is multiplied to obtain the price of the good. When the Lerner index is zero, the markup factor is 1, and thus the price is exactly equal to marginal cost. If the Lerner index is $1/2$, the markup factor is 2. In this case, the price charged by a firm is two times the marginal cost of production.

Table 7–3 provides estimates of the average Lerner index and markup factors for industries in 7 U.S. sectors. Notice that there are considerable differences in Lerner indexes and markup factors across these sectors of the economy. The sector with the highest average Lerner index and markup is Agriculture, Forestry, Fishing and Hunting. In this sector, the average Lerner index is 0.46. This means that, on average, for each $1 paid to the firm by consumers, $0.46 is markup. Alternatively, the price is 1.85 times the actual marginal cost of production.

In contrast, the average Lerner index and markup for wholesale trade is much lower. Based on the Lerner index for wholesale trade, we see that for each $1 a wholesale trader receives, only $0.21 is markup. Alternatively, the price of a wholesale trade product is only 1.27 times the actual marginal cost of production. Again, the message for managers is that the

Table 7–3

Average Industry Lerner indexes and Markup Factors for Selected U.S. Sectors

Sector	Average Industry Lerner Index	Average Industry Markup Factor
Wholesale trade	0.21	1.27
Transportation and warehousing	0.21	1.27
Finance and insurance	0.24	1.32
Arts, entertainment, and recreation	0.29	1.41
Retail trade	0.31	1.45
Accommodation and food services	0.34	1.52
Agriculture, forestry, fishing, and hunting	0.46	1.85

SOURCE: Robert E. Hall, "Using Empirical Marginal Cost to Measure Market Power in the US Economy," NBER working paper, 2018.

markup charged for a product will vary depending on the nature of the market in which the product is sold. An important goal in the remaining chapters is to help managers determine the optimal markup for a product.

DEMONSTRATION PROBLEM 7–4

For a video walkthrough of this problem, visit www.mhhe.com/baye10e

A firm in the airline industry has a marginal cost of $200 and charges a price of $300. What are the Lerner index and markup factor?

ANSWER:

The Lerner index is

$$L = \frac{P - MC}{P} = \frac{300 - 200}{300} = \frac{1}{3}$$

The markup factor is

$$\frac{1}{1 - L} = \frac{1}{1 - 1/3} = 1.5$$

Integration and Merger Activity

Integration and merger activity also differ across industries. *Integration* refers to uniting productive resources. Integration can occur through a merger, in which two or more existing firms "unite," or merge, into a single firm. Alternatively (and as discussed in Chapter 6), integration can occur during the formation of a firm. By its very nature, integration results in larger firms than would exist in the absence of integration.

Mergers can result from an attempt by firms to reduce transaction costs, reap the benefits of economies of scale and scope, increase market power, or gain better access to capital markets. Some mergers are "friendly" in that both firms desire to merge into a single firm. Others are "hostile," meaning that one of the firms does not desire the merger to take place.

In some instances, mergers or takeovers occur because it is perceived that the management of one of the firms is doing an inadequate job of managing the firm. In this instance, the benefit of the takeover is the increased profits that result from "cleaning house," that is, firing

the incompetent managers. Many managers fear mergers and acquisitions because they are uncertain about the impact of a merger on their positions.

Economists distinguish among three types of integration, or mergers: vertical, horizontal, and conglomerate.

Vertical Integration

Vertical integration refers to a situation where various stages in the production of a single product are carried out in a single firm. For instance, an automobile manufacturer that produces its own steel, uses the steel to make car bodies and engines, and finally sells an automobile is vertically integrated. This is in contrast to a firm that buys car bodies and engines from other firms and then assembles all the parts supplied by the different suppliers. A *vertical merger* is the integration of two or more firms that produce components for a single product. We learned in Chapter 6 that firms vertically integrate to reduce the transaction costs associated with acquiring inputs.

Horizontal Integration

Horizontal integration refers to the merging of the production of similar products into a single firm. For example, if two computer firms merged into a single firm, horizontal integration would occur. Horizontal integration involves merging two or more final products into a single firm, whereas vertical integration involves merging two or more phases of production into a single firm.

In contrast to vertical integration, which occurs because this strategy reduces transaction costs, two primary reasons firms engage in horizontal integration are (1) to enjoy the cost savings of economies of scale or scope and (2) to enhance their market power. In some instances, horizontal integration allows firms to enjoy economies of scale and scope, thus leading to cost savings in producing the good. As a general rule, these types of horizontal mergers are socially beneficial. On the other hand, a *horizontal merger*, by its very definition, reduces the number of firms that compete in the product market. This tends to increase both the four-firm concentration ratio and the Herfindahl-Hirschman index for the industry, which may reflect an increase in the market power of firms in the industry. The social benefits of the reduced costs due to a horizontal merger must be weighed against the social costs associated with a more concentrated industry.

When the benefits of cost reductions are small relative to the gain in market power enjoyed by the horizontally integrated firm, the government may challenge the merger. Specifically, the Federal Trade Commission (FTC) and the Antitrust Division of the U.S. Department of Justice (DOJ) are empowered to file a lawsuit to prevent firms from merging into a single firm. Under their current *Horizontal Merger Guidelines*, these antitrust authorities view industries with Herfindahl-Hirschman indexes in excess of 2,500 to be "highly concentrated" and may attempt to block a horizontal merger if it will increase the Herfindahl-Hirschman index by more than 200. It is important to stress, however, that these are merely guidelines. In the absence of evidence that a merger is likely to harm consumers, the FTC and DOJ may decide not to challenge a merger even though the HHI (and its change) exceed these thresholds. In addition, antitrust authorities sometimes permit mergers in industries that have high Herfindahl-Hirschman indexes when there is evidence of significant foreign competition, an emerging new technology, or increased efficiency, or when one of the firms has financial problems.

Industries with Herfindahl-Hirschman indexes below 1,500 after a merger generally are considered "unconcentrated" by the FTC and DOJ, and horizontal mergers usually are not challenged. Also, if a merger changes the Herfindahl-Hirschman index by less than 100, it

usually goes unchallenged. If the Herfindahl-Hirschman index is between 1,500 and 2,500 after a merger, and the merger increases the Herfindahl-Hirschman index by more than 100, the FTC and DOJ may potentially challenge the merger. A challenge is also more likely if the Herfindahl-Hirschman index exceeds 2,500 and the merger increases the Herfindahl-Hirschman index by 100 to 200. However, in these last two cases, the agencies generally rely more heavily on other factors, such as economies of scale and ease of entry into an industry, in determining whether to attempt to block a horizontal merger. In Module Group B, we will discuss these and other government actions designed to reduce market power.

Conglomerate Mergers

Finally, a *conglomerate merger* involves the integration of different product lines into a single firm. For example, if a cigarette maker and a cookie manufacturer merged into a single firm, a conglomerate merger would result. A conglomerate merger is similar to a horizontal merger in that it involves merging final products into a single firm. It differs from a horizontal merger because the final products are not related.

The economic rationale for conglomerates is far from clear; merging completely different business lines is often counterproductive because doing so leads to a loss of specialization without offsetting beneficial synergies. Some have argued that conglomerate mergers can create synergies through improved cash flows for products with cyclical demands. Revenues derived from one product line can be used to generate working capital when the demand for another product is low. While this is a potential rationale when imperfections in capital markets prevent a firm from using financial markets to obtain working capital, engaging in a conglomerate merger for this purpose should be viewed as a last resort. Others have argued that, when the supply of superior managerial talent is tight, the overall profits of a conglomerate managed by a superior CEO can exceed the combined profits of several independent (but highly focused) firms that are managed by different CEOs with only average managerial talent.

Research and Development

Earlier we noted that firms and industries differ with respect to the underlying technologies used to produce goods and services. One way firms gain a technological advantage is by engaging in research and development (R&D) and then obtaining a patent for the technology developed through the R&D. Table 7–4 provides R&D spending as a percentage of sales for

Table 7–4

R&D, Advertising, and Profits as a Percentage of Sales for Selected Firms

Company	Industry	R&D as Percentage of Sales	Advertising as Percentage of Sales	Profit as Percentage of Sales
Bristol-Myers Squibb	Pharmaceuticals	24.4	19.3	13.7
Ford	Motor vehicle and parts	5.1	2.6	3.4
Goodyear Tire and Rubber	Rubber and plastic parts	2.8	2.4	Negative
Kellogg	Food	1.0	5.0	7.1
Procter & Gamble	Soaps and cosmetics	2.7	10.0	5.8

SOURCE: Annual reports of the companies; authors' calculation.

selected firms. Notice the variation in R&D spending across industries. In the pharmaceutical industry, for example, Bristol-Myers Squibb reinvested 24.4 percent of sales revenue in R&D; in the food industry, Kellogg reinvested only 1 percent of sales revenue in R&D.

The message for managers is clear: The optimal amount to spend on R&D will depend on the characteristics of the industry in which the firm operates. One goal in the remaining chapters is to examine the major determinants of R&D spending.

Advertising

As Table 7–4 reveals, there is also considerable variation across firms in the level of advertising utilized. Firms in the soaps and cosmetics industry, such as Procter & Gamble, spend about 10 percent of their sales revenue on advertising. In contrast, firms in the rubber and plastic parts industry, such as Goodyear, spend about 2 percent of their sales revenue on advertising. Another goal of the remaining chapters is to examine why advertising intensities vary across firms in different industries. We will also see how firms determine the optimal amount and type of advertising to utilize.

PERFORMANCE

Performance refers to the profits and social welfare that result in a given industry. It is important for future managers to recognize that profits and social welfare vary considerably across industries.

Profits

Table 7–4 highlights differences in profits across firms in selected industries. Ford's sales were among the highest in the group, yet its profits as a percentage of sales were second lowest in the group. One task in the next several chapters is to examine why "big" firms do not always earn big profits. As a manager, it would be a mistake to believe that just because your firm is large, it will automatically earn profits.

Social Welfare

Dansby-Willig (DW) performance index
Ranks industries according to how much social welfare would improve if the output in an industry were increased by a small amount.

Another gauge of industry performance is the amount of consumer and producer surplus generated in a market. While this type of performance is difficult to measure, R. E. Dansby and R. D. Willig have proposed a useful index. The **Dansby-Willig (DW) performance index** measures how much social welfare (defined as the sum of consumer and producer surplus) would improve if firms in an industry expanded output in a socially efficient manner. If the DW index for an industry is zero, there are no gains to be obtained by inducing firms in the industry to alter their outputs; consumer and producer surplus are maximized given industry demand and cost conditions. When the index is greater than zero, social welfare would improve if industry output were expanded.

The DW index thus allows one to rank industries according to how much social welfare would rise if the industry altered its output. Industries with large index values have poorer performance than industries with lower values. For example, suppose the DW index for chemicals were 0.67 while the DW index for textiles were 0.38. These figures suggest that a slight change in output in the chemical industry would increase social welfare more than would a slight change in output in the textile industry.

DEMONSTRATION PROBLEM 7–5

Suppose you are the manager of a firm in the textile industry. You have just learned that the government has placed the textile industry at the top of its list of industries it plans to regulate and intends to force the industry to expand output and lower the price of textile products. In preparation for your response, your analytics team has conducted analysis on Lerner and Dansby-Willig indexes across a wide range of industries, including textiles. Their analyses indicate that textiles have a Lerner index of 0.2 and a DW index of 0.35. The full range of Lerner and DW indexes across major industries is 0.18 to 0.52 and 0.33 to 0.68, respectively. How should you respond?

ANSWER:

You should point out to government's counsel that the textile industry has nearly the lowest Lerner index across major industries (0.2 vs. 0.18); only $0.20 of each $1 paid by consumers is markup. Furthermore, the Dansby-Willig index for the textile industry again is near the bottom. The efficient way for government to improve social welfare is to alter output in other industries first.

THE STRUCTURE–CONDUCT–PERFORMANCE PARADIGM

You now have a broad overview of the structure, conduct, and performance of U.S. industry. The *structure* of an industry refers to factors such as technology, concentration, and market conditions. *Conduct* refers to how individual firms behave in the market; it involves pricing decisions, advertising decisions, and decisions to invest in research and development, among other factors. *Performance* refers to the resulting profits and social welfare that arise in the market. The *structure–conduct–performance paradigm* views these three aspects of industry as being integrally related.

The Causal View

The *causal view* of industry asserts that market structure "causes" firms to behave in a certain way. In turn, this behavior, or conduct, "causes" resources to be allocated in certain ways, leading to either "good" or "poor" market performance. To better understand the causal view, consider a highly concentrated industry in which only a few firms compete for the right to sell products to consumers. According to the causal view, this structure gives firms market power, enabling them to charge high prices for their products. The behavior (charging high prices) is caused by market structure (the presence of few competitors). The high prices, in turn, "cause" high profits and poor performance (low social welfare). Thus, according to the causal view, a concentrated market "causes" high prices and poor performance.

The Feedback Critique

Today most economists recognize that the causal view provides, at best, an incomplete view of the relation among structure, conduct, and performance. According to the *feedback critique*, there is no one-way causal link among structure, conduct, and performance. The conduct of firms can affect market structure; market performance can affect conduct as well as market

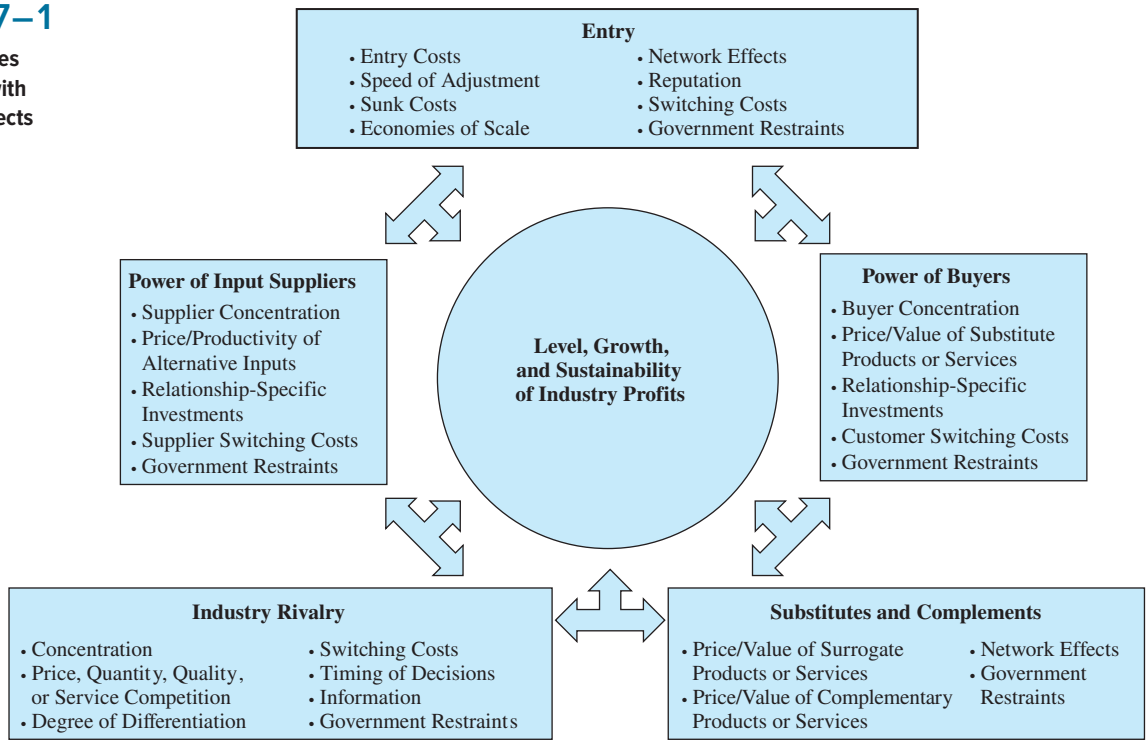
structure. To illustrate the feedback critique, let us apply it to the previous analysis, which stated that concentration causes high prices and poor performance.

According to the feedback critique, the conduct of firms in an industry may itself lead to a concentrated market. If the (few) existing firms are charging low prices and earning low economic profits, there will be no incentive for additional firms to enter the market. If this is the case, it could actually be low prices that "cause" the presence of few firms in the industry. In summary, then, it is a simplification of reality to assert that concentrated markets cause high prices. Indeed, the pricing behavior of firms can affect the number of firms. As we will see in subsequent chapters, low prices and good performance can occur even if only one or two firms are operating in an industry. A detailed explanation of this possibility will have to wait until we develop models for various market structures.

Relation to the Five Forces Framework

The structure–conduct–performance paradigm and the feedback critique are closely related to the *five forces framework* discussed in Chapter 1. Recall that the five forces framework suggests that five interrelated "forces" affect the level, growth, and sustainability of industry profits: (1) entry, (2) power of input suppliers, (3) power of buyers, (4) industry rivalry, and (5) substitutes and complements. These five forces capture elements of the structure and conduct of firms in the industry, while the level, growth, and sustainability of industry profits are elements of performance. In light of the feedback critique, the five forces framework can be modified as shown in Figure 7–1 to illustrate that these forces are interconnected.

Figure 7–1
The Five Forces Framework with Feedback Effects



OVERVIEW OF THE REMAINDER OF THE BOOK

In the remaining chapters of this book, we examine the optimal managerial conduct under a variety of market structures. To have some terminology that will enable us to distinguish among various types of market structures, it is useful to introduce the four basic models we will use to accomplish this goal. Recognize, however, that our discussion of these four models provides only an overview; indeed, entire chapters will be devoted to making managerial decisions in each of these situations.

Perfect Competition

In markets characterized by *perfect competition*, there are many firms, each of which is small relative to the entire market. The firms have access to the same technologies and produce similar products, so no firm has any real advantage over other firms in the industry. Firms in perfectly competitive markets do not have market power; that is, no individual firm has a perceptible impact on the market price, quantity, or quality of the product produced in the market. In perfectly competitive markets, both concentration ratios and Rothschild indexes tend to be close to zero. We will study perfectly competitive markets in detail in the next chapter.

Monopoly

A *monopoly* is a firm that is the sole producer of a good or service in the relevant market. For instance, most local utility companies are the sole providers of electricity and natural gas in a given city. Some towns have a single gasoline station or movie theater that serves the entire local market. All of these constitute local monopolies.

When there is a single provider of a good or service in a market, there is a tendency for the seller to capitalize on the monopoly position by restricting output and charging a price above marginal cost. Because there are no other firms in the market, consumers cannot switch to another producer in the face of higher prices. Consequently, consumers either buy some of the product at the higher price or go without it. In monopolistic markets, there is extreme concentration and the Rothschild index is unity.

Monopolistic Competition

In a market characterized by *monopolistic competition*, there are many firms and consumers, just as in perfect competition. Thus, concentration measures are close to zero. Unlike in perfect competition, however, each firm produces a product that is slightly different from the products produced by other firms; Rothschild indexes are greater than zero. Those who manage restaurants in a city containing numerous food establishments operate in a monopolistically competitive industry.

A firm in a monopolistically competitive market has some control over the price charged for the product. By raising the price, some consumers will remain loyal to the firm due to a preference for the particular characteristics of its product. But some consumers will switch to other brands. For this reason, firms in monopolistically competitive industries often spend considerable sums on advertising in an attempt to convince consumers that their brands are "better" than other brands. This reduces the number of customers who switch to other brands when a firm raises the price for its product.

INSIDE BUSINESS 7–3

The Evolution of Market Structure in the Computer Industry

Industries can change dramatically over time. During the course of its evolution, a given industry may go through phases that include monopoly, oligopoly, monopolistic competition, and perfect competition. For this reason, it is important to understand how to make decisions in all four environments, even if you "know" you will work for a monopoly when you graduate. The following description of the evolution in the computer industry should convince you of this fact.

In the 1960s, a few large firms produced mainframe computers for universities, scientific think tanks, and large business applications. Each computer was designed almost exclusively for a specific user, and its cost often was over $100,000. Because each computer kept its own standards, a customer whose computer needed repair was forced to go to the original manufacturer or write off the original purchase. This allowed the few companies that produced computers to act as virtual monopolists once they had a customer base. The early computer firms enjoyed high profit margins, some as high as 50 to 60 percent. These large profits induced several new firms to enter the computer market.

With entry came innovations in technology that reduced the size of mainframes, lowered the cost of production, and, because of increased competition, reduced the price to the customer. This influx of new competitors and products brought the market for computers into an oligopolistic-type structure. As a result, each firm became acutely aware of competitors and their actions. However, each firm held on to the specialized hardware and software for each user. Because of the specialized nature of the smaller machines, customers were still subject to their original purchases when it came to upgrades. However, since the price of the original machines was lower in the new environment, it was less costly to write off the original purchase and shift from one company to another. Of course, suppliers recognized this fact, which led to more vigorous competition. In the 1970s, the combination of lower prices and more competition decreased the returns in the market to 20 to 40 percent for the industry.

The 1980s brought the personal computer into many medium-sized businesses that previously could not afford a computer. Along with the PC came workstations and minicomputers. Although profit margins had dropped in the 1970s, they were still high enough in the 1980s to entice new entry. The computer market of the 1980s was moving toward monopolistic competition, with a few large firms and many small firms, each producing slightly different styles of computers. Computers became affordable to many households and smaller businesses. As more firms entered the market, profit margins dropped drastically and copycat firms began opening the systems; thus, many parts became interchangeable among machines. Economic profits still were being earned, but profit margins had dropped to around 10 to 20 percent.

During the 1990s, computer makers attempted to maintain margins by differentiating their products. This tactic was of limited success, as the open systems of the 1990s led to standardized technology at virtually all levels of the computer industry. By the early 2000s, many components of PCs had become "commodities" that were bought and sold in markets resembling those with perfect competition. As a consequence, there were few dimensions other than price for PC makers to use in differentiating their products. This heightened price competition in the 2000s significantly reduced the profits of computer manufacturers, including key players such as Dell and Gateway. By the end of the first decade of the twenty-first century, competitive strains have led some firms to abandon their "direct sales" approach in favor of distributing computers through popular retailers. The strain on profits has translated into exit and consolidation within the industry, which continues through the present day.

SOURCES: Statista, "Quarterly Market Share of Personal Computer (PC) Shipments Worldwide from 2011 to 2019, by Vendor," 2019; Roger Kay, "The PC Industry Is Digging Its Own Grave," *Forbes*, April 2013; "Gateway CEO Out after Profit Miss," *Ecommerce Times*, November 26, 2006; Simon Forge, "Why the Computer Industry Is Restructuring Now," *Futures* 23 (November 1991), pp. 960–77; annual reports of the companies.

Oligopoly

In an *oligopolistic* market, a few large firms tend to dominate the market. Firms in highly concentrated industries such as the airline, automobile, and aerospace industries operate in an oligopolistic market.

When one firm in an oligopolistic market changes its price or marketing strategy, not only its own profits but the profits of the other firms in the industry are affected. Consequently,

when one firm in an oligopoly changes its conduct, other firms in the industry have an incentive to react to the change by altering their own conduct. Thus, the distinguishing feature of an oligopolistic market is *mutual interdependence* among firms in the industry.

The interdependence of profits in an oligopoly gives rise to strategic interaction among firms. For example, suppose the manager of an oligopoly is considering increasing the price charged for the firm's product. To determine the impact of the price increase on profits, the manager must consider how rival firms in the industry will respond to the price increase. Thus, the strategic plans of one firm in an oligopoly depend on how that firm expects other firms in the industry to respond to the plans, if they are adopted. For this reason, it is very difficult to manage a firm that operates in an oligopoly. Because large rewards are paid to managers who know how to operate in oligopolistic markets, we will devote two chapters to an analysis of managerial decisions in such markets.

ANSWERING THE headLINE

Managers at T-Mobile and Sprint should have expected and been prepared for the merger to be heavily scrutinized by antitrust authorities given the high concentration of the market. As we learned in this chapter, the FTC and DOJ *Horizontal Merger Guidelines* suggest that U.S. antitrust authorities are more likely to challenge a merger when the relevant Herfindahl-Hirschman index is greater than 2,500 and the resulting increase in the index as a result of the merger is more than 200. Based on the reported market shares of the four largest firms in this industry, the Herfindahl-Hirschman index for the wireless subscription market was at least 2,796 before the proposed merger and would have increased to at least 3,244 after the merger. Thus, both firms should have anticipated that the Justice Department might attempt to block the merger, and prepared strong justifications to overcome the presumption that the merger would harm consumers. The firms proved prepared; after deep scrutiny by the DOJ (along with the FCC and even challenges by state antitrust authorities), the merger was ultimately approved and finalized nearly two years after its announcement.

SUMMARY

This chapter reveals that different industries have different market structures and require different types of managerial decisions. The structure of an industry, and therefore the job of the manager, is dependent on the number of firms in the industry, the structure of demand and costs, the availability of information, and the behavior of other firms in the industry.

The four-firm concentration ratio is one measure of market structure. If the ratio equals one, the industry is a monopoly or oligopoly; if it is zero, the industry is competitive. Another measure of market structure is the Herfindahl-Hirschman index (HHI), which can range from 10,000 for a monopoly to zero for a perfectly competitive industry. Of course, these indexes must be used in conjunction with other information, including whether the market is local and whether the firm competes with foreign firms.

Other summary statistics include the Lerner index, the Rothschild index, and the Dansby-Willig index. These indexes provide a manager information about industry cost and demand conditions. For instance, the greater the Lerner index in an industry, the greater the ability of a firm in the industry to charge a high markup on its product.

The data presented in this chapter reveal industrywide differences in activities such as advertising and research and development. The remainder of the book will explain why these differences exist and the optimal managerial decisions for alternative market structures. The next chapter begins with a study of managerial decisions under perfect competition, monopoly, and monopolistic competition.

KEY TERMS AND CONCEPTS

barrier to entry
causal view
concentration ratio
conduct
conglomerate merger
Dansby-Willig (DW) performance index
feedback critique
five forces framework
four-firm concentration ratio
Herfindahl-Hirschman index (HHI)
horizontal integration
horizontal merger
integration
Lerner index
market structure
monopolistic competition
monopoly
oligopoly
perfect competition
performance
Rothschild index
structure
structure–conduct–performance paradigm
vertical integration
vertical merger

CONCEPTUAL AND COMPUTATIONAL QUESTIONS

connect

connect Excel Exercises

1. Ten firms compete in a market to sell product *X*. The total sales of all firms selling the product are $3 million. Ranking the firms' sales from highest to lowest, we find the top four firms' sales to be $425,000, $385,000, $320,000, and $290,000, respectively. Calculate the four-firm concentration ratio in the market for product *X*. *(LO1)*
2. An industry consists of three firms with sales of $225,000, $45,000, and $315,000. *(LO3)*
   a. Calculate the Herfindahl-Hirschman index (HHI).
   b. Calculate the four-firm concentration ratio (C_4).
   c. Based on the FTC and DOJ *Horizontal Merger Guidelines* described in the text, do you think the Department of Justice would attempt to block a horizontal merger between two firms with sales of $225,000 and $315,000? Explain.
3. Suppose the own price elasticity of market demand for retail gasoline is −0.8, the Rothschild index is 0.5, and a typical gasoline retailer enjoys sales of $1.5 million annually. What is the price elasticity of demand for a representative gasoline retailer's product? *(LO1)*

connect Excel Exercises

4. A firm has $1.6 million in sales, a Lerner index of 0.55, and a marginal cost of $45, and competes against 1000 other firms in its relevant market. *(LO1)*
   a. What price does this firm charge its customers?
   b. By what factor does this firm mark up its price over marginal cost?
   c. Do you think this firm enjoys much market power? Explain.
5. Evaluate the following statement: "Managers should specialize by acquiring only the tools needed to operate in a particular market structure. That is, managers should specialize in managing either a perfectly competitive, monopoly, monopolistically competitive, or oligopoly firm." *(LO1)*
6. Under what conditions might the Justice Department approve a merger between two companies that operate in an industry with a premerger Herfindahl-Hirschman index of 2,900 if the postmerger index is expected to increase by 225? *(LO5)*
7. Based only on the knowledge that the premerger market share of two firms proposing to merge was 30 percent each, an economist working for the Justice Department was able to determine that, if approved, the postmerger HHI would increase by 1,800. How was the economist able to draw this conclusion without knowledge of the other firms' market shares? From this information, can you devise a general rule explaining how the Herfindahl-Hirschman index is affected when exactly two firms in the market merge? (*Hint:* Compare $a^2 + b^2$ with $[a + b]^2$.) *(LO3, LO4)*
8. Consider a firm that operates in a market that competes aggressively in prices. Due to the high fixed cost of obtaining the technology associated with entering this

market, only a limited number of other firms exist. Furthermore, over 70 percent of the products sold in this market are protected by patents for the next eight years. Does this industry conform to an economist's definition of a perfectly competitive market? *(LO3)*

9. Based on the information given, indicate whether the following industry is best characterized by the model of perfect competition, monopoly, monopolistic competition, or oligopoly. *(LO5)*
   a. Industry A has a four-firm concentration ratio of 0.005 percent and a Herfindahl-Hirschman index of 75. A representative firm has a Lerner index of 0.45 and a Rothschild index of 0.34.
   b. Industry B has a four-firm concentration ratio of 0.0001 percent and Herfindahl-Hirschman index of 55. A representative firm has a Lerner index of 0.0034 and Rothschild index of 0.00023.
   c. Industry C has a four-firm concentration ratio of 100 percent and Herfindahl-Hirschman index of 10,000. A representative firm has a Lerner index of 0.4 and Rothschild index of 1.0.
   d. Industry D has a four-firm concentration ratio of 100 percent and Herfindahl-Hirschman index of 5,573. A representative firm has a Lerner index equal to 0.43 and Rothschild index of 0.76.
10. The four-firm concentration ratios for industries X and Y are 81 percent and 74 percent, respectively, while the corresponding Herfindahl-Hirschman indexes are 3,100 and 1,600. The Dansby-Willig performance index for industry X is 0.7, while that for industry Y is 0.55. Based on this information, which would lead to the greater increase in social welfare: a slight increase in industry X's output or a slight increase in industry Y's output? *(LO5)*

PROBLEMS AND APPLICATIONS



11. You work at a firm on Wall Street that specializes in mergers, and you are the team leader in charge of getting approval for a merger between two major beer manufacturers in the United States. While Table 7–2 in the text indicates that the four-firm concentration ratio for all of the breweries operating in the United States is 90 percent, your team has put together a report suggesting that the merger does not present antitrust concerns even though the two firms each enjoys a 15 percent share of the U.S. market. Provide an outline of your report. *(LO1)*
12. Forey Inc. competes against many other firms in a highly competitive industry. Over the last decade, several firms have entered this industry and, as a consequence, Forey is earning a return on investment that roughly equals the interest rate. Furthermore, the four-firm concentration ratio and the Herfindahl-Hirschman index are both quite small, but the Rothschild index is significantly greater than zero. Based on this information, which market structure best characterizes the industry in which Forey competes? Explain. *(LO3, LO4)*
13. Firms like Papa John's, Domino's, and Pizza Hut sell pizza and other products that are differentiated in nature. While numerous pizza chains exist in most locations, the differentiated nature of these firms' products permits them to charge prices above marginal cost. Given these observations, is the pizza industry most likely a monopoly, perfectly competitive, monopolistically competitive, or an oligopoly industry? Use the causal view of structure, conduct, and performance to explain the role of differentiation in the market for pizza. Then apply the feedback critique to the role of differentiation in the industry. *(LO1, LO5)*

14. Which of the following would most likely be scrutinized under the FTC and DOJ *Horizontal Merger Guidelines*? *(LO4, LO5)*
    a. Two major players in Internet services and retailing—Amazon.com and eBay—merge.
    b. Cigarette maker Philip Morris merges with the Molson Coors Brewing Company.
    c. Lockheed Martin, a large firm that manufactures aircraft, merges with United States Steel.

15. Nationwide Bank has approached Hometown Bank with a proposal to merge. The following table lists the sales of the banks in the area. Use this information to calculate the four-firm concentration ratio and the Herfindahl-Hirschman index. Based on the FTC and DOJ *Horizontal Merger Guidelines*, do you think the Justice Department is likely to challenge the proposed merger? *(LO2)*

Bank Name	Sales (in millions)
MegaBank	$1,100
City Bank	950
Nationwide Bank	845
Atlantic Savings	785
Bulk Bank	665
Metropolitan Bank	480
American Bank	310
Hometown Bank	260
Urban Bank	140

16. Suppose Fiat recently entered into an Agreement and Plan of Merger with Case for $4.3 billion. Prior to the merger, the market for four-wheel-drive tractors consisted of five firms. The market was highly concentrated, with a Herfindahl-Hirschman index of 3,150. Case's share of that market was 12 percent, while Fiat comprised just 7 percent of the market. If approved, by how much would the postmerger Herfindahl-Hirschman index increase? Based only on this information, do you think the Justice Department would challenge the merger? Explain. *(LO3)*

17. Suppose your analytics team was able to estimate the own price elasticity of market demand, E_T, and the own price elasticity of demand for a representative firm's product, E_F, for two industries. For agriculture, your team estimates that $E_T = -1.8$ and $E_F = -96.2$. For communication and utilities, they find that $E_T = -1.2$ and $E_F = -1.8$. Use these estimated elasticities to calculate the Rothschild index for each industry. Based on these calculations, which industry most closely resembles perfect competition? Which industry most closely resembles monopoly? *(LO3)*

18. Recently, Pfizer and Allergan—the makers of Viagra and Botox, respectively—initiated a $160 billion merger. Pharmaceutical companies tend to spend a greater percentage of sales on R&D activities than other industries. The government encourages these R&D activities by granting companies patents for drugs approved by the Food and Drug Administration. For instance, Allergan spent large sums of money developing its popular wrinkle-removing neurotoxin, Botox, which is currently protected under a patent. Botox sells for about $15 per vial. Calculate the Lerner index if the marginal cost of producing Botox is $1.50 per vial. Does the Lerner index make sense in this situation? Explain. *(LO1, LO5)*

19. In 2006, the five leading suppliers of digital cameras in the United States were Canon, Sony, Kodak, Olympus, and Samsung. The combined market share of these five firms was 60.9 percent. The leading firm was Canon, with a market share of 18.7 percent. The own price elasticity for Canon's cameras was −4.0 and the market elasticity of demand was −1.6. Suppose that in 2006, the average retail price of a Canon digital camera was $240 and that Canon's marginal cost was $180 per camera. Based on this information, discuss industry concentration, demand and market conditions, and the pricing behavior of Canon in 2006. Do you think the industry environment is significantly different today? Explain. *(LO1, LO5)*

20. Del Monte has a long and rich tradition in the American food processing industry. It is perhaps best known for packaging canned fruits and vegetables. Part of its success has involved acquiring other brands of canned fruits and vegetables. Suppose that Del Monte is continuing its business plan of expansion by acquisition and that the following table summarizes potential acquisition targets. As the CEO's horizontal merger and acquisition advisor, it is your task to guide the decision-making process. Based only on the information contained in the table, is a horizontal merger with one of these companies likely to pass the U.S. government's scrutiny and enhance Del Monte's performance? Justify your conclusion. *(LO2, LO3)*

Company	Product Line	Profit as % of Sales	C_4	HHI	Rothschild Index	Lerner Index	Dansby-Willig Index
Unilever	Dove—personal care	5.2	24.1%	874	0.11	0.94	0.01
TricorBraun	Food-grade cans	6.8	32.7%	1,065	0.64	0.67	0.40
Goya	Canned tomatoes	7.1	86.3%	3,297	0.74	0.32	0.66
Dole	Canned pineapple	8.7	94.2%	5,457	0.76	0.14	0.72

21. In January 2007, XM enjoyed about 58 percent of satellite radio subscribers, and Sirius had the remaining 42 percent. Both firms were suffering losses, despite their dominance in the satellite radio market. In 2008, the DOJ decided not to challenge a merger, and these two firms united to become Sirius XM. If you were an economic consultant for Sirius, what economic arguments would you have presented to the DOJ to persuade it not to challenge the merger? Explain. *(LO3, LO4)*

22. Not long ago, the Federal Communications Commission (FCC) implemented "local number portability" rules allowing cellular phone consumers to switch cellular providers within the same geographic area and maintain the same phone number. How would you expect this change to affect the Rothschild index for the cellular service industry? *(LO1, LO4)*

23. As a manager in a new product market, you are interested in whether or not your competitors actually produce a close substitute for your product. Your analytics team has carefully collected data on prices and quantities for your product, as well as market-level prices and quantities across many different geographical regions. The data are contained in the file called *Q07-23.xls* (the first tab has data on your firm and the second tab has market-level data). Using these data, does it appear your product has many close substitutes? (*Hint:* Consider how to get an estimate of the Rothschild index.)

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Managing in Competitive, Monopolistic, and Monopolistically Competitive Markets

8

LEARNING OBJECTIVES

After completing this chapter, you will be able to:

- **LO1** Identify the conditions under which a firm operates as perfectly competitive, monopolistically competitive, or a monopoly.
- **LO2** Identify sources of (and strategies for obtaining) monopoly power.
- **LO3** Apply the marginal principle to determine the profit-maximizing price and output.
- **LO4** Show the relationship between the elasticity of demand for a firm's product and its marginal revenue.
- **LO5** Explain how long-run adjustments affect perfectly competitive, monopoly, and monopolistically competitive firms; discuss the ramifications of each of these market structures on social welfare.
- **LO6** Decide whether a firm making short-run losses should continue to operate or shut down its operations.
- **LO7** Illustrate the relationship among marginal cost, a competitive firm's short-run supply curve, and the competitive industry supply; explain why supply curves do not exist for firms that have market power.
- **LO8** Calculate the optimal output of a firm that operates two plants and the optimal level of advertising for a firm that enjoys market power.

headLINE

McDonald's New Buzz: Specialty Coffee

McDonald's unveiled plans to roll out McCafé in the United States—a premium line of coffee that includes cappuccino, latte, and iced mocha—in the midst of a recession. At the time, some analysts questioned whether it was the right time for McDonald's to roll out its line of new specialty drinks. However, McDonald's quickly saw a tripling of its share of U.S. coffee sales.

Why do you think McDonald's embarked on the program, and related, what do you think was the source of its success? Do you think this new product line will sustain

its impact on the company's bottom line? Can you think of other, similar strategies undertaken by McDonald's competitors that have successfully improved their bottom line, and if so, is there reason to think these strategies will have sustained impact? Explain.

SOURCES: J. Adamy, "McDonald's Coffee Strategy Is a Tough Sell," *The Wall Street Journal*, October 27, 2008; M. Brandau, "McDonald's McCafé: An Evolution," *Nation's Restaurant News*, August 16, 2011; www.mcdonalds.com/mccafe

INTRODUCTION

In Chapter 7, we examined the nature of industries and saw that industries differ with respect to their underlying structures, conduct, and performances. In this chapter, we characterize the optimal price, output, and advertising decisions of managers operating in environments of (1) perfect competition, (2) monopoly, and (3) monopolistic competition. We will analyze oligopoly decisions in Chapters 9 and 10, examine more sophisticated pricing strategies in Chapter 11, and examine more elaborate business strategies in Module Group A. With an understanding of the concepts presented in these chapters and modules, you will be equipped to manage a firm that operates in virtually any environment.

Because this is the beginning of our analysis of output decisions of managers operating in an industry, it is logical to start with the simplest case: a situation where managerial decisions have no perceptible impact on the market price. Thus, in the first section of this chapter, we will analyze output decisions of managers operating in perfectly competitive markets. In subsequent sections, we will examine output decisions by firms that have market power: monopoly and monopolistic competition. The analysis in this chapter will serve as a building block for the analyses in the remainder of the book.

PERFECT COMPETITION

perfectly competitive market
A market in which (1) there are many buyers and sellers, (2) each firm produces a homogeneous product, (3) buyers and sellers have perfect information, (4) there are no transaction costs, and (5) there is free entry and exit.

We begin our analysis by examining the output decisions of managers operating in **perfectly competitive markets**. The key conditions for *perfect competition* are as follows:

1. There are many buyers and sellers in the market, each of which is "small" relative to the market.
2. Each firm in the market produces a homogeneous (identical) product.
3. Buyers and sellers have perfect information.
4. There are no transaction costs.
5. There is free entry into and exit from the market.

Taken together, the first four assumptions imply that no single firm can influence the price of the product. The fact that there are many small firms, each selling an identical product, means that consumers view the products of all firms in the market as perfect substitutes. Because there is perfect information, consumers know the quality and price of each firm's product. There are no transaction costs (such as the cost of traveling to a store); if one firm charged a slightly higher price than the other firms, consumers would not shop at that firm but instead would purchase from a firm charging a lower price. Thus, in a perfectly competitive market all firms charge the same price for the good, and this price is determined by the interaction of all buyers and sellers in the market.

The assumption of *free entry* and *exit* simply implies that additional firms can enter the market if economic profits are being earned, and firms are free to leave the market if they are sustaining losses. As we will show later in this chapter, this assumption implies that in the long run, firms operating in a perfectly competitive market earn zero economic profits.

One classic example of a perfectly competitive market is agriculture. There are many farmers and ranchers, and each is so small relative to the market that he or she has no perceptible impact on the prices of corn, wheat, pork, or beef. Agricultural products tend to be homogeneous; there is little difference between corn produced by farmer Jones and corn produced by farmer Smith. The retail market for several types of computer hardware (i.e., the physical components of a computer, such as memory) also is close to perfect competition. A quick look at any price comparison site online reveals that there are many computer hardware retailers, each selling identical brands of computer hardware and charging a similar price for a given product. The reason there is so little price variation is that if one retailer charged a higher price than a competitor, consumers would purchase from another retailer.

Demand at the Market and Firm Levels

No single firm operating in a perfectly competitive market exerts any influence on price; price is determined by the interaction of all buyers and sellers in the market. The firm manager must charge this "market price" or consumers will purchase from a firm charging a lower price. Before we characterize the profit-maximizing output decisions of managers operating in perfectly competitive markets, it is important to explain more precisely the relation between the market demand for a product and the demand for a product produced by an individual perfectly competitive firm.

In a competitive market, price is determined by the intersection of the market supply and demand curves. Because the market supply and demand curves depend on all buyers and sellers, the market price is outside the control of a single perfectly competitive firm. In other words, because the individual firm is "small" relative to the market, it has no perceptible influence on the market price.

firm demand curve
The demand curve for an individual firm's product; in a perfectly competitive market, it is simply the market price.

Figure 8–1 illustrates the distinction between the market demand curve and the **firm demand curve** facing a perfectly competitive firm. The left-hand panel depicts the market, where the equilibrium price, P^e, is determined by the intersection of the market supply and demand curves. From the individual firm's point of view, the firm can sell as much as it

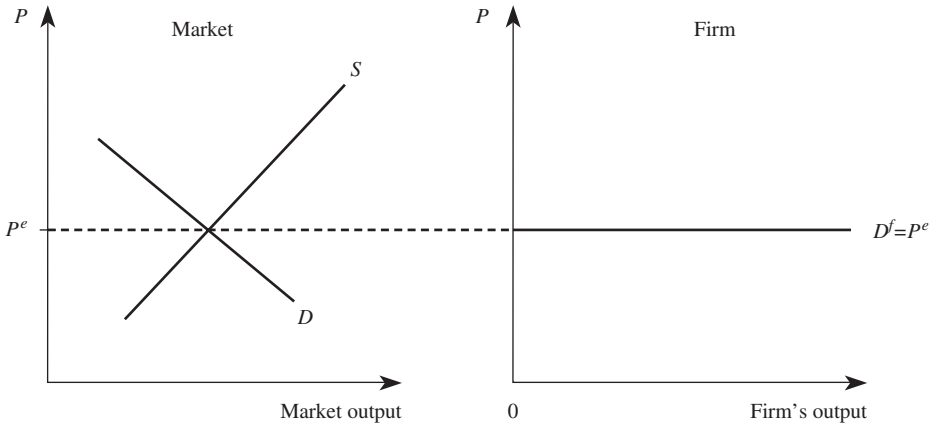


Figure 8–1
Demand at the Market and Firm Levels under Perfect Competition

wishes at a price of P^e; thus, the demand curve facing an individual perfectly competitive firm is given by the horizontal line in the right-hand panel, labeled D^f. The fact that the individual firm's demand curve is perfectly elastic reflects the fact that if the firm charged a price even slightly above the market price, it would sell nothing. Thus, in a perfectly competitive market, the demand curve for an individual firm's product is simply the market price.

Since the demand curve for an individual perfectly competitive firm's product is perfectly elastic, the pricing decision of the individual firm is trivial: Charge the price that every other firm in the industry charges. All that remains is to determine how much output should be produced to maximize profits.

Short-Run Output Decisions

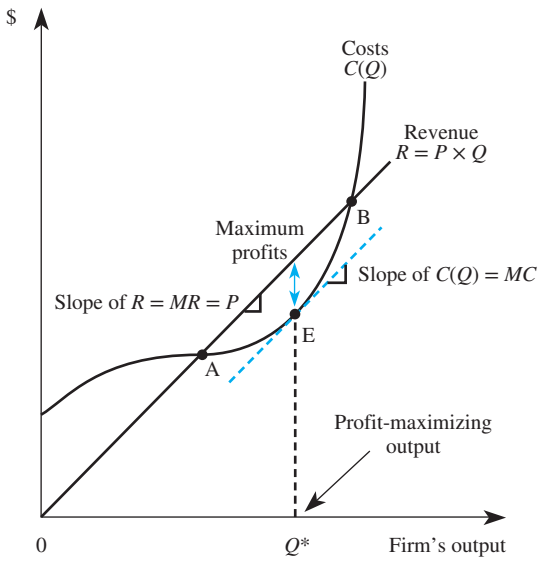
Recall that the short run is the period of time in which there are some fixed factors of production. For example, suppose a building is leased at a cost of $10,000 for a one-year period. In the short run (for one year) these costs are fixed, and they are paid regardless of whether the firm produces zero or one million units of output. In the long run (after the lease is up), this cost is variable; the firm can decide whether or not to renew the lease. To maximize profits in the short run, the manager must take as given the fixed inputs (and thus the fixed costs) and determine how much output to produce given the variable inputs that are within his or her control. The next subsection characterizes the profit-maximizing output decision of the manager of a perfectly competitive firm.

Maximizing Profits

Under perfect competition, the demand for an individual firm's product is the market price of output, which we denote P. If we let Q represent the output of the firm, the total revenue to the firm of producing Q units is $R = PQ$. Since each unit of output can be sold at the market price of P, each unit adds exactly P dollars to revenues. As Figure 8–2 illustrates, there is a linear relation between revenues and the output of a competitive firm. **Marginal revenue** is the change in revenue attributable to the last unit of output. Geometrically, it is the slope of the revenue curve. Expressed in economic terms, the marginal revenue for a competitive firm is the market price.

marginal revenue
The change in revenue attributable to the last unit of output; for a competitive firm, *MR* is the market price.

Figure 8–2
Revenue, Costs, and Profits for a Perfectly Competitive Firm



A CALCULUS ALTERNATIVE

Marginal revenue is the derivative of the revenue function. If revenues are a function of output,

$$R = R(Q)$$

then

$$MR = \frac{dR}{dQ}$$

Competitive Firm's Demand

The demand curve for a competitive firm's product is a horizontal line at the market price. This price is the competitive firm's marginal revenue.

PRINCIPLE

$$D^f = P = MR$$

A CALCULUS ALTERNATIVE

Marginal revenue is the derivative of the revenue function. For a perfectly competitive firm, revenue is

$$R = PQ$$

where P is the market equilibrium price. Thus,

$$MR = \frac{dR}{dQ} = P$$

The profits of a perfectly competitive firm are simply the difference between revenues and costs:

$$\pi = PQ - C(Q)$$

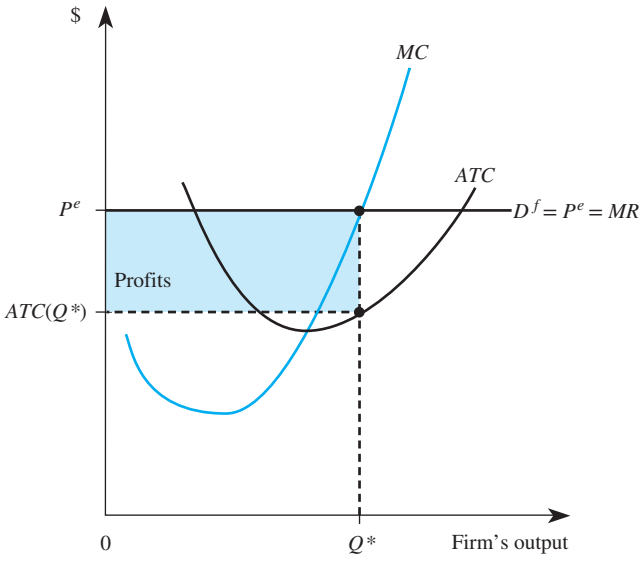
Geometrically, profits are given by the vertical distance between the cost function, labeled $C(Q)$ in Figure 8–2, and the revenue line. Note that for output levels to the left of point A, the cost curve lies above the revenue line, which implies that the firm would incur losses if it produced any output to the left of point A. The same is true of output levels to the right of point B.

For output levels between points A and B, the revenue line lies above the cost curve. This implies that these outputs generate positive levels of profit. The profit-maximizing level of output is the level at which the vertical distance between the revenue line and the cost curve is greatest. This is given by the output level Q^* in Figure 8–2.

There is a very important geometric property at the profit-maximizing level of output. As we see in Figure 8–2, the slope of the cost curve at the profit-maximizing level of output (point E) exactly equals the slope of the revenue line. Recall that the slope of the cost curve is marginal cost and the slope of the revenue line is marginal revenue. Therefore, the profit-maximizing output is the output at which marginal revenue equals marginal cost. Since marginal revenue is equal to the market price for a perfectly competitive firm, the manager must equate the market price with marginal cost to maximize profits.

Figure 8–3

Profit Maximization under Perfect Competition



An alternative way to express the competitive output rule is depicted in Figure 8–3, where standard average and marginal cost curves have been drawn. If the market price is given by P^e, this price intersects the marginal cost curve at an output of Q^*. Thus, Q^* represents the profit-maximizing level of output. For outputs below Q^*, price exceeds marginal cost. This implies that by expanding output, the firm can sell additional units at a price that exceeds the cost of producing the additional units. Thus, a profit-maximizing firm will not choose to produce output levels below Q^*. Similarly, output levels above Q^* correspond to the situation in which marginal cost exceeds price. In this instance, a reduction in output would reduce costs by more than it would reduce revenue. Thus, Q^* is the profit-maximizing level of output.

The shaded rectangle in Figure 8–3 represents the maximum profits of the firm. To see this, note that the area of the shaded rectangle is given by its base (Q^*) times the height $[P^e - ATC(Q^*)]$. Recall that $ATC(Q^*) = C(Q^*)/Q^*$; that is, average total cost is total cost divided by output. The area of the shaded rectangle is

$$Q^*\left[P^e - \frac{C(Q^*)}{Q^*}\right] = P^eQ^* - C(Q^*)$$

which is the definition of profits. Intuitively, $[P^e - ATC(Q^*)]$ represents the profits per unit produced. When this is multiplied by the profit-maximizing level of output (Q^*), the result is the amount of total profits earned by the firm.

PRINCIPLE

Competitive Output Rule

To maximize profits, a perfectly competitive firm produces the output at which price equals marginal cost in the range over which marginal cost is increasing:

$$P = MC(Q)$$

A CALCULUS ALTERNATIVE

The profits of a perfectly competitive firm are

$$\pi = PQ - C(Q)$$

The first-order condition for maximizing profits requires that the marginal profits be zero:

$$\frac{d\pi}{dQ} = P - \frac{dC(Q)}{dQ} = 0$$

Thus, we obtain the profit-maximizing rule for a firm in perfect competition:

$$P = \frac{dC}{dQ}$$

or

$$P = MC$$

DEMONSTRATION PROBLEM 8–1

Professional analysts have estimated a firm's cost function as

$$C(Q) = 5 + Q^2$$

If the firm sells output in a perfectly competitive market and other firms in the industry sell output at a price of $20, what price should the manager of this firm put on the product? What level of output should be produced to maximize profits? How much profit will be earned?

(*Hint:* Recall that for a cubic cost function

$$C(Q) = f + aQ + bQ^2 + cQ^3$$

the marginal cost function is

$$MC(Q) = a + 2bQ + 3cQ^2$$

Since $a = 0$, $b = 1$, and $c = 0$ for the cost function in this problem, we see that the marginal cost function for the firm is $MC(Q) = 2Q$.

ANSWER:

Since the firm competes in a perfectly competitive market, it must charge the same price other firms charge; thus, the manager should price the product at $20. To find the profit-maximizing output, we must equate price with marginal cost. This firm's marginal costs are $MC = 2Q$. Equating this with price yields

$$20 = 2Q$$

so the profit-maximizing level of output is 10 units. The maximum profits are thus

$$\pi = (20)\,(10) - (5 + 10^2) = 200 - 5 - 100 = \$95$$

Minimizing Losses

In the previous section, we demonstrated the optimal level of output to maximize profits. In some instances, short-run losses are inevitable. Here we analyze procedures for minimizing losses in the short run. If losses persist into the long run, the best thing for the firm to do is exit the industry.

INSIDE BUSINESS 8–1

Peugeot-Citroën of France: A Price-Taker in China's Auto Market

Competition in international markets is often more keen than in domestic markets. This is especially true in developing economies, where price rather than product differentiation is the main driver of consumer purchase decisions.

Consider, for instance, the French automaker PSA Peugeot-Citroën. In the mid-2000s, its Citroën division had a minuscule share of China's auto market—especially compared to the market share it enjoyed in France and Europe. In an interview regarding the Chinese market, one of its managers remarked, "If prices fall, we will also follow suit, but not by more than the decrease in the market." Another manager added, "This is a very competitive market . . . we have to think about the capacity at the factory."

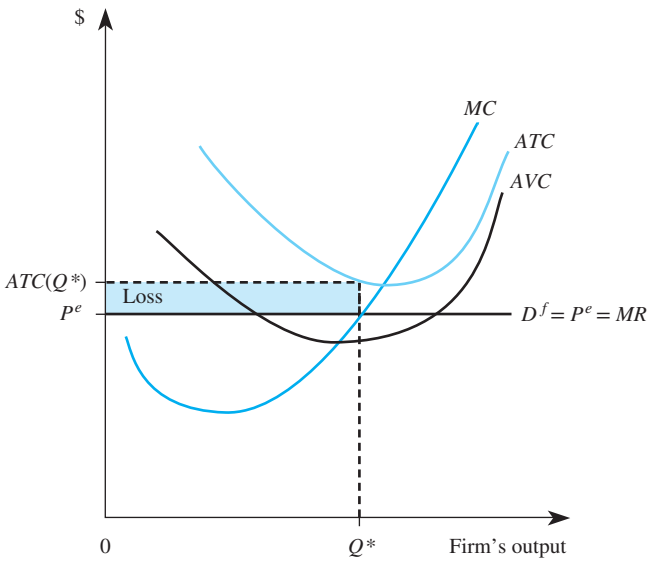
These remarks suggest that, in China, Citroën had very little control over price; in essence, it operated as a "price-taker" in the Chinese market for automobiles. As a price-taker, it had no incentive to price below the market price. Furthermore, Citroën would lose customers to other automakers if it attempted to charge a price premium in the developing Chinese market.

As a price-taker, Citroën's main decision was how many cars to produce at the market price. Managers in China had to ensure that the capacity at factories was sufficient for producing the optimal volume of cars. Citroën continues to face aggressive competition from other international firms as well as domestic Chinese firms. In light of the large capacities of GM and other automakers with operations in China, Peugeot-Citroën is likely to continue to have limited power over its price for many years to come.

SOURCES: "Citroën Forecasts Slowdown in Sales Growth in China This Year," *Channel News Asia*, June 9, 2004; "General Motors' China Success," *BusinessWeek*, January 8, 2006; "China: One of the Group's Regions of Development Priority," PSA Peugeot-Citroën website, December 2015; "China Auto Brands Vulnerable to Price Cuts, Group Says," *Bloomberg Businessweek*, June 2015.

Short-Run Operating Losses. Consider first a situation where there are some fixed costs of production. Suppose the market price, P^e, lies below the average total cost curve but above the average variable cost curve, as in Figure 8–4. In this instance, if the firm produces the output Q^*, where $P^e = MC$, a loss of the shaded area will result. However, since the price exceeds the average variable cost, each unit sold generates more revenue than the cost per unit

Figure 8–4
Loss Minimization



of the variable inputs. Thus, the firm should continue to produce in the short run, even though it is incurring losses.

Expressed differently, notice that the firm in Figure 8–4 has fixed costs that would have to be paid even if the firm decided to shut down its operation. Therefore, the firm would *not* earn zero economic profits if it shut down but would instead realize a loss equal to these fixed costs. Since the price in Figure 8–4 exceeds the average variable cost of producing Q^* units of output, the firm earns revenues on each unit sold that are more than enough to cover the variable cost of producing each unit. By producing Q^* units of output, the firm is able to put an amount of money into its cash drawer that exceeds the variable costs of producing these units and thus contributes toward the firm's payment of fixed costs. In short, while the firm in Figure 8–4 suffers a short-run loss by operating, this loss is less than the loss that would result if the firm completely shut down its operation.

The Decision to Shut Down. Now suppose the market price is so low that it lies below the average variable cost, as in Figure 8–5. If the firm produced Q^*, where $P^e = MC$ in the range of increasing marginal cost, it would incur a loss equal to the sum of the two shaded rectangles in Figure 8–5. In other words, for each unit sold, the firm would lose

$$ATC(Q^*) - P^e$$

When this per-unit loss is multiplied by Q^*, negative profits result that correspond to the sum of the two shaded rectangles in Figure 8–5.

Now suppose that instead of producing Q^* units of output, this firm decided to shut down its operation. In this instance, its losses would equal its fixed costs; that is, those costs that must be paid even if no output is produced. Geometrically, fixed costs are represented by the top rectangle in Figure 8–5 since the area of this rectangle is

$$[ATC(Q^*) - AVC(Q^*)]Q^*$$

which equals fixed costs. Thus, when price is less than the average variable cost of production, the firm loses less by shutting down its operation (and producing zero units) than it does by producing Q^* units. To summarize, we have demonstrated the following principle:

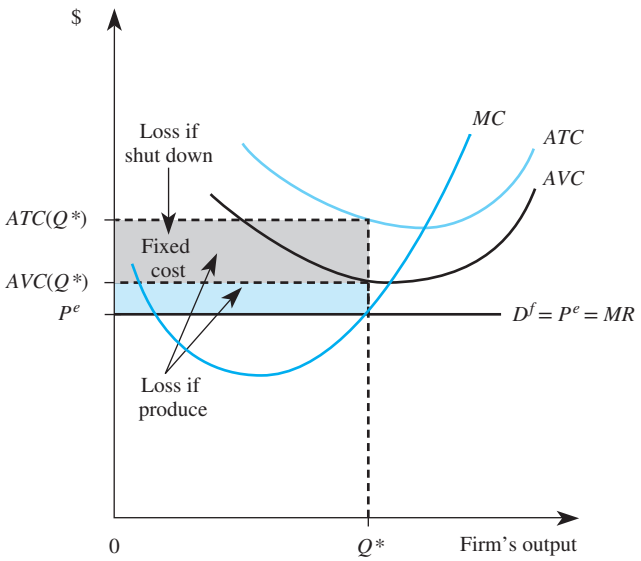


Figure 8–5
The Shut-Down Case

PRINCIPLE

Short-Run Output Decision under Perfect Competition

To maximize short-run profits, a perfectly competitive firm should produce in the range of increasing marginal cost where $P = MC$, provided that $P \geq AVC$. If $P < AVC$, the firm should shut down its plant to minimize its losses.

DEMONSTRATION PROBLEM 8–2

Suppose analysts have estimated a firm's cost function to be $C(Q) = 100 + Q^2$. If the firm sells output in a perfectly competitive market and other firms in the industry sell output at a price of \$10, what level of output should the firm produce to maximize profits or minimize losses? What will be the level of profits or losses if the firm makes the optimal decision?

ANSWER:

First, note that there are fixed costs of 100 and variable costs of Q^2, so the question deals with a short-run scenario. If the firm produces a positive level of output, it will produce where price equals marginal cost. The firm's marginal costs are $MC = 2Q$. Equating this with price yields $10 = 2Q$, or $Q = 5$ units. The average variable cost of producing 5 units of output is $AVC = 5^2/5 = 25/5 = 5$. Since $P \geq AVC$, the firm should produce 5 units in the short run. By producing 5 units of output, the firm incurs a loss of

$$\pi = (10)(5) - (100 + 5^2) = 50 - 100 - 25 = -\$75$$

which is less than the loss of \$100 (fixed costs) that would result if the firm shut down its plant in the short run.

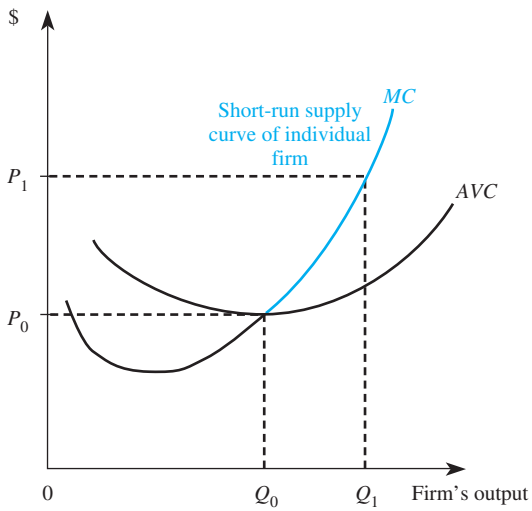
The Short-Run Firm and Industry Supply Curves

Now that you understand how perfectly competitive firms determine their output, we will examine how to derive firm and industry short-run supply curves.

Recall that the profit-maximizing perfectly competitive firm produces the output at which price equals marginal cost. For example, when the price is given by P_0 as in Figure 8–6, the

Figure 8–6

The Short-Run Supply Curve for a Competitive Firm



firm produces Q_0 units of output (the point where $P = MC$ in the range of increasing marginal cost). When the price is P_1, the firm produces Q_1 units of output. For prices between P_0 and P_1, output is determined by the intersection of price and marginal cost.

When the price falls below the *AVC* curve, however, the firm produces zero units because it does not cover the variable costs of production. Thus, to determine how much a perfectly competitive firm will produce at each price, we simply determine the output at which marginal cost equals that price. To ensure that the firm will produce a positive level of output, price must be above the average variable cost curve.

The Firm's Short-Run Supply Curve

The short-run supply curve for a perfectly competitive firm is its marginal cost curve above the minimum point on the *AVC* curve, as illustrated in Figure 8–6.

PRINCIPLE

The market (or industry) supply curve is closely related to the supply curve of individual firms in a perfectly competitive industry. Recall that the market supply curve reveals the total quantity that will be produced in the market at each possible price. Since the amount an individual firm will produce at a given price is determined by its marginal cost curve, the horizontal sum of the marginal costs of all firms determines how much total output will be produced at each price. More specifically, since each firm's supply curve is the firm's marginal cost curve above the minimum *AVC*, the market supply curve for a perfectly competitive industry is the horizontal sum of the individual marginal costs above their respective *AVC* curves.

Figure 8–7 illustrates the relation between an individual firm's supply curve (MC_i) and the market supply curve (S) for a perfectly competitive industry composed of 500 firms. When the price is $10, each firm produces zero units, and thus total industry output also is zero. When the price is $12, each firm produces 1 unit, so the total output produced by all 500 firms is 500 units. Notice that the industry supply curve is flatter than the supply curve of an individual firm and that the more firms in the industry, the farther to the right is the market supply curve.

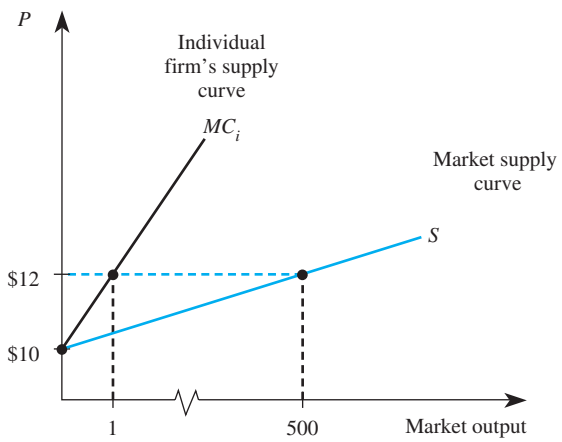
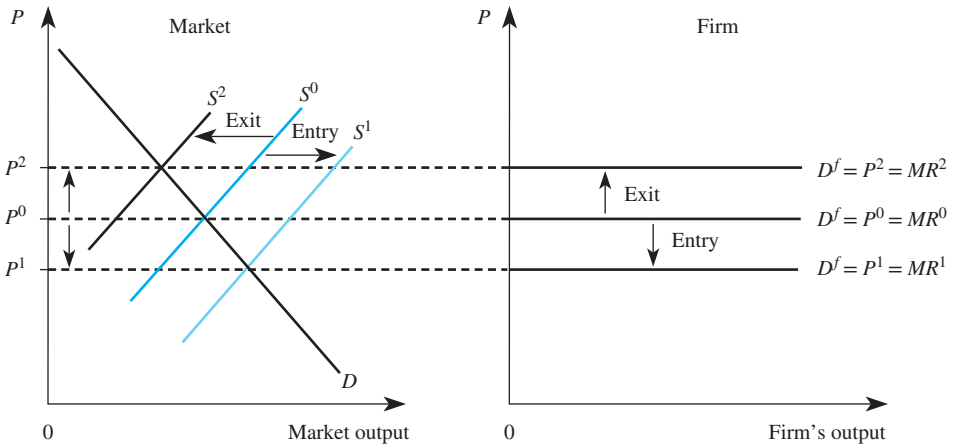


Figure 8–7
The Market Supply Curve

Figure 8–8
Entry and Exit: The Market and Firm's Demand



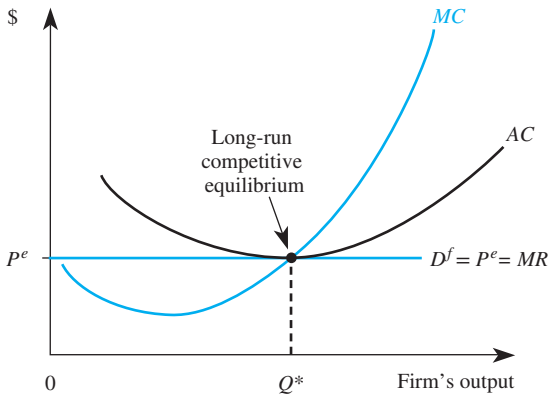
Long-Run Decisions

One important assumption underlying the theory of perfect competition is that of free entry and exit. If firms earn short-run economic profits, in the long run additional firms will enter the industry in an attempt to reap some of those profits. As more firms enter the industry, the industry supply curve shifts to the right. This is illustrated in Figure 8–8 as the shift from S^0 to S^1,which lowers the equilibrium market price from P^0 to P^1. This shifts down the demand curve for an individual firm's product, which in turn lowers its profits.

If firms in a competitive industry sustain short-run losses, in the long run they will exit the industry since they are not covering their opportunity costs. As firms exit the industry, the market supply curve decreases from S^0 in Figure 8–8 to S^2, thus increasing the market price from P^0 to P^2. This, in turn, shifts up the demand curve for an individual firm's product, which increases the profits of the firms remaining in the industry.

The process just described continues until ultimately the market price is such that all firms in the market earn zero economic profits. This is the case in Figure 8–9. At the price of P^e, each firm receives just enough to cover the average costs of production (*AC* is used because in the long run there is no distinction between fixed and variable costs), and economic profits are zero. If economic profits were positive, entry would occur and the market price would fall until the demand curve for an individual firm's product was just tangent to the *AC*

Figure 8–9
Long-Run Competitive Equilibrium



curve. If economic profits were negative, exit would occur, increasing the market price until the firm demand curve was tangent to the *AC* curve.

Long-Run Competitive Equilibrium
In the long run, perfectly competitive firms produce a level of output such that

1. $P = MC$
2. $P =$ minimum of AC

PRINCIPLE

These long-run properties of perfectly competitive markets have two important welfare implications. First, note that the market price is equal to the marginal cost of production. The market price reflects the value to society of an additional unit of output. This valuation is based on the preferences of all consumers in the market. Marginal cost reflects the cost to society of producing another unit of output. These costs represent the resources that would have to be taken from some other sector of the economy to produce more output in this industry.

To see why it is important, from a social perspective, that price equal marginal cost, suppose price exceeded marginal cost in equilibrium. This would imply that society would value another unit of output more than it would cost to produce another unit of output. If the industry produced at a level such that price exceeded the marginal cost of the last unit produced, it would thus be inefficient; social welfare would be improved by expanding output. Since in a competitive industry price equals marginal cost, the industry produces the socially efficient level of output.

The second thing to note about long-run competitive equilibrium is that price equals the minimum point on the average cost curve. This implies not only that firms are earning zero economic profits (i.e., just covering their opportunity costs) but also that all economies of scale have been exhausted. There is no way to produce the output at a lower average cost of production.

It is important to remember the distinction we made in Chapters 1 and 5 between economic profits and accounting profits. The fact that a firm in a perfectly competitive industry earns zero economic profits in the long run does not mean that accounting profits are zero; rather, zero economic profits implies that accounting profits are just high enough to offset any implicit costs of production. The firm earns no more, and no less, than it could earn by using the resources in some other capacity. This is why firms continue to produce in the long run even though their economic profits are zero.

MONOPOLY

In the previous section we characterized the optimal output decisions of firms that are small relative to the total market. In this context, *small* means the firms have no control whatsoever over the prices they charge for the product. In this section, we will consider the opposite extreme: monopoly. **Monopoly** refers to a situation where a single firm serves an entire market for a good for which there are no close substitutes.

monopoly
A market structure in which a single firm serves an entire market for a good that has no close substitutes.

Monopoly Power

In determining whether a market is characterized by monopoly, it is important to specify the relevant market for the product. For example, some utilities, such as electric or water

companies, are local monopolies in that only one utility offers service to a given neighborhood. Even though there may be similar companies serving other towns, they do not directly compete against one another for customers. The substitutes for electric services in a given city are poor and, short of moving to a different city, consumers must pay the price for local utility services or go without electricity. It is in this sense that a utility company may be a monopoly in the local market for utility services.

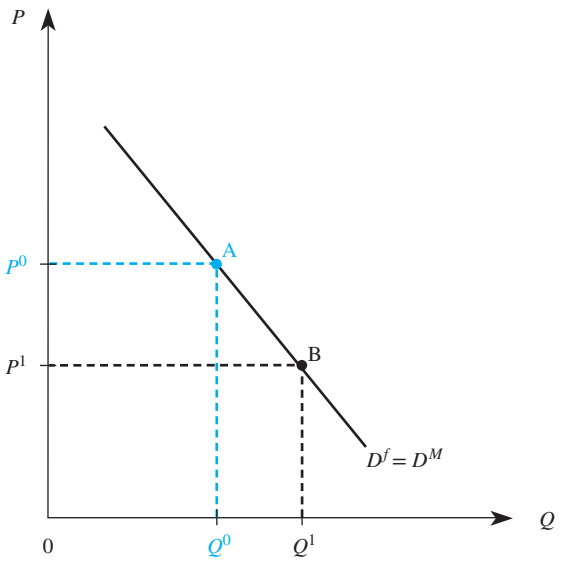
When one thinks of a monopoly, one usually envisions a very large firm. This needn't be the case, however; the relevant consideration is whether there are other firms selling close substitutes for the good in a given market. For example, a gas station located in a small town that is several hundred miles from another gas station is a monopolist in that town. In a large town there typically are many gas stations, and the market for gasoline is not characterized by monopoly.

The fact that a firm is the sole seller of a good in a market clearly gives that firm greater market power than it would have if it competed against other firms for consumers. Since there is only one producer in the market, the market demand curve is the demand curve for the monopolist's product. This is in contrast to the case of perfect competition, where the demand curve for an individual firm is perfectly elastic. A monopolist does not have unlimited power, however.

Figure 8–10 depicts the demand curve for a monopolist. Since all consumers in the market demand the good from the monopolist, the market demand curve, D^M, is the same as the demand for the firm's product, D^f. In the absence of legal restrictions, the monopolist is free to charge any price for the product. But this does not mean the firm can sell as much as it wants to at that price. Given the price set by the monopolist, consumers decide how much to purchase. For example, if the monopolist sets the relatively low price of P^1, the quantity demanded by consumers is Q^1. The monopolist can set a higher price of P^0, but there will be a lower quantity demanded of Q^0 at that price.

In summary, the monopolist is restricted by consumers to choose only those price–quantity combinations along the market demand curve. The monopolist can choose a price or a quantity, but not both. The monopolist can sell higher quantities only by lowering the price. If the price is too high, consumers may choose to buy nothing at all.

Figure 8–10
The Monopolist's Demand



Sources of Monopoly Power

The next issue we will address is how a firm obtains monopoly power, that is, why a monopolist has no competitors. There are four primary sources of monopoly power. One or more of these sources create a barrier to entry that prevents other firms from entering the market to compete against the monopolist.

Economies of Scale

The first source of monopoly power we will discuss is technological in nature. First, however, it is useful to recall some important terminology. **Economies of scale** exist whenever long-run average costs decline as output increases. **Diseconomies of scale** exist whenever long-run average costs increase as output increases. For many technologies, there is a range over which economies of scale exist and a range over which diseconomies exist. For example, in Figure 8–11 there are economies of scale for output levels below Q^* (since ATC is declining in this range) and diseconomies of scale for output levels above Q^* (since ATC is increasing in this range).

economies of scale
Exist whenever long-run average costs decline as output increases.

diseconomies of scale
Exist whenever long-run average costs increase as output increases.

Notice in Figure 8–11 that if the market were composed of a single firm that produced Q^M units, consumers would be willing to pay a price of P^M per unit for the Q^M units. Since $P^M > ATC(Q^M)$, the firm sells the goods at a price that is higher than the average cost of production and thus earns positive profits. Now suppose another firm entered the market and the two firms ended up sharing the market (each firm producing $Q^M/2$). The total quantity produced would be the same, and thus the price would remain at P^M. But with two firms, each producing only $Q^M/2$ units, each firm has an average total cost of $ATC(Q^M/2)$—a higher average total cost than when a single firm produced all the output. For example, in a market with overhead costs and two firms, each firm must incur these costs of production, and each can only spread the costs over half as much output as a monopolist. Also notice in Figure 8–11 that each firm's average cost is greater than P^M, which is the price consumers are willing to pay for the total Q^M units produced in the market. Having two firms in the industry leads to losses, but a single firm can earn positive profits because it has higher volume and enjoys

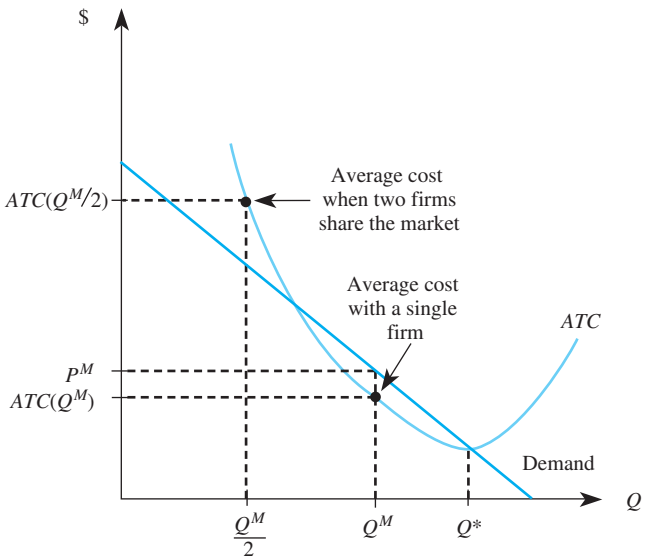


Figure 8–11
Economies of Scale and Minimum Prices

reduced average costs due to economies of scale. Thus, we see that economies of scale can lead to a situation where a single firm services the entire market for a good.

This analysis of economies of scale also reveals why it is so important to define the relevant market when determining whether or not a firm is a monopolist. As we noted earlier, a gas station may be a monopolist in a small town located several hundred miles from another gas station, whereas a gas station situated in a large city is unlikely to be a monopolist. In terms of Figure 8–11, the demand for gasoline in a small town typically is low relative to Q^*, which gives rise to economies of scale in the relevant range (outputs below Q^*). In large cities the demand for gasoline is large relative to Q^*, which makes it possible for several gas stations to coexist in the market.

Economies of Scope

economies of scope
Exist when the total cost of producing two products within the same firm is lower than when the products are produced by separate firms.

Recall that **economies of scope** exist when the total cost of producing two products within the same firm is lower than when the products are produced by separate firms, that is, when it is cheaper to produce outputs Q_1 and Q_2 jointly. Pharmaceutical companies often enjoy economies of scope in their development of new drugs; breakthroughs in developing a product that cures one disease may reduce the cost of developing additional products that cure other illnesses.

In the presence of economies of scope, efficient production requires that a firm produce several products jointly. While multiproduct firms do not necessarily have more market power than firms producing a single product, economies of scope tend to encourage "larger" firms. In turn, this may provide greater access to capital markets, where working capital and funds for investment are obtained. To the extent that smaller firms have more difficulty obtaining funds than do larger firms, the higher cost of capital may serve as a barrier to entry. In extreme cases, economies of scope can lead to monopoly power.

Cost Complementarity

cost complementarities
Exist when the marginal cost of producing one output is reduced when the output of another product is increased.

Cost complementarities exist in a multiproduct cost function when the marginal cost of producing one output is reduced when the output of another product is increased; that is, when an increase in the output of product 2 decreases the marginal cost of producing output 1. A simple example of a multiproduct cost function with cost complementarities involves the production of doughnuts and doughnut holes.

Multiproduct firms that enjoy cost complementarities tend to have lower marginal costs than firms producing a single product. This gives multiproduct firms a cost advantage over single-product firms. Thus, in the presence of cost complementarities, firms must produce several products to be able to compete against the firm with lower marginal costs. To the extent that greater capital requirements exist for multiproduct firms than for single-product firms, this requirement can limit the ability of small firms to enter the market. In extreme cases, monopoly power can result.

Patents and Other Legal Barriers

The sources of monopoly power just described are technological in nature. In some instances, government may grant an individual or a firm a monopoly right. For example, a city may prevent another utility company from competing against the local utility company. Another example is the potential monopoly power generated by the *patent* system.

The patent system gives the inventor of a new product the exclusive right to sell the product for a given period of time (see Inside Business 8–2). The rationale behind granting monopoly power to a new inventor is based on the following argument: Inventions take many years and considerable sums of money to develop. Once an invention becomes public

information, in the absence of a patent system, other firms could produce the product and compete against the individual or firm that developed it. Since these firms do not have to expend resources developing the product, they would make higher profits than the original developer. In the absence of a patent system, there would be a reduced incentive on the part of firms to develop new technologies and products.

It is important to stress that patents rarely lead to absolute monopoly because competitors are often quick to develop similar products or technologies in order to get a piece of the action. Furthermore, several firms taking different R&D paths may each obtain a patent for a product that is a close substitute for other patented products. For example, the two best-selling erectile dysfunction medications—Pfizer's Viagra and Eli Lilly's Cialis—are competitors even though both have "enjoyed" patents. For these reasons, managers enjoying patent protection are by no means immune from competitive pressures.

Maximizing Profits

Now that you know what monopoly power is and the factors that lead to monopoly power, we will see how the manager of a monopoly may exploit this power to maximize profits. In particular, in this section we presume that the manager is in charge of a firm that is a monopoly. Our goal is to characterize the price and output decisions that maximize the monopolist's profits.

Marginal Revenue

Suppose the monopolist faces a demand curve for its product such as the one in Figure 8–12(a). In Chapter 3, we learned that a linear demand curve is elastic at high prices and inelastic at

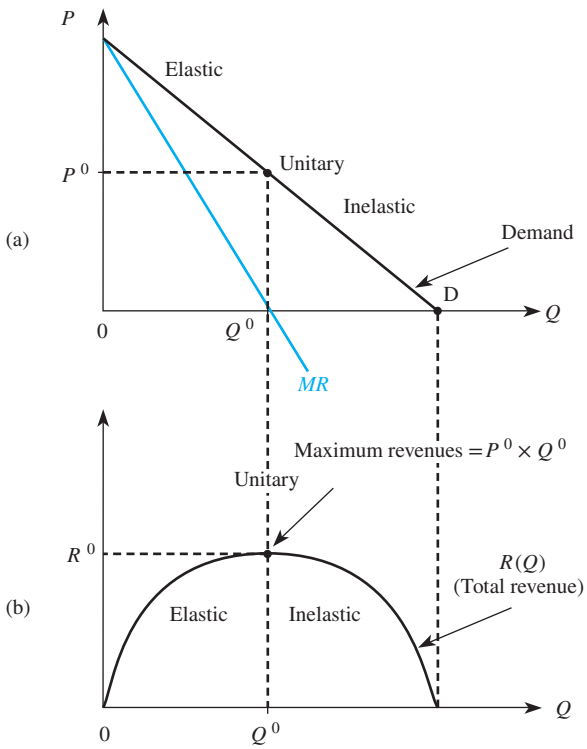


Figure 8–12
Elasticity of Demand and Total Revenues

low prices. If the monopolist produces zero units of output, its revenues are zero. As output is increased above zero, demand is elastic and the increase in output (which implies a lower price) leads to an increase in total revenue, as shown in Figure 8–12(b). This follows from the total revenue test. As output is increased beyond Q^0 into the inelastic region of demand, further increases in output actually decrease total revenue, until at point D the price is zero and revenues are again zero. This is depicted in Figure 8–12(b). Thus, total revenue is maximized at an output of Q^0 in Figure 8–12(b). This corresponds to the price of P^0 in Figure 8–12(a), where demand is unitary elastic.

The line labeled *MR* in Figure 8–12(a) is the marginal revenue schedule for the monopolist. Recall that marginal revenue is the change in total revenue attributable to the last unit of output; geometrically, it is the slope of the total revenue curve. As Figure 8–12(a) shows, the marginal revenue schedule for a monopolist lies below the demand curve; in fact, for a linear demand curve, the marginal revenue schedule lies exactly halfway between the demand curve and the vertical axis. This means that for a monopolist, marginal revenue is less than the price charged for the good.

There are two ways to understand why the marginal revenue schedule lies below the monopolist's demand curve. Consider first a geometric explanation. Marginal revenue is the slope of the total revenue curve [$R(Q)$] in Figure 8–12(b). As output increases from zero to Q^0, the slope of the total revenue curve decreases until it becomes zero at Q^0. Over this range, marginal revenue decreases until it reaches zero when output is Q^0. As output expands beyond Q^0, the slope of the total revenue curve becomes negative and gets increasingly negative as output continues to expand. This means that marginal revenue is negative for outputs in excess of Q^0.

Formula: Monopolist's Marginal Revenue. The marginal revenue of a monopolist is given by the formula

$$MR = P\left[\frac{1+E}{E}\right]$$

where E is the elasticity of demand for the monopolist's product and P is the price charged for the product.

INSIDE BUSINESS 8–2

Patent, Trademark, and Copyright Protection

The United States grants inventors three types of patent protection: utility, design, and plant patents. A "utility patent" protects the way an invention is used and works, while a "design patent" protects the way an invention looks. A "plant patent" protects an inventor who has discovered and asexually reproduced a distinct and new variety of plant (excluding tuber propagated plants or plants found in uncultivated states). Utility and plant patents provide 20 years of protection, while design patents last 14 years.

Trademarks are different from patents in that they protect words, names, symbols, or images that are used in connection with goods or services. Similarly, a copyright protects a creator's form of expression (including literary, dramatic, musical, and artistic works). Patents and trademarks are administered through the U.S. Patent and Trademark Office, while the U.S. Copyright Office handles copyrights.

SOURCES: United States Patent and Trademark Office; United States Copyright Office.

A CALCULUS ALTERNATIVE

The monopolist's revenue is

$$R(Q) = P(Q)\,Q$$

Taking the derivative with respect to Q yields

$$\begin{aligned}\frac{dR}{dQ} &= \frac{dP}{dQ}\,Q + P \\ &= P\left[\left(\frac{dP}{dQ}\right)\left(\frac{Q}{P}\right) + 1\right] \\ &= P\left[\frac{1}{E} + 1\right] \\ &= P\left[\frac{1+E}{E}\right]\end{aligned}$$

where E is the elasticity of demand. Since $dR/dQ = MR$, this means that

$$MR = P\left[\frac{1+E}{E}\right]$$

DEMONSTRATION PROBLEM 8–3

Show that if demand is elastic (say, $E = -2$), marginal revenue is positive but less than price. Show that if demand is unitary elastic ($E = -1$), marginal revenue is zero. Finally, show that if demand is inelastic (say, $E = -0.5$), marginal revenue is negative.

ANSWER:

Setting $E = -2$ in the marginal revenue formula yields

$$MR = P\left[\frac{1-2}{-2}\right] = \frac{-1}{-2}\,P$$

so $MR = 0.5P$. Thus, when demand is elastic, marginal revenue is positive but less than price (in this example, marginal revenue is one-half of the price).

Setting $E = -1$ in the marginal revenue formula yields

$$MR = P\left[\frac{1-1}{-1}\right] = 0$$

so $MR = 0$. Thus, when demand is unitary elastic, marginal revenue is zero.

Finally, setting $E = -0.5$ in the marginal revenue formula yields

$$MR = P\left[\frac{1-.5}{-.5}\right] = P\left[\frac{.5}{-.5}\right] = -P$$

so $MR = -P$. Thus, when demand is inelastic, marginal revenue is negative and less than price (in this example, marginal revenue is the negative of the price).

An alternative explanation for why marginal revenue is less than price for a monopolist is as follows: Suppose a monopolist sells one unit of output at a price of $4 per unit, for a total revenue of $4. What happens to revenue if the monopolist produces one more unit of output? Revenue increases by less than $4. To see why, note that the monopolist can sell one more unit

of output only by lowering price, say, from \$4 to \$3 per unit. But the price reduction necessary to sell one more unit lowers the price received on the first unit from \$4 to \$3. The total revenue associated with two units of output thus is \$6. The change in revenue due to producing one more unit is therefore \$2, which is less than the price charged for the product.

Since the price a monopolist can charge for the product depends on how much is produced, let $P(Q)$ represent the price per unit paid by consumers for Q units of output. This relation summarizes the same information as a demand curve, but because price is expressed as a function of quantity instead of the other way around, it is called an *inverse demand function*. The inverse demand function, denoted $P(Q)$, indicates the price per unit as a function of the firm's output. The most common inverse demand function is the linear inverse demand function. The *linear inverse demand function* is given by

$$P(Q) = a + bQ$$

where a is a number greater than zero and b is a number less than zero.

In addition to the general formula for marginal revenue that is valid for all demand functions, it is useful to have the following formula for marginal revenue, which is valid for the special case of a linear inverse demand function.

Formula: MR for Linear Inverse Demand. For the linear inverse demand function, $P(Q) = a + bQ$, marginal revenue is given by

$$MR = a + 2bQ$$

A CALCULUS ALTERNATIVE

With a linear inverse demand function, the revenue function is

$$R(Q) = (a + bQ)\,Q$$

Marginal revenue is

$$MR = \frac{dR}{dQ} = a + 2bQ$$

DEMONSTRATION PROBLEM 8–4

Suppose the inverse demand function for a monopolist's product is given by

$$P = 10 - 2Q$$

What is the maximum price per unit a monopolist can charge to be able to sell 3 units? What is marginal revenue when $Q = 3$?

ANSWER:

First, we set $Q = 3$ in the inverse demand function (here $a = 10$ and $b = -2$) to get

$$P = 10 - 2(3) = 4$$

Thus, the maximum price per unit the monopolist can charge to be able to sell 3 units is \$4. To find marginal revenue when $Q = 3$, we set $Q = 3$ in the marginal revenue formula for linear inverse demand to get

$$MR = 10 - [(2)(2)(3)] = -2$$

The Output Decision

Revenues are one determinant of profits; costs are the other. Since the revenue a monopolist receives from selling Q units is $R(Q) = Q[P(Q)]$, the profits of a monopolist with a cost function of $C(Q)$ are

$$\pi = R(Q) - C(Q)$$

Typical revenue and cost functions are graphed in Figure 8–13(a). The vertical distance between the revenue and cost functions in panel (a) reflects the profits to the monopolist of alternative levels of output. Output levels below point A and above point B imply losses since the cost curve lies above the revenue curve. For output levels between points A and B, the revenue function lies above the cost function, and profits are positive for those output levels.

Figure 8–13(b) depicts the profit function, which is the difference between R and C in panel (a). As Figure 8–13(a) shows, profits are greatest at an output of Q^M, where the vertical distance between the revenue and cost functions is the greatest. This corresponds to the maximum profit point in panel (b). A very important property of the profit-maximizing level of output (Q^M) is that the slope of the revenue function in panel (a) equals the slope of the cost function. In economic terms, marginal revenue equals marginal cost at an output of Q^M.

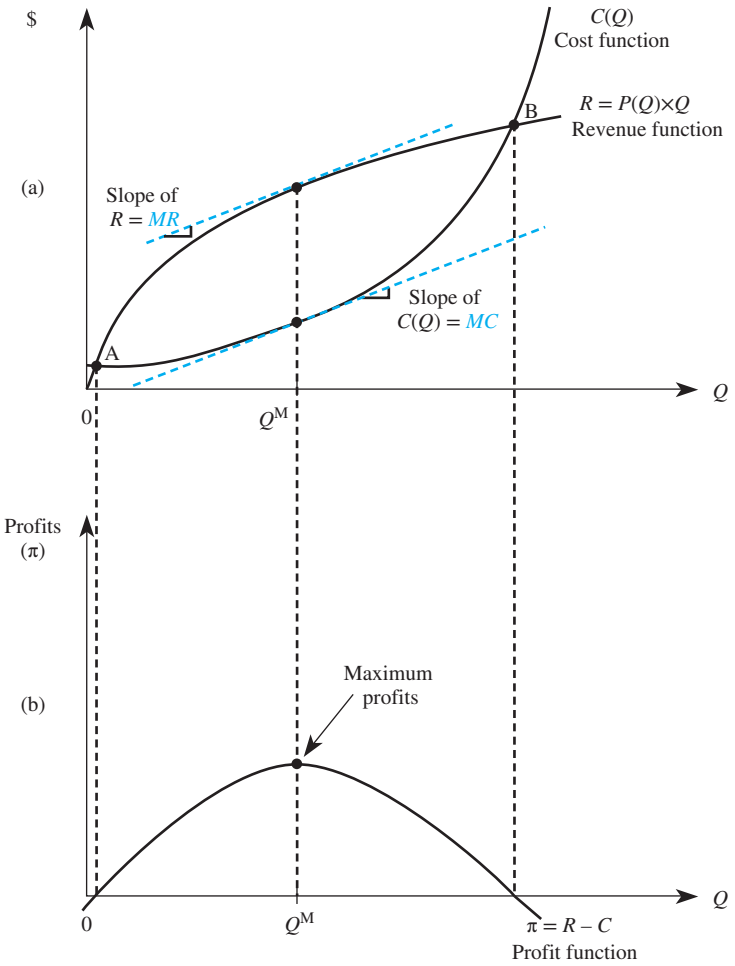


Figure 8–13
Costs, Revenues, and Profits under Monopoly

PRINCIPLE

Monopoly Output Rule

A profit-maximizing monopolist should produce the output Q^M such that marginal revenue equals marginal cost:

$$MR(Q^M) = MC(Q^M)$$

A CALCULUS ALTERNATIVE

The profits for a monopolist are

$$\pi = R(Q) - C(Q)$$

where $R(Q)$ is total revenue. To maximize profits, marginal profits must be zero:

$$\frac{d\pi}{dQ} = \frac{dR(Q)}{dQ} - \frac{dC(Q)}{dQ} = 0$$

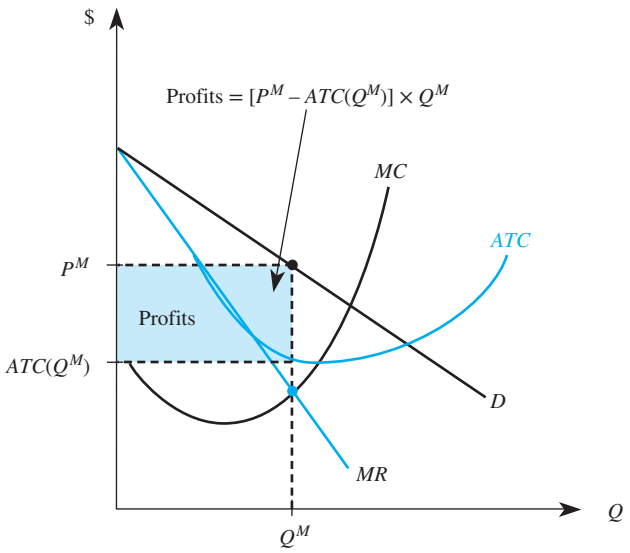
or

$$MR = MC$$

The economic intuition behind this important rule is as follows: If marginal revenue was greater than marginal cost, an increase in output would increase revenues more than it would increase costs. Thus, a profit-maximizing manager of a monopoly should continue to expand output when $MR > MC$. On the other hand, if marginal cost exceeded marginal revenue, a reduction in output would reduce costs by more than it would reduce revenue. A profit-maximizing manager thus is motivated to produce where marginal revenue equals marginal cost.

An alternative characterization of the profit-maximizing output decision of a monopoly is presented in Figure 8–14. The marginal revenue curve intersects the marginal cost curve when Q^M units are produced, so the profit-maximizing level of output is Q^M. The maximum price per unit that consumers are willing to pay for Q^M units is P^M, so the profit-maximizing price is P^M. Monopoly profits are given by the shaded rectangle in the figure, which is the base (Q^M) times the height [$P^M - ATC(Q^M)$].

Figure 8–14
Profit Maximization under Monopoly



Monopoly Pricing Rule

Given the level of output, Q^M, that maximizes profits, the monopoly price is the price on the demand curve corresponding to the Q^M units produced:

$$P^M = P(Q^M)$$

PRINCIPLE

DEMONSTRATION PROBLEM 8–5

For a video walkthrough of this problem, visit www.mhhe.com/baye10e

Suppose a monopolist's analytics team estimated its demand function as

$$P = 100 - 2Q$$

and the cost function is estimated as

$$C(Q) = 10 + 2Q$$

Determine the profit-maximizing price and quantity and the maximum profits.

ANSWER:

Using the marginal revenue formula for linear inverse demand and the formula for marginal cost, we see that

$$MR = 100 - (2)(2)(Q) = 100 - 4Q$$
$$MC = 2$$

Next, we set $MR = MC$ to find the profit-maximizing level of output:

$$100 - 4Q = 2$$

or

$$4Q = 98$$

Solving for Q yields the profit-maximizing output of $Q^M = 24.5$ units. We find the profit-maximizing price by setting $Q = Q^M$ in the inverse demand function:

$$P = 100 - 2(24.5) = 51$$

Thus, the profit-maximizing price is \$51 per unit. Finally, profits are given by the difference between revenues and costs:

$$\begin{aligned}\pi &= P^M Q^M - C(Q^M) \\ &= (51)(24.5) - [10 + 2(24.5)] \\ &= \$1{,}190.50\end{aligned}$$

The Absence of a Supply Curve

Recall that a supply curve determines how much will be produced at a given price. Since perfectly competitive firms determine how much output to produce based on price ($P = MC$), supply curves exist in perfectly competitive markets. In contrast, a monopolist determines how much to produce based on marginal revenue, which is less than price ($P > MR = MC$). This is because a change in quantity by a monopolist actually changes the market price. Consequently, there is no way to express how a monopolist's quantity choice would change for different given prices, so there is no supply curve for a monopolist. In fact, there is no supply curve in markets served by firms with market power, such as monopolistic competition, which we discuss in the next section.

Multiplant Decisions

Up until this point, we have assumed that the monopolist produces output at a single location. In many instances, however, a monopolist has different plants at different locations. An important issue for the manager of such a *multiplant monopoly* is the determination of how much output to produce at each plant.

Suppose the monopolist produces output at two plants. The cost of producing Q_1 units at plant 1 is $C_1(Q_1)$, and the cost of producing Q_2 units at plant 2 is $C_2(Q_2)$. Further, suppose the products produced at the two plants are identical, so the price per unit consumers are willing to pay for the total output produced at the two plants is $P(Q)$, where

$$Q = Q_1 + Q_2$$

Profit maximization implies that the two-plant monopolist should produce output in each plant such that the marginal cost of producing in each plant equals the marginal revenue of total output.

PRINCIPLE

Multiplant Output Rule

Let $MR(Q)$ be the marginal revenue of producing a total of $Q = Q_1 + Q_2$ units of output. Suppose the marginal cost of producing Q_1 units of output in plant 1 is $MC_1(Q_1)$ and that of producing Q_2 units in plant 2 is $MC_2(Q_2)$. The profit maximization rule for the two-plant monopolist is to allocate output among the two plants such that

$$MR(Q) = MC_1(Q_1)$$
$$MR(Q) = MC_2(Q_2)$$

A CALCULUS ALTERNATIVE

If profits are

$$\pi = R(Q_1 + Q_2) - C_1(Q_1) - C_2(Q_2)$$

the first-order conditions for maximizing profits are

$$\frac{d\pi}{dQ_1} = \frac{dR(Q_1 + Q_2)}{dQ_1} - \frac{dC_1(Q_1)}{dQ_1} = 0$$
$$\frac{d\pi}{dQ_2} = \frac{dR(Q_1 + Q_2)}{dQ_2} - \frac{dC_2(Q_2)}{dQ_2} = 0$$

The economic intuition underlying the multiplant output rule is precisely the same as all of the profit maximization principles. If the marginal revenue of producing output in a plant exceeds the marginal cost, the firm will add more to revenue than to cost by expanding output in the plant. As output is expanded, marginal revenue declines until it ultimately equals the marginal cost of producing in the plant.

The conditions for maximizing profits in a multiplant setting imply that

$$MC_1(Q_1) = MC_2(Q_2)$$

This too has a simple economic explanation. If the marginal cost of producing in plant 1 is lower than that of producing in plant 2, the monopolist could reduce costs by producing more output in plant 1 and less in plant 2. As more output is produced in plant 1, the marginal cost of producing in the plant increases until it ultimately equals the marginal cost of producing in plant 2.

DEMONSTRATION PROBLEM 8–6

Suppose a monopolist's analytics team estimated inverse demand as

$$P(Q) = 70 - .5Q$$

The monopolist can produce output in two plants. The marginal cost of producing in plant 1 is $MC_1 = 3Q_1$, and the marginal cost of producing in plant 2 is $MC_2 = Q_2$. How much output should be produced in each plant to maximize profits, and what price should be charged for the product?

ANSWER:

To maximize profits, the firm should produce output in the two plants such that

$$MR(Q) = MC_1(Q_1)$$
$$MR(Q) = MC_2(Q_2)$$

In this instance, marginal revenue is given by

$$MR(Q) = 70 - Q$$

where $Q = Q_1 + Q_2$. Substituting these values into the formula for the multiplant output rule, we get

$$70 - (Q_1 + Q_2) = 3Q_1$$
$$70 - (Q_1 + Q_2) = Q_2$$

Thus, we have two equations and two unknowns, and we must solve for the two unknowns. The first equation implies that

$$Q_2 = 70 - 4Q_1$$

Substituting this into the second equation yields

$$70 - (Q_1 + 70 - 4Q_1) = 70 - 4Q_1$$

Solving this equation, we find that $Q_1 = 10$. Next, we substitute this value of Q_1 into the first equation:

$$70 - (10 + Q_2) = 3(10)$$

Solving this equation, we find that $Q_2 = 30$. Thus, the firm should produce 10 units in plant 1 and 30 units in plant 2 for a total output of $Q = 40$ units.

To find the profit-maximizing price, we must find the maximum price per unit that consumers will pay for 40 units of output. To do this, we set $Q = 40$ in the inverse demand function:

$$P = 70 - .5(40) = 50$$

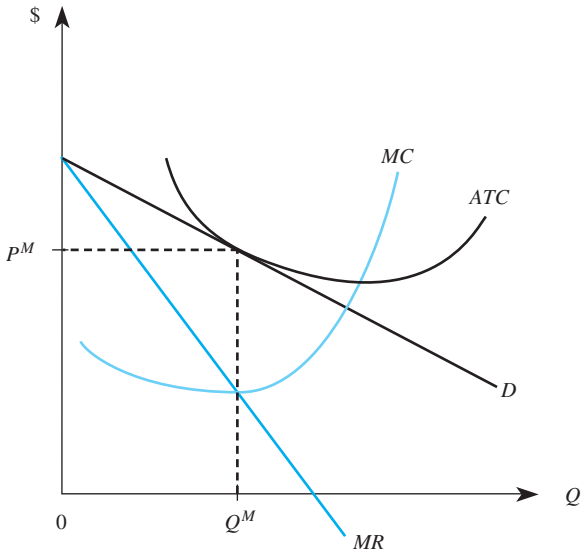
Thus, the profit-maximizing price is $50.

Implications of Entry Barriers

Our analysis of monopoly reveals that a monopolist may earn positive economic profits. If a monopolist is earning positive economic profits, the presence of barriers to entry prevents other firms from entering the market to reap a portion of those profits. Thus, monopoly profits, if they exist, will continue over time so long as the firm maintains its monopoly power. It is important to note, however, that the presence of monopoly power does not imply positive profits; it depends solely on where the demand curve lies in relation to the average total cost curve. For example, the monopolist depicted in Figure 8–15 earns zero economic profits

Figure 8–15

A Monopolist Earning Zero Profits



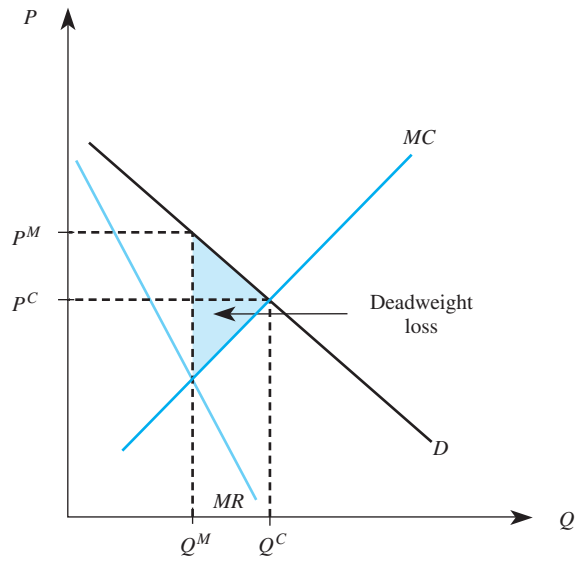
because the optimal price exactly equals the average total cost of production. Moreover, in the short run a monopolist may even experience losses.

The monopoly power a monopolist enjoys often implies some social costs to society. Consider, for example, the monopolist's demand, marginal revenue, and marginal cost curves graphed in Figure 8–16. For simplicity, these curves are graphed as linear functions of output, and the position of the average cost curve is suppressed for now. The profit-maximizing monopolist produces Q^M units of output and charges a price of P^M.

The first thing to notice about monopoly is that price exceeds the marginal cost of production: $P^M > MC$. The price in a market reflects the value to society of another unit of output. Marginal cost reflects the cost to society of the resources needed to produce an additional unit of output. Since price exceeds marginal cost, the monopolist produces less output than is

Figure 8–16

Deadweight Loss of Monopoly



socially desirable. In effect, society would be willing to pay more for one more unit of output than it would cost to produce the unit. Yet the monopolist refuses to do so because it would reduce the firm's profits. This is because marginal revenue for a monopolist lies below the demand curve, and thus $MR < MC$ at this level of output.

In contrast, given the same demand and cost conditions, a firm in a perfectly competitive industry would continue to produce output up to the point where price equals marginal cost; this corresponds to an industry output and price of Q^C and P^C under perfect competition. Thus, the monopolist produces less output and charges a higher price than would a perfectly competitive industry. The shaded area in Figure 8–16 represents the **deadweight loss of monopoly**, that is, the welfare loss to society due to the monopolist producing output below the competitive level. To see this, recall from Chapter 2 that the vertical difference between demand and marginal cost (competitive supply) at each quantity represents the change in social welfare associated with each incremental unit of output. Summing these vertical distances for all units between the monopoly (Q^M) and competitive (Q^C) outputs yields the shaded triangle in Figure 8–16 and thus represents the welfare loss to society (in dollars) due to the monopolization of the market.

deadweight loss of monopoly
The consumer and producer surplus that is lost due to the monopolist charging a price in excess of marginal cost.

MONOPOLISTIC COMPETITION

A market structure that lies between the extremes of monopoly and perfect competition is **monopolistic competition**. This market structure exhibits some characteristics present in both perfect competition and monopoly.

monopolistic competition
A market in which (1) there are many buyers and sellers, (2) each firm produces a differentiated product, and (3) there is free entry and exit.

Conditions for Monopolistic Competition

An industry is monopolistically competitive if:

1. There are many buyers and sellers.
2. Each firm in the industry produces a differentiated product.
3. There is free entry into and exit from the industry.

There are numerous industries in which firms produce products that are close substitutes, and the market for hamburgers is a prime example. Many fast-food restaurants produce hamburgers, but the hamburgers produced by one firm differ from those produced by other firms. Moreover, it is relatively easy for new firms to enter the market for hamburgers.

The key difference between the models of monopolistic competition and perfect competition is that in a market with monopolistic competition, each firm produces a product that differs slightly from other firms' products. The products are close, but not perfect, substitutes. For example, other things being equal, some consumers prefer McDonald's hamburgers, whereas others prefer to eat at Wendy's, Burger King, or one of the many other restaurants that serve hamburgers. As the price of a McDonald's hamburger increases, some consumers will substitute toward hamburgers produced by another firm. But some consumers may continue to eat at McDonald's even if the price is higher than at other restaurants. The fact that the products are not perfect substitutes in a monopolistically competitive industry thus implies that each firm faces a downward-sloping demand curve for its product. To sell more of its product, the firm must lower the price. In this sense, the demand curve facing a monopolistically competitive firm looks more like the demand for a monopolist's product than like the demand for a competitive firm's product.

INSIDE BUSINESS 8–3

Product Differentiation, Cannibalization, and Colgate's Smile

In 1896, Colgate dental cream was introduced in tubes similar to those we use now. Today, the Colgate-Palmolive Company's brand of toothpaste is the best-selling toothpaste in the world (ahead of other major brands, including Crest brand marketed by Procter & Gamble, which was introduced in 1955).

While Colgate and Crest enjoy the lion's share of the toothpaste market, if you view the oral care shelf at your local drugstore or supermarket, you will find over a hundred different varieties of toothpaste. Colgate alone sells over 40 different varieties that are marketed under names ranging from *Trolls Bubble Fruit* to *Colgate Total SF*.

Why would a dominant company like Colgate choose to sell so many different varieties of toothpaste—varieties that compete against each other for consumers' dollars?

The high level of product differentiation in the toothpaste market stems from firms introducing new varieties in an attempt to boost their economic profits. In environments where makers of other brands (such as Crest) can easily enter profitable segments of the market, a profitable strategy is to attempt to quickly cover that segment (introducing *Shrek Bubble Fruit* toothpaste, for instance) in order to earn short-run profits until other firms enter to steal a share of that segment. While introducing new varieties may cannibalize sales of your existing products, cannibalizing your own sales is better than having them stolen by a hungry competitor.

SOURCES: Corporate websites of the Colgate-Palmolive Company and Procter & Gamble and *Hoover's Online*.

There are two important differences between a monopolistically competitive market and a market serviced by a monopolist. First, while a monopolistically competitive firm faces a downward-sloping demand for its product, there are other firms in the industry that sell similar products. Second, in a monopolistically competitive industry, there are no barriers to entry. As we will see later, this implies that firms will enter the market if existing firms earn positive economic profits.

Profit Maximization

The determination of the profit-maximizing price and output under monopolistic competition is precisely the same as for a firm operating under monopoly. To see this, consider the demand curve for a monopolistically competitive firm presented in Figure 8–17. Since the demand curve slopes downward, the marginal revenue curve lies below it, just as under monopoly. To maximize profits, the monopolistically competitive firm produces where marginal revenue equals marginal cost. This output is given by Q^* in Figure 8–17. The profit-maximizing price is the maximum price consumers are willing to pay for Q^* units of the firm's output. The firm's profits are given by the shaded region.

Now that you understand that the basic principles of profit maximization are the same under monopolistic competition and monopoly, it is important to highlight one important difference in the interpretation of our analysis. The demand and marginal revenue curves used to determine the monopolistically competitive firm's profit-maximizing output and price are based not on the market demand for the product but on the demand for the individual firm's product. The demand curve facing a monopolist, in contrast, is the market demand curve.

In fact, because the firms in a monopolistically competitive industry produce differentiated products, the notion of an industry or market demand curve is not well defined. To find market demand, one must add up the total quantities purchased from all firms in the market at

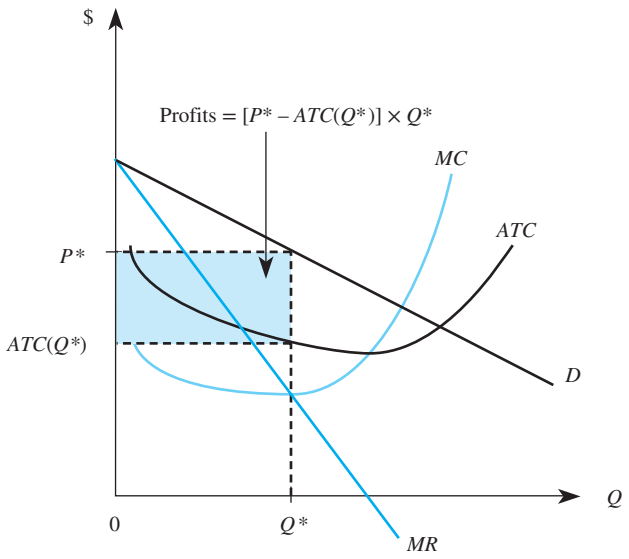


Figure 8–17
Profit Maximization under Monopolistic Competition

each price. But in monopolistically competitive markets, each firm produces a product that differs from other firms' products. Adding up these different products would be like adding up apples and oranges.

Profit Maximization Rule for Monopolistic Competition

To maximize profits, a monopolistically competitive firm produces where its marginal revenue equals marginal cost. The profit-maximizing price is the maximum price per unit that consumers are willing to pay for the profit-maximizing level of output. In other words, the profit-maximizing output, Q^*, is such that

PRINCIPLE

$$MR(Q^*) = MC(Q^*)$$

and the profit-maximizing price is

$$P^* = P(Q^*)$$

DEMONSTRATION PROBLEM 8–7

Suppose analysts for a monopolistically competitive firm have estimated its inverse demand curve as

$$P = 100 - 2Q$$

and the cost function as

$$C(Q) = 5 + 2Q$$

Determine the profit-maximizing price and quantity and the maximum profits.

ANSWER:

Using the marginal revenue formula for linear inverse demand and the formula for marginal cost, we see that

$$MR = 100 - (2)(2)(Q) = 100 - 4Q$$

$$MC = 2$$

Next, we set $MR = MC$ to find the profit-maximizing level of output:

$$100 - 4Q = 2$$

or

$$4Q = 98$$

Solving for Q yields the profit-maximizing output of $Q^* = 24.5$ units. The profit-maximizing price is found by setting $Q = Q^*$ in the inverse demand function:

$$P^* = 100 - 2 \times 24.5 = 51$$

Thus, the profit-maximizing price is \$51 per unit. Finally, profits are given by the difference between revenues and costs:

$$\begin{aligned} \pi &= P^*Q^* - C(Q^*) \\ &= (51)(24.5) - [5 + 2(24.5)] \\ &= \$1{,}195.50 \end{aligned}$$

Long-Run Equilibrium

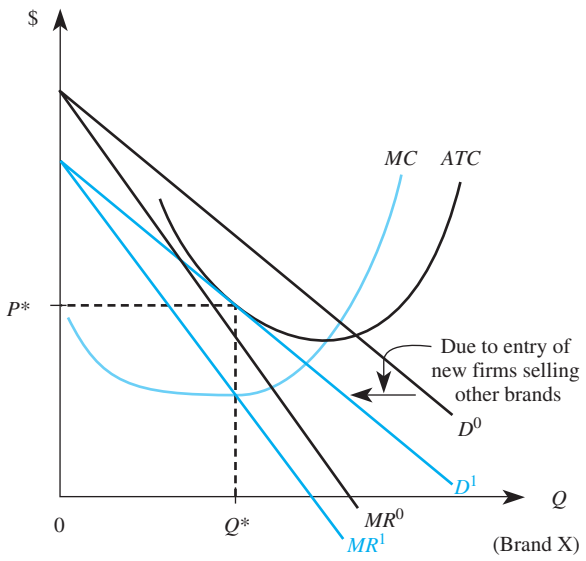
Because there is free entry into monopolistically competitive markets, if firms earn short-run profits in a monopolistically competitive industry, additional firms will enter the industry in the long run to capture some of those profits. Similarly, if existing firms incur losses, in the long run some firms will exit the industry.

To explain the impact of entry and exit in monopolistically competitive markets, suppose a monopolistically competitive firm is earning positive economic profits. The potential for profits induces other firms to enter the market and produce slight variations of the existing firm's product. As additional firms enter the market, some consumers who were buying the firm's product will begin to consume one of the new firms' products. Thus, one would expect the existing firms to lose a share of the market when new firms enter.

To make this notion more precise, suppose a monopolistically competitive firm that sells brand X faces an initial demand curve of D^0 in Figure 8–18. Since this demand curve

Figure 8–18

Effect of Entry on a Monopolistically Competitive Firm's Demand



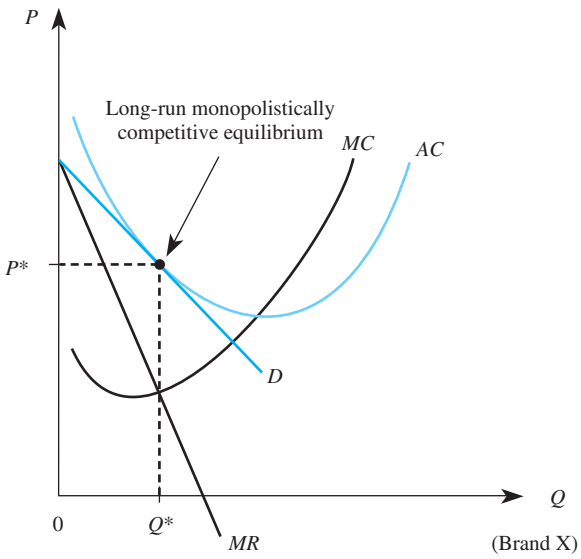


Figure 8–19
Long-Run Equilibrium under Monopolistic Competition

lies above the *ATC* curve, the firm is earning positive economic profits. This, of course, lures more firms into the industry. As additional firms enter, the demand for this firm's product will decrease because some consumers will substitute toward the new products offered by the entering firms. Entry continues until the demand curve decreases to D^1, where it is just tangential to the firm's average cost curve. At this point, firms in the industry are earning zero economic profits, and there is no incentive for additional firms to enter the industry.

The story is similar if firms in the industry initially are incurring losses. However, in this instance firms will exit the industry, and the demand for the products offered by the firms that remain will increase. This process leads to increased profits (or, more accurately, reduced losses) for the remaining firms. Ultimately, firms stop leaving the industry when the remaining firms earn zero economic profits.

Thus, the long-run equilibrium in a monopolistically competitive industry is characterized by the situation in Figure 8–19. Each firm earns zero economic profits but charges a price that exceeds the marginal cost of producing the good.

The Long Run and Monopolistic Competition

In the long run, monopolistically competitive firms produce a level of output such that

1. $P > MC$.
2. $P = ATC >$ minimum of average costs.

PRINCIPLE

As in the case of monopoly, the fact that price exceeds marginal cost implies that monopolistically competitive firms produce less output than is socially desirable. In essence, consumers are willing to pay more for another unit than it would cost the firm to produce another unit, yet the firm will not produce more output because of its concern with profits.

Because price equals average costs, firms earn zero economic profits just as firms in perfectly competitive markets do. Even though the firms have some control over price, competition among them leads to a situation where no firm earns more than its opportunity cost of producing.

Finally, note that the price of output exceeds the minimum point on the average cost curve. This implies that firms do not take full advantage of economies of scale in production. In a sense, there are too many firms in the industry to enable any individual firm to take full advantage of economies of scale in production. On the other hand, some argue that this is simply the cost to society of having product variety. If there were fewer firms, economies of scale could be fully exploited, but there would be less product variety in the market.

Implications of Product Differentiation

The key difference between perfect competition and monopolistic competition is the assumption that firms produce *differentiated products*. Since there are many products in a monopolistically competitive industry, the only reason firms have any control over their price is that consumers view the products as differentiated. The demand for a firm's product is less elastic when consumers view other firms' products as poor substitutes for it. The less elastic the demand for a firm's product, the greater the potential for earning profits.

For this reason, many firms in monopolistically competitive industries continually attempt to convince consumers that their products are better than those offered by other firms. A number of examples of such industries come readily to mind: fast-food restaurants, toothpaste, mouthwash, gasoline, aspirin, car wax—undoubtedly you can add other industries to the list. Each of these industries consists of many firms, and the different brands offered by firms in each industry are very close substitutes. In some instances, firms introduce several varieties of products; each soft-drink producer, for example, produces a variety of cola and noncola drinks.

comparative advertising
A form of advertising where a firm attempts to increase the demand for its brand by differentiating its product from competing brands.

brand equity
The additional value added to a product because of its brand.

niche marketing
A marketing strategy where goods and services are tailored to meet the needs of a particular segment of the market.

green marketing
A form of niche marketing where firms target products toward consumers who are concerned about environmental issues.

Firms in monopolistically competitive industries employ two strategies to persuade consumers that their products are better than those offered by competitors. First, monopolistically competitive firms spend considerable amounts on advertising campaigns. Very typically, these campaigns involve **comparative advertising** designed to differentiate a given firm's brand from brands sold by competing firms. Comparative advertising is common in the fast-food industry. For example, Subway attempts to stimulate demand for its food by differentiating itself as the healthy fast-food alternative. To the extent that comparative advertising is effective, it may induce consumers to pay a premium for a particular brand. The additional value that a brand adds to the product is known as **brand equity**.

Second, firms in monopolistically competitive industries frequently introduce new products into the market to further differentiate their products from other firms. These include not only "new, improved" products, such as an "improved" version of laundry detergent, but completely different product lines. Monopolistically competitive firms may also attempt to create and advertise new products that fill special needs in the market. This strategy—called **niche marketing**—involves products or services targeted to a specific group of consumers. Through **green marketing**, for instance, firms create and advertise "environmentally friendly" products in an attempt to capture the segment of the market that is concerned with environmental issues. Examples of green marketing include package labels that prominently indicate that a toy is made from recycled plastic or a particular brand of laundry detergent is biodegradable.

Unfortunately, successful differentiation and branding strategies sometimes make managers myopic. A **brand myopic** manager is satisfied with an existing brand, is slow to launch new products, and is not aware of emerging industry trends or changes in consumer preferences. Essentially, a brand myopic company rests on its past laurels and, in so doing, misses opportunities to enhance (and hence protect) its brand. A few decades ago, for instance, Crest became the best-selling toothpaste through advertising campaigns that touted Crest as the brand that helps fight cavities. In recent years, however, fresh breath, white teeth, and gum sensitivity emerged as issues that consumers care about. Colgate capitalized on Crest's brand myopia by exploiting these new trends in consumer preferences and ultimately surpassed Crest as the leading toothpaste in the market.

brand myopic
A manager or company that rests on a brand's past laurels instead of focusing on emerging industry trends or changes in consumer preferences.

As the manager of a firm in a monopolistically competitive industry, it is important for you to remember that, in the long run, additional firms will enter the market if your firm earns short-run profits with its product. Thus, while you may make short-run profits by introducing a new product line, in the long run other firms will mimic your product and/or introduce new product lines, and your economic profits will decrease to zero.

OPTIMAL ADVERTISING DECISIONS

How much should a firm spend on advertising in order to maximize profits? The answer depends, in part, on the nature of the industry in which the firm operates. Firms that operate in perfectly competitive markets generally do not find it profitable to advertise because consumers already have perfect information about the large number of substitutes that exist for any given firm's product. A wheat farmer who operates a small family farm, for instance, is unlikely to profit by spending family funds on an advertising campaign designed to increase the demand for the family's wheat. In contrast, firms that have market power—such as monopolists and monopolistically competitive firms—will generally find it profitable to spend a fraction of their revenues on advertising.

As with any economic decision, the optimal amount of advertising balances marginal benefits and marginal costs: To maximize these profits, managers should advertise up to the point where the incremental revenue from advertising equals the incremental cost. The incremental cost of advertising is simply the dollar cost of the resources needed to increase the level of advertising. These costs include fees paid for additional advertising space and the opportunity cost of the human resources needed to put together the advertising campaign. The incremental revenue is the extra revenue the firm gets as a result of the advertising campaign. These extra revenues depend on the number of additional units that will be sold as a result of an advertising campaign and how much is earned on each of these units. Fortunately, a simple formula is available that permits managers to easily determine the optimal level of advertising.

Formula: The Profit-Maximizing Advertising-to-Sales Ratio. The profit-maximizing advertising-to-sales ratio (A/R) is given by

$$\frac{A}{R} = \frac{E_{Q,A}}{-E_{Q,P}}$$

where $E_{Q,P}$ represents the own-price elasticity of demand for the firm's product, $E_{Q,A}$ is the advertising elasticity of demand for the firm's product, A represents the firm's expenditures

on advertising, and $R = PQ$ denotes the dollar value of the firm's sales (i.e., the firm's revenues).

A CALCULUS ALTERNATIVE

A firm's profits are revenues minus production costs and advertising expenditures. If we let A represent advertising expenditures, $Q = Q(P, A)$ denote the demand for the firm's product, and $C(Q)$ denote production costs, firm profit is a function of P and A:

$$\pi(P, A) = Q(P, A)\, P - C[Q(P, A)] - A$$

The first-order conditions for maximizing profits require

$$\frac{\partial \pi}{\partial P} = \frac{\partial Q}{\partial P} P + Q - \frac{\partial C}{\partial Q}\frac{\partial Q}{\partial P} = 0 \tag{8–1}$$

and

$$\frac{\partial \pi}{\partial A} = \frac{\partial Q}{\partial A} P - \frac{\partial C}{\partial Q}\frac{\partial Q}{\partial A} - 1 = 0 \tag{8–2}$$

Noting that $\partial C/\partial Q = MC$ and $E_{Q,P} = (\partial Q/\partial P)(P/Q)$, we may write Equation 8–1 as

$$\frac{P - MC}{P} = \frac{-1}{E_{Q,P}} \tag{8–3}$$

Similarly, using the fact that $E_{Q,A} = (\partial Q/\partial A)(A/Q)$, Equation 8–2 implies

$$\frac{A}{R} = \left(\frac{P - MC}{P}\right) E_{Q,A} \tag{8–4}$$

Substituting Equation 8–3 into Equation 8–4 yields the above formula.

Two aspects of this formula are worth noting. First, the more elastic the demand for a firm's product, the lower the optimal advertising-to-sales ratio. In the extreme case where $E_{Q,P} = -\infty$ (perfect competition), the formula indicates that the optimal advertising-to-sales ratio is zero. Second, the greater the advertising elasticity, the greater the optimal advertising-to-sales ratio. Firms that have market power (such as monopolists and monopolistically competitive firms) face a demand curve that is not perfectly elastic. As a consequence, these firms will generally find it optimal to engage in some degree of advertising. Exactly how much such firms should spend on advertising, however, depends on the quantitative impact of advertising on demand. The more sensitive demand is to advertising (that is, the greater the advertising elasticity), the greater the number of additional units sold because of a given increase in advertising expenditures, and thus the greater the optimal advertising-to-sales ratio.

DEMONSTRATION PROBLEM 8–8

Corpus Industries produces a product at constant marginal cost that it sells in a monopolistically competitive market. In an attempt to bolster profits, the manager hired an economist to estimate the demand for its product. She found that the demand for the firm's product is log-linear, with an own price elasticity of demand of –10 and an advertising elasticity of demand of 0.2. To maximize profits, what fraction of revenues should the firm spend on advertising?

ANSWER:

To find the profit-maximizing advertising-to-sales ratio, we simply plug $E_{Q,P} = -10$ and $E_{Q,A} = 0.2$ into the formula for the optimal advertising-to-sales ratio:

$$\frac{A}{R} = \frac{E_{Q,A}}{-E_{Q,P}} = \frac{0.2}{10} = 0.02$$

Thus, Corpus Industries' optimal advertising-to-sales ratio is 2 percent—to maximize profits, the firm should spend 2 percent of its revenues on advertising.

ANSWERING THE headLINE

As noted earlier in this chapter, the fast-food restaurant business has many features of monopolistic competition. Indeed, the owner of a typical McDonald's franchise competes not only against Burger King and Wendy's but against a host of other establishments. While each of these restaurants offers quick meals at reasonable prices, the products offered are clearly differentiated. Product differentiation gives these businesses some market power.

The McCafé program discussed in the opening headline was designed to further differentiate McDonald's from the competition. In so doing, McDonald's hoped to increase its own demand by attracting customers away from traditional coffee shops and other fast-food restaurants. In fact, this is exactly what happened, as McDonald's saw a large increase in its coffee sales over a short period of time. While a monopolistically competitive business like McDonald's might benefit in the short run by introducing new products more quickly than its rivals, in the long run its competitors will attempt to mimic the strategies that are profitable. For example, Starbucks subsequently acquired the La Boulange bakery brand, allowing it to offer more food options along with its coffee—an apparent response to McDonald's invading its turf. This type of entry by rival firms would likely reduce the demand for meals (and coffee) at McDonald's and ultimately result in long-run economic profits of zero. It is worth noting that a similar chain of events occurred way back in 1978 when McDonald's successfully launched its Egg McMuffin. Other fast-food restaurants eventually responded by launching their own breakfast items, which ultimately reduced McDonald's share of the breakfast market and its economic profits. For these reasons, it is unlikely for strategies such as McDonald's McCafé program or Starbucks' increased food offerings to have a sustainable impact on their bottom lines.

SUMMARY

In this chapter, we examined managerial decisions in three market environments: perfect competition, monopoly, and monopolistic competition. Each of these market structures provides a manager with a different set of variables that can influence the firm's profits. A manager may need to pay particularly close attention to different decision parameters because different market structures allow control of only certain variables. Managers who recognize which variables are relevant for a particular industry will make more profits for their firms.

Managers in perfectly competitive markets should concentrate on producing the proper quantity and keeping costs low. Because perfectly competitive markets contain a very large number of firms that produce perfect substitutes, a manager in this market has no control over price. A manager in a monopoly, in contrast, needs to recognize the relation between price and quantity. By setting a quantity at which marginal cost equals marginal revenue, the manager of a monopoly will maximize profits. This is also true for the manager of a firm in a monopolistically competitive market, who also must evaluate the firm's product periodically to ensure that it is differentiated from other products in the market. In many instances, the manager of a monopolistically competitive firm will find it advantageous to slightly change the product from time to time to enhance product differentiation.

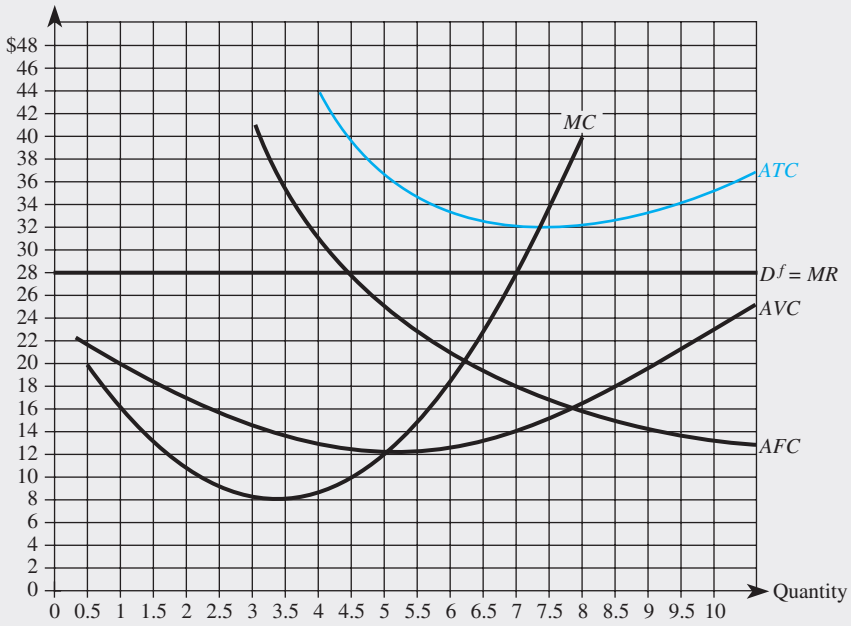
KEY TERMS AND CONCEPTS

brand equity
brand myopic
comparative advertising
cost complementarities
deadweight loss of monopoly
diseconomies of scale
economies of scale
economies of scope
firm demand curve
free entry
free exit
green marketing
inverse demand function
linear inverse demand function
marginal revenue
monopolistic competition
monopoly
multiplant monopoly
niche marketing
patents
perfectly competitive market
product differentiation

CONCEPTUAL AND COMPUTATIONAL QUESTIONS

connect

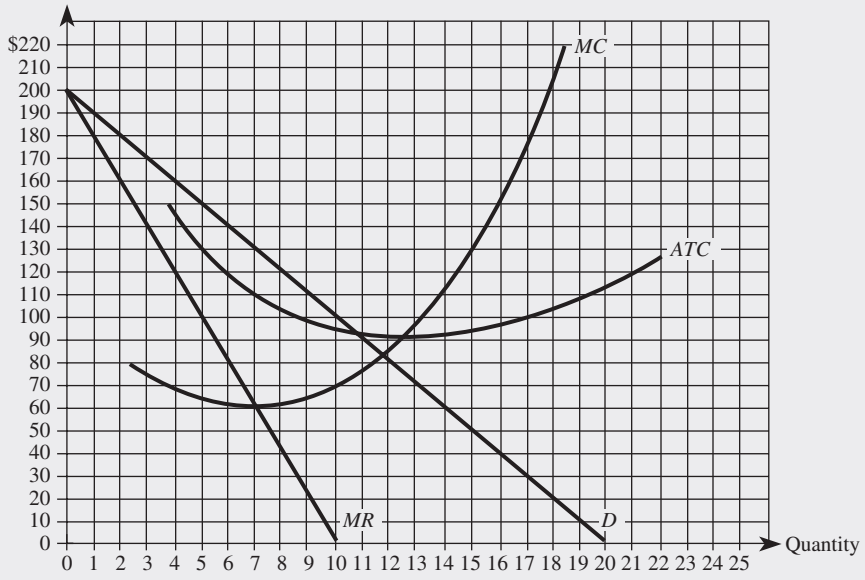
1. The following graph summarizes the demand and costs for a firm that operates in a perfectly competitive market. *(LO1, LO6)*



   a. What level of output should this firm produce in the short run?
   b. What price should this firm charge in the short run?
   c. What is the firm's total cost at this level of output?
   d. What is the firm's total variable cost at this level of output?
   e. What is the firm's fixed cost at this level of output?
   f. What is the firm's profit if it produces this level of output?
   g. What is the firm's profit if it shuts down?
   h. In the long run, should this firm continue to operate or shut down?

2. A firm sells its product in a perfectly competitive market where other firms charge a price of \$110 per unit. The firm estimates its total costs as $C(Q) = 70 + 14Q + 2Q^2$. *(LO3)*
   a. How much output should the firm produce in the short run?
   b. What price should the firm charge in the short run?
   c. What are the firm's short-run profits?
   d. What adjustments should be anticipated in the long run?

3. The following graph summarizes the demand and costs for a firm that operates in a monopolistically competitive market. *(LO1, LO3, LO5)*

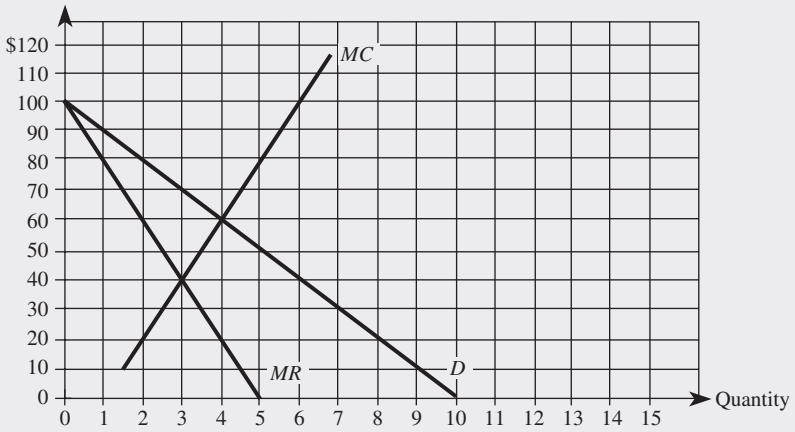


   a. What is the firm's optimal output?
   b. What is the firm's optimal price?
   c. What are the firm's maximum profits?
   d. What adjustments should the manager be anticipating?

4. You are the manager of a monopoly, and your analysts have estimated your demand and costs functions as $P = 300 - 3Q$ and $C(Q) = 1{,}500 + 2Q^2$, respectively. *(LO3, LO4)*
   a. What price–quantity combination maximizes your firm's profits?
   b. Calculate the maximum profits.
   c. Is demand elastic, inelastic, or unit elastic at the profit-maximizing price–quantity combination?
   d. What price–quantity combination maximizes revenue?
   e. Calculate the maximum revenues.
   f. Is demand elastic, inelastic, or unit elastic at the revenue-maximizing price–quantity combination?

5. You are the manager of a firm that produces a product according to the cost function $C(q_i) = 160 + 58q_i - 6q_i^2 + q_i^3$. Determine the short-run supply function if: *(LO1, LO7)*
   a. You operate a perfectly competitive business.
   b. You operate a monopoly.
   c. You operate a monopolistically competitive business.

6. The accompanying diagram shows the demand, marginal revenue, and marginal cost of a monopolist. *(LO1, LO3, LO5)*
   a. Determine the profit-maximizing output and price.
   b. What price and output would prevail if this firm's product were sold by price-taking firms in a perfectly competitive market?
   c. Calculate the deadweight loss of this monopoly.



Excel Exercises

7. You are the manager of a monopolistically competitive firm, and your demand and cost functions are estimated as $Q = 36 - 4P$ and $C(Q) = 4 + 4Q + Q^2$. *(LO1, LO3, LO5)*
   a. Find the inverse demand function for your firm's product.
   b. Determine the profit-maximizing price and level of production.
   c. Calculate your firm's maximum profits.
   d. What long-run adjustments should you expect? Explain.
8. The elasticity of demand for a firm's product is –4 and its advertising elasticity of demand is 0.32. *(LO8)*
   a. Determine the firm's optimal advertising-to-sales ratio.
   b. If the firm's revenues are $30,000, what is its profit-maximizing level of advertising?
9. A monopolist's inverse demand function is estimated as $P = 150 - 3Q$. The company produces output at two facilities; the marginal cost of producing at facility 1 is $MC_1(Q_1) = 6Q_1$, and the marginal cost of producing at facility 2 is $MC_2(Q_2) = 2Q_2$. *(LO1, LO8)*
   a. Provide the equation for the monopolist's marginal revenue function. (*Hint:* Recall that $Q_1 + Q_2 = Q$.)
   b. Determine the profit-maximizing level of output for each facility.
   c. Determine the profit-maximizing price.
10. The manager of a local monopoly estimates that the elasticity of demand for its product is constant and equal to –4. The firm's marginal cost is constant at $25 per unit. *(LO1, LO3, LO4)*
    a. Express the firm's marginal revenue as a function of its price.
    b. Determine the profit-maximizing price.

PROBLEMS AND APPLICATIONS

11. The CEO of a major automaker overheard one of its division managers make the following statement regarding the firm's production plans: "In order to maximize profits, it is essential that we operate at the minimum point of our average total cost curve." If you were the CEO of the automaker, would you praise or chastise the manager? Explain. *(LO3)*
12. You are the manager of a small U.S. firm that sells nails in a competitive U.S. market (the nails you sell are a standardized commodity; stores view your nails as identical to those available from hundreds of other firms). You are concerned about two events you recently learned about through trade publications: (*a*) the overall market supply of nails will decrease by 2 percent, due to exit by foreign competitors, and (*b*) due to a growing U.S. economy, the overall market demand for nails will increase by 2 percent. Based on this information, should you plan to increase or decrease your production of nails? Explain. *(LO1, LO7)*

13. When the first Pizza Hut opened its doors back in 1958, it offered consumers one style of pizza: its Original Thin Crust Pizza. Since its modest beginnings, Pizza Hut has established itself as the leader of the $25 billion pizza industry. Today, Pizza Hut offers six styles of pizza, including Pan Pizza, Stuffed Crust Pizza, and its Hand-Tossed Style. Explain why Pizza Hut has expanded its offerings of pizza over the past six decades, and discuss the long-run profitability of such a strategy. *(LO1, LO2, LO5)*
14. You are the manager of a small pharmaceutical company that received a patent on a new drug three years ago. Despite strong sales ($150 million last year) and a low marginal cost of producing the product ($0.50 per pill), your company has yet to show a profit from selling the drug. This is, in part, due to the fact that the company spent $1.7 billion developing the drug and obtaining FDA approval. An economist has estimated that, at the current price of $1.50 per pill, the own price elasticity of demand for the drug is –2. Based on this information, what can you do to boost profits? Explain. *(LO1, LO3, LO4)*
15. The second-largest public utility in the nation is the sole provider of electricity in 32 counties of southern Florida. To meet the monthly demand for electricity in these counties, which is represented by the estimated inverse demand function $P = 1{,}200 - 4Q$, the utility company has set up two electric generating facilities: Q_1 kilowatts are produced at facility 1 and Q_2 kilowatts are produced at facility 2 (so $Q = Q_1 + Q_2$). The costs of producing electricity at each facility are estimated as $C_1(Q_1) = 8{,}000 + 6Q_1^2$ and $C_2(Q_2) = 6{,}000 + 3Q_2^2$, respectively. Determine the profit-maximizing amounts of electricity to produce at the two facilities, the optimal price, and the utility company's profits. *(LO1, LO8)*
16. You are the manager of College Computers, a manufacturer of customized computers that meet the specifications required by the local university. More than 90 percent of your clientele consists of college students. College Computers is not the only firm that builds computers to meet this university's specifications; indeed, it competes with many manufacturers online and through traditional retail outlets. To attract its large student clientele, College Computers runs a weekly ad in the student paper advertising its "free service after the sale" policy in an attempt to differentiate itself from the competition. The weekly demand for computers produced by College Computers is given by $Q = 800 - 2P$, and its weekly cost of producing computers is $C(Q) = 1{,}200 + 2Q^2$. If other firms in the industry sell PCs at $300, what price and quantity of computers should you produce to maximize your firm's profits? What long-run adjustments should you anticipate? Explain. *(LO1, LO2, LO3, LO5)*
17. You are the general manager of a firm that manufactures personal computers. Due to a soft economy, demand for PCs has dropped 50 percent from the previous year. The sales manager of your company has identified only one potential client, who has received several quotes for 10,000 new PCs. According to the sales manager, the client is willing to pay $800 each for 10,000 new PCs. Your production line is currently idle, so you can easily produce the 10,000 units. The accounting department has provided you with the following information about the unit (or average) cost of producing three potential quantities of PCs:

	10,000 PCs	15,000 PCs	20,000 PCs
Materials (PC components)	$ 600	$600	$600
Depreciation	300	225	150
Labor	150	150	150
Total unit cost	$1,050	$975	$900

Based on this information, should you accept the offer to produce 10,000 PCs at $800 each? Explain. *(LO6)*

18. You are a manager at Spacely Sprockets—a small firm that manufactures Type A and Type B bolts. The accounting and marketing departments have provided you with the following information about the per-unit costs and demand for Type A bolts:

Accounting Data for Type A Bolts		*Marketing Data for Type A Bolts*	
Item	**Unit Cost**	**Quantity**	**Price**
Materials and labor	$2.75	0	$10
Overhead	5.00	1	9
		2	8
Total cost per unit	$7.75	3	7
		4	6
		5	5

Materials and labor are obtained in a competitive market on an as-needed basis, and the reported costs per unit for materials and labor are constant over the relevant range of output. The reported unit overhead costs reflect the $10 spent last month on machines, divided by the projected output of 2 units that was planned when the machines were purchased. In addition to the above information, you know that the firm's assembly line can produce no more than five bolts. Since the firm also makes Type B bolts, this means that each Type A bolt produced reduces the number of Type B bolts that can be produced by one unit; the total number of Types A and B bolts produced cannot exceed 5 units. A call to a reputable source has revealed that unit costs for producing Type B bolts are identical to those for producing Type A bolts and that Type B bolts can be sold at a constant price of $4.75 per unit. Determine your relevant marginal cost of producing Type A bolts and your profit-maximizing production of Type A bolts. *(LO3)*

19. In a statement to P&G shareholders, the CEO of Gillette (which is owned by P&G) indicated, "Despite several new product launches, Gillette's advertising-to-sales declined dramatically . . . to 7.5 percent last year. Gillette's advertising spending, in fact, is one of the lowest in our peer group of consumer product companies." If the elasticity of demand for Gillette's consumer products is similar to that of other firms in its peer group (which averages –4), what is Gillette's advertising elasticity? Is Gillette's demand more or less responsive to advertising than other firms in its peer group? Explain. *(LO8)*

20. Recently, the spot market price of U.S. hot rolled steel plummeted to $400 per ton. Just one year ago, this same ton of steel cost $700. According to Metals Monitor, the drop in price was due to falling oil prices, along with a rise in cheap imports and excess capacity. These dramatic market changes have greatly impacted the supply of raw steel. Suppose that last year the supply for raw steel was $Q^S_{\text{raw}} = 600 + 4P$, but this year it has shifted to $Q^S_{\text{raw}} = 4{,}200 + 4P$. Assuming the market for raw steel is competitive and that the current worldwide demand for steel is $Q^d_{\text{raw}} = 9{,}000 - 8P$, compute the equilibrium price and quantity for the steel market one year ago, and the equilibrium price–quantity combination for the current steel market. Suppose the cost function of a representative steel producer is $C(Q) = 1{,}200 + 15Q^2$. Compare the change in the quantity of raw steel exchanged at the market level with the change in raw steel produced by a representative firm. How do you explain this difference? *(LO1, LO3, LO7)*

21. The French government announced plans to convert state-owned power firms EDF and GDF into separate limited companies that operate in geographically distinct markets.

BBC News reported that France's CFT union responded by organizing a mass strike, which triggered power outages in some Paris suburbs. Union workers are concerned that privatizing power utilities would lead to large-scale job losses and power outages similar to those experienced in parts of the eastern coast of the United States and parts of Italy in 2003. Suppose that prior to privatization, the price per kilowatt-hour of electricity was €0.13 and that the inverse demand for electricity in each of these two regions of France is estimated as $P = 1.35 - 0.002Q$ (in euros). Furthermore, to supply electricity to its particular region of France, it costs each firm $C(Q) = 120 + 0.13Q$ (in euros). Once privatized, each firm will have incentive to maximize profits. Determine the number of kilowatt-hours of electricity each firm will produce and supply to the market and the per-kilowatt-hour price. Compute the price elasticity of demand at the profit-maximizing price–quantity combination. Explain why the price elasticity makes sense at the profit-maximizing price–quantity combination. Compare the price–quantity combination before and after privatization. How much more profit will each firm earn as a result of privatization? *(LO2, LO3)*

22. The owner of an Italian restaurant has just been notified by her landlord that the monthly lease on the building in which the restaurant operates will increase by 20 percent at the beginning of the year. Her current prices are competitive with nearby restaurants of similar quality. However, she is now considering raising her prices by 20 percent to offset the increase in her monthly rent. Would you recommend that she raise prices? Explain. *(LO3)*
23. Last month you assumed the position of manager for a large car dealership. The distinguishing feature of this dealership is its "no hassle" pricing strategy; prices (usually well below the sticker price) are posted on the windows, and your sales staff has a reputation for not negotiating with customers. Last year, your company spent $2 million on advertisements to inform customers about its "no hassle" policy and had overall sales revenue of $40 million. A recent study from an agency on Madison Avenue indicates that, for each 3 percent increase in TV advertising expenditures, a car dealer can expect to sell 12 percent more cars—but that it would take a 4 percent decrease in price to generate the same 12 percent increase in units sold. Assuming the information from Madison Avenue is correct, should you increase or decrease your firm's level of advertising? Explain. *(LO1, LO2, LO8)*
24. As a manager in a monopolistically competitive industry, you are trying to determine the optimal price for your product. You've asked the analysts in your firm to determine as closely as possible the inverse demand curve for your product and your cost function. They've reported back to you the following two tables:

Price regressed on Quantity:

	Coefficients	Standard Error	*t*-Stat	*P*-value	Lower 95%	Upper 95%
Intercept	300.287	1.005	298.65	7.05E-216	298.300	302.273
Quantity	–4.048	0.062	–65.67	4.79E-115	–4.170	–3.926

Costs regressed on Quantity:

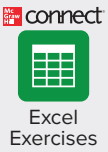
	Coefficients	Standard Error	*t*-Stat	*P*-value	Lower 95%	Upper 95%
Intercept	8.249	1.052	7.845	6.58E-13	6.172	10.326
Quantity	3.072	0.064	47.651	1.77E-94	2.944	3.199

Using this information, determine:

a. The estimated inverse demand curve and cost function for your product, and comment on whether these are precisely estimated.

b. The profit maximizing quantity and price for your product.

c. The maximum profits you can attain.



25. As a newly hired manager at your firm, you decide to start your tenure by assessing the sensibility of your current advertising expenditure. To do this, you ask your analytics team to collect useful data on the quantity of your product sold, the price, and advertising (in thousands) across a range of markets where your product is sold. The data they collected are in *Q08-25.xls.*

a. Using these data, determine the advertising elasticity of demand and the own-price elasticity of demand. (*Hint:* Recall what a log-log regression provides in terms of estimates).

b. What is the profit-maximizing advertising-to-sales ratio for your product? Do you have any concern about the precision of this estimate?

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APPENDIX

THE CALCULUS OF PROFIT MAXIMIZATION

PERFECT COMPETITION

The profits of a perfectly competitive firm are

$$\pi = PQ - C(Q)$$

The first-order conditions for maximizing profits require that marginal profits be zero:

$$\frac{d\pi}{dQ} = P - \frac{dC(Q)}{dQ} = 0$$

Thus, we obtain the profit-maximizing rule for a firm in perfect competition:

$$P = \frac{dC}{dQ}$$

or

$$P = MC$$

The second-order condition for maximizing profits requires that

$$\frac{d^2\pi}{dQ^2} = -\frac{d^2C}{dQ^2} = -\frac{dMC}{dQ} < 0$$

This means that $d(MC)/dQ > 0$, or that marginal cost must be increasing in output.

MONOPOLY AND MONOPOLISTIC COMPETITION *MR = MC* RULE

The profits for a firm with market power are

$$\pi = R(Q) - C(Q)$$

where $R(Q) = P(Q)Q$ is total revenue. To maximize profits, marginal profits must be zero:

$$\frac{d\pi}{dQ} = \frac{dR(Q)}{dQ} - \frac{dC(Q)}{dQ} = 0$$

or

$$MR = MC$$

The second-order condition requires that

$$\frac{d^2\pi}{dQ^2} = \frac{d^2R(Q)}{dQ^2} - \frac{d^2C(Q)}{dQ^2} < 0$$

which means that

$$\frac{dMR}{dQ} < \frac{dMC}{dQ}$$

But this simply means that the slope of the marginal revenue curve must be less than the slope of the marginal cost curve.

APPENDIX

THE ALGEBRA OF PERFECTLY COMPETITIVE SUPPLY FUNCTIONS

This appendix shows how to obtain the short-run firm and industry supply functions from cost data. Suppose there are 500 firms in a perfectly competitive industry, with each firm having a cost function of

$$C(q_i) = 50 + 2q_i + 4q_i^2$$

The corresponding average total cost (ATC), average variable cost (AVC), and marginal cost (MC) functions are

$$ATC_i = \frac{50}{q_i} + 2 + 4q_i$$

$$AVC_i = 2 + 4q_i$$

and

$$MC_i = 2 + 8q_i$$

Recall that a firm's supply curve is the firm's marginal cost curve above the minimum of average variable cost. Since AVC is at its minimum where it equals marginal cost, to find the quantity where average variable cost equals marginal cost, we must set the two functions equal to each other and solve for q_i. When we do this for the given equations, we find that the quantity at which marginal cost equals average variable cost is $q_i = 0$.

Next, we recognize that an individual firm maximizes profits by equating $P = MC_i$, so

$$P = 2 + 8q_i$$

Solving for q_i gives us the individual firm's supply function:

$$q_i = -\frac{2}{8} + \frac{1}{8}P$$

To find the supply curve for the industry, we simply sum the above equation over all 500 firms in the market:

$$Q = \sum_{i=1}^{500} q_i = 500\left(-\frac{2}{8} + \frac{1}{8}P\right) = -\frac{1{,}000}{8} + \frac{500}{8}P$$

or

$$Q = -125 + 62.5P$$

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9 Basic Oligopoly Models

LEARNING OBJECTIVES

After completing this chapter, you will be able to:

- **LO1** Explain how beliefs and strategic interaction shape optimal decisions in oligopoly environments.
- **LO2** Identify the conditions under which a firm operates in a Sweezy, Cournot, Stackelberg, or Bertrand oligopoly, and the ramifications of each type of oligopoly for optimal pricing decisions, output decisions, and firm profits.
- **LO3** Apply reaction (or best-response) functions to identify optimal decisions and likely competitor responses in oligopoly settings.
- **LO4** Identify the conditions for a contestable market and explain the ramifications for market power and the sustainability of long-run profits.

headLINE

Crude Oil Prices Fall, but Consumers in Some Areas See No Relief at the Pump

Thanks to a recent decline in crude oil prices, consumers in most locations recently enjoyed lower gasoline prices. In a few isolated areas, however, consumers cried foul because gasoline retailers did not pass on the price reductions to those who pay at the pump. Consumer groups argued that this corroborated their claim that gasoline retailers in these areas were colluding in order to earn monopoly profits. For obvious reasons, the gasoline retailers involved denied the allegations.

Based on the evidence, do you think that gasoline stations in these areas were colluding in order to earn monopoly profits? Explain.

INTRODUCTION

Up until now, our analysis of markets has not considered the impact of strategic behavior on managerial decision making. At one extreme, we examined profit maximization in perfectly competitive and monopolistically competitive markets. In these types of markets, so many firms are competing with one another that no individual firm has any effect on other firms in the market. At the other extreme, we examined profit maximization in a monopoly market. In this instance there is only one firm in the market, and strategic interactions among firms thus are irrelevant.

This chapter is the first of two chapters in which we examine managerial decisions in oligopoly markets. Here we focus on basic output and pricing decisions in four specific types of oligopolies: Sweezy, Cournot, Stackelberg, and Bertrand. In the next chapter, we will develop a more general framework for analyzing other decisions, such as advertising, research and development, entry into an industry, and so forth. Then, in Module Group A, we will explore other business strategies that may be pertinent when there is strategic interaction. First, let us briefly review what is meant by the term *oligopoly*.

CONDITIONS FOR OLIGOPOLY

oligopoly
A market structure in which there are only a few firms, each of which is large relative to the total industry.

Oligopoly refers to a situation where there are relatively few large firms in an industry. No explicit number of firms is required for oligopoly, but the number usually is somewhere between 2 and 10. The products the firms offer may be either identical (as in a perfectly competitive market) or differentiated (as in a monopolistically competitive market). An oligopoly composed of only two firms is called a *duopoly*.

Oligopoly is perhaps the most interesting of all market structures; in fact, the next chapter is devoted entirely to the analysis of situations that arise under oligopoly. But from the viewpoint of the manager, a firm operating in an oligopoly setting is the most difficult to manage. The key reason is that there are few firms in an oligopolistic market and the manager must consider the likely impact of her or his decisions on the decisions of other firms in the industry. Moreover, the actions of other firms will have a profound impact on the manager's optimal decisions. It should be noted that due to the complexity of oligopoly, there is no single model that is relevant for all oligopolies.

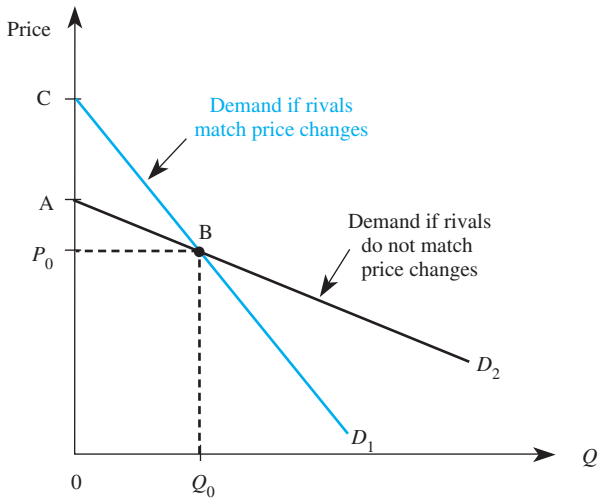
THE ROLE OF BELIEFS AND STRATEGIC INTERACTION

To gain an understanding of oligopoly interdependence, consider a situation where several firms selling differentiated products compete in an oligopoly. In determining what price to charge, the manager must consider the impact of his or her decisions on other firms in the industry. For example, if the price for the product is lowered, will other firms lower their prices or maintain their existing prices? If the price is increased, will other firms do likewise or maintain their current prices? The optimal decision of whether to raise or lower price will depend on how the manager believes other managers will respond. If other firms lower their prices when the firm lowers its price, it will not sell as much as it would if the other firms maintained their existing prices.

As a point of reference, suppose the firm initially is at point B in Figure 9–1, charging a price of P_0. Demand curve D_1 is based on the assumption that rivals will match any price

Figure 9–1

A Firm's Demand Depends on Actions of Rivals



change, while D_2 is based on the assumption that they will not match a price change. Note that demand is more inelastic when rivals match a price change than when they do not. The reason for this is simple. For a given price reduction, a firm will sell more if rivals do not cut their prices (D_2) than it will if they lower their prices (D_1). In effect, a price reduction increases quantity demanded only slightly when rivals respond by lowering their prices. Similarly, for a given price increase, a firm will sell more when rivals also raise their prices (D_1) than it will when they maintain their existing prices (D_2).

DEMONSTRATION PROBLEM 9–1

Suppose the manager is at point B in Figure 9–1, charging a price of P_0. If the manager believes rivals will not match price reductions but will match price increases, what does the demand for the firm's product look like?

ANSWER:

If rivals do not match price reductions, prices below P_0 will induce quantities demanded along curve D_2. If rivals do match price increases, prices above P_0 will generate quantities demanded along D_1. Thus, if the manager believes rivals will not match price reductions but will match price increases, the demand curve for the firm's product is given by CBD_2.

DEMONSTRATION PROBLEM 9–2

Suppose the manager is at point B in Figure 9–1, charging a price of P_0. If the manager believes rivals will match price reductions but will not match price increases, what does the demand for the firm's product look like?

ANSWER:

If rivals match price reductions, prices below P_0 will induce quantities demanded along curve D_1. If rivals do not match price increases, prices above P_0 will induce quantities demanded along D_2. Thus, if the manager believes rivals will match price reductions but will not match price increases, the demand curve for the firm's product is given by ABD_1.

The preceding analysis reveals that the demand for a firm's product in oligopoly depends critically on how rivals respond to the firm's pricing decisions. If rivals will match any price change, the demand curve for the firm's product is given by D_1. In this instance, the manager will maximize profits where the marginal revenue associated with demand curve D_1 equals marginal cost. If rivals will not match any price change, the demand curve for the firm's product is given by D_2. In this instance, the manager will maximize profits where the marginal revenue associated with demand curve D_2 equals marginal cost. In each case, the profit-maximizing rule is the same as that under monopoly; the only difficulty for the firm manager is determining whether or not rivals will match price changes.

PROFIT MAXIMIZATION IN FOUR OLIGOPOLY SETTINGS

In the following subsections, we will examine profit maximization based on alternative assumptions regarding how rivals will respond to price or output changes. Each of the four models has different implications for the manager's optimal decisions, and these differences arise because of differences in the ways rivals respond to the firm's actions.

Sweezy Oligopoly

The Sweezy model is based on a very specific assumption regarding how other firms will respond to price increases and price cuts. An industry is characterized as a **Sweezy oligopoly** if

1. There are few firms in the market serving many consumers.
2. The firms produce differentiated products.
3. Each firm believes rivals will cut their prices in response to a price reduction but will not raise their prices in response to a price increase.
4. Barriers to entry exist.

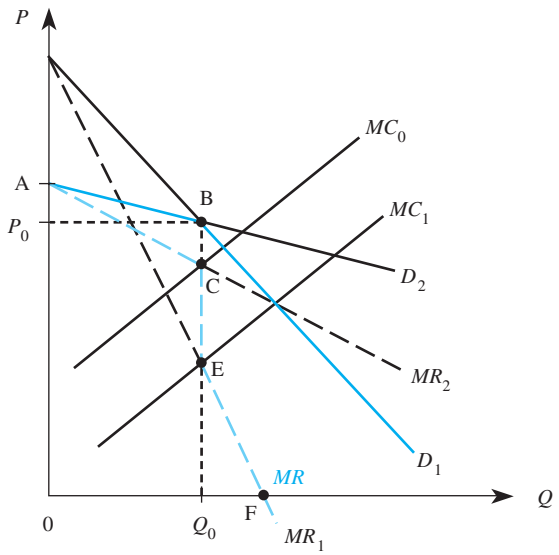
Sweezy oligopoly
An industry in which (1) there are few firms serving many consumers, (2) firms produce differentiated products, (3) each firm believes rivals will respond to a price reduction but will not follow a price increase, and (4) barriers to entry exist.

Because the manager of a firm competing in a Sweezy oligopoly believes other firms will match any price decrease but not match price increases, the demand curve for the firm's product is given by ABD_1 in Figure 9–2. For prices above P_0, the relevant demand curve is D_2; thus, marginal revenue corresponds to this demand curve. For prices below P_0, the relevant demand curve is D_1, and marginal revenue corresponds to D_1. Thus, the marginal revenue curve (MR) the firm faces is initially the marginal revenue curve associated with D_2; at Q_0, it jumps down to the marginal revenue curve corresponding to D_1. In other words, the Sweezy oligopolist's marginal revenue curve, denoted MR, is ACEF in Figure 9–2.

The profit-maximizing level of output occurs where marginal revenue equals marginal cost, and the profit-maximizing price is the maximum price consumers will pay for that level of output. For example, if marginal cost is given by MC_0 in Figure 9–2, marginal revenue equals marginal cost at point C. In this case the profit-maximizing output is Q_0 and the optimal price is P_0. Since price exceeds marginal cost ($P_0 > MC_0$), output is below the socially efficient level. This situation translates into a deadweight loss (lost consumer and producer surplus) that does not arise in a perfectly competitive market.

An important implication of the Sweezy model of oligopoly is that there will be a range (CE) over which changes in marginal cost do not affect the profit-maximizing level of output. This is in contrast to competitive, monopolistically competitive, and monopolistic firms, all of which increase output when marginal costs decline.

Figure 9–2
Sweezy Oligopoly



To see why firms competing in a Sweezy oligopoly may not increase output when marginal cost declines, suppose marginal cost decreases from MC_0 to MC_1 in Figure 9–2. Marginal revenue now equals marginal cost at point E, but the output corresponding to this point is still Q_0. Thus the firm continues to maximize profits by producing Q_0 units at a price of P_0.

In a Sweezy oligopoly, firms have an incentive not to change their pricing behavior provided marginal costs remain in a given range. The reason for this stems purely from the assumption that rivals will match price cuts but not price increases. Firms in a Sweezy oligopoly do not want to change their prices because of the effect of price changes on the behavior of other firms in the market.

The Sweezy model has been criticized because it offers no explanation of how the industry settles on the initial price P_0 that generates the kink in each firm's demand curve. Nonetheless, the Sweezy model does show us that strategic interactions among firms and a manager's beliefs about rivals' reactions can have a profound impact on pricing decisions. In practice, the initial price and a manager's beliefs may be based on a manager's experience with, or analytics of, the pricing patterns of rivals in a given market. If your experience or market analytics suggests that rivals will match price reductions but will not match price increases, the Sweezy model is probably the best tool to use in formulating your pricing decisions.

Cournot Oligopoly

Cournot oligopoly
An industry in which (1) there are few firms serving many consumers, (2) firms produce either differentiated or homogeneous products, (3) each firm believes rivals will hold their output constant if it changes its output, and (4) barriers to entry exist.

Imagine that a few large oil producers must decide how much oil to pump out of the ground. The total amount of oil produced will certainly affect the market price of oil, but the underlying decision of each firm is not a pricing decision but rather the *quantity* of oil to produce. If each firm must determine its output level at the same time other firms determine their output levels, or, more generally, if each firm expects its own output decision to have no impact on rivals' output decisions, then this scenario describes a **Cournot oligopoly**.

More formally, an industry is a *Cournot oligopoly* if

1. There are few firms in the market serving many consumers.
2. The firms produce either differentiated or homogeneous products.

3. Each firm believes rivals will hold their output constant if it changes its output.
4. Barriers to entry exist.

Thus, in contrast to the Sweezy model of oligopoly, the Cournot model is relevant for decision making when managers make output decisions and believe that their decisions do not affect the output decisions of rival firms. Furthermore, the Cournot model applies to situations in which the products are either identical or differentiated.

Reaction Functions and Equilibrium

To highlight the implications of Cournot oligopoly, suppose there are only two firms competing in a Cournot duopoly: Each firm must make an output decision, and each firm believes that its rival will hold output constant as it changes its own output. To determine its optimal output level, firm 1 will equate marginal revenue with marginal cost. Notice that since this is a duopoly, firm 1's marginal revenue is affected by firm 2's output level. In particular, the greater the output of firm 2, the lower the market price and thus the lower is firm 1's marginal revenue. This means that the profit-maximizing level of output for firm 1 depends on firm 2's output level: A greater output by firm 2 leads to a lower profit-maximizing output for firm 1. This relationship between firm 1's profit-maximizing output and firm 2's output is called a best-response or reaction function.

A **best-response function** (also called a **reaction function**) defines the profit-maximizing level of output for a firm for given output levels of the other firm. More formally, the profit-maximizing level of output for firm 1 given that firm 2 produces Q_2 units of output is

best-response (or reaction) function
A function that defines the profit-maximizing level of output for a firm for given output levels of another firm.

$$Q_1 = r_1(Q_2)$$

Similarly, the profit-maximizing level of output for firm 2 given that firm 1 produces Q_1 units of output is given by

$$Q_2 = r_2(Q_1)$$

Cournot reaction (best-response) functions for a duopoly are illustrated in Figure 9–3, where firm 1's output is measured on the horizontal axis and firm 2's output is measured on the vertical axis.

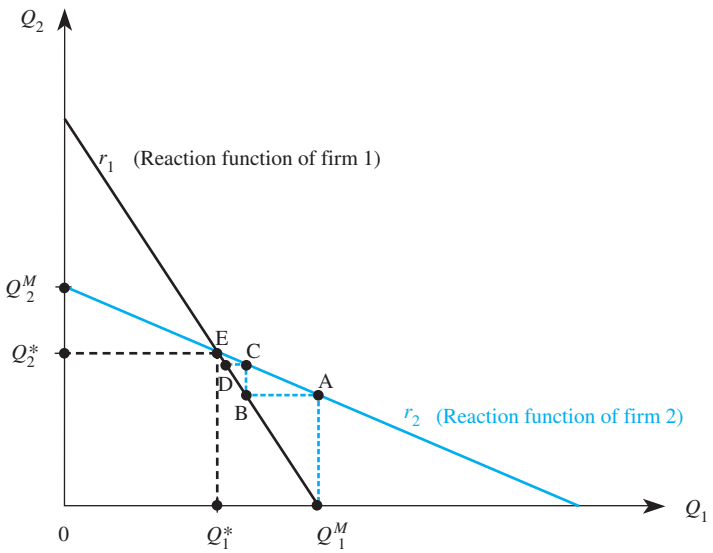


Figure 9–3
Cournot Reaction Functions

To understand why reaction functions are shaped as they are, let us highlight a few important points in the diagram. First, if firm 2 produced zero units of output, the profit-maximizing level of output for firm 1 would be Q_1^M since this is the point on firm 1's reaction function (r_1) that corresponds to zero units of Q_2. This combination of outputs corresponds to the situation where only firm 1 is producing a positive level of output; thus, Q_1^M corresponds to the situation where firm 1 is a monopolist. If instead of producing zero units of output firm 2 produced Q_2^* units, the profit-maximizing level of output for firm 1 would be Q_1^* since this is the point on r_1 that corresponds to an output of Q_2^* by firm 2.

The reason the profit-maximizing level of output for firm 1 decreases as firm 2's output increases is as follows: The demand for firm 1's product depends on the output produced by other firms in the market. When firm 2 increases its level of output, the demand and marginal revenue for firm 1 decline. The profit-maximizing response by firm 1 is to reduce its level of output.

DEMONSTRATION PROBLEM 9–3

In Figure 9–3, what is the profit-maximizing level of output for firm 2 when firm 1 produces zero units of output? What is it when firm 1 produces Q_1^* units?

ANSWER:

If firm 1 produces zero units of output, the profit-maximizing level of output for firm 2 will be Q_2^M since this is the point on firm 2's reaction function that corresponds to zero units of Q_1. The output of Q_2^M corresponds to the situation where firm 2 is a monopolist. If firm 1 produces Q_1^* units, the profit-maximizing level of output for firm 2 will be Q_2^*, since this is the point on r_2 that corresponds to an output of Q_1^* by firm 1.

To examine equilibrium in a Cournot duopoly, suppose firm 1 produces Q_1^M units of output. Given this output, the profit-maximizing level of output for firm 2 will correspond to point A on r_2 in Figure 9–3. Given this positive level of output by firm 2, the profit-maximizing level of output for firm 1 will no longer be Q_1^M, but will correspond to point B on r_1. Given this reduced level of output by firm 1, point C will be the point on firm 2's reaction function that maximizes profits. Given this new output by firm 2, firm 1 will again reduce output to point D on its reaction function.

How long will these changes in output continue? Until point E in Figure 9–3 is reached. At point E, firm 1 produces Q_1^* and firm 2 produces Q_2^* units. Neither firm has an incentive to change its output given that it believes the other firm will hold its output constant at that level. Point E thus corresponds to the Cournot equilibrium. **Cournot equilibrium** is the situation where neither firm has an incentive to change its output given the output of the other firm. Graphically, this condition corresponds to the intersection of the reaction curves.

Cournot equilibrium
A situation in which neither firm has an incentive to change its output given the other firm's output.

Thus far, our analysis of Cournot oligopoly has been graphical rather than algebraic. However, given estimates of the demand and costs within a Cournot oligopoly, we can explicitly solve for the Cournot equilibrium. How do we do this? To maximize profits, a manager in a Cournot oligopoly produces where marginal revenue equals marginal cost. The calculation of marginal cost is straightforward; it is done just as in the other market structures we have analyzed. The calculation of marginal revenues is a little more subtle. Consider the following formula:

Formula: Marginal Revenue for Cournot Duopoly. If the (inverse) market demand in a homogeneous-product Cournot duopoly is

$$P = a - b(Q_1 + Q_2)$$

where a and b are positive constants, then the marginal revenues of firms 1 and 2 are

$$MR_1(Q_1, Q_2) = a - bQ_2 - 2bQ_1$$
$$MR_2(Q_1, Q_2) = a - bQ_1 - 2bQ_2$$

A CALCULUS ALTERNATIVE

Firm 1's revenues are

$$R_1 = PQ_1 = [a - b(Q_1 + Q_2)]Q_1$$

Thus,

$$MR_1(Q_1, Q_2) = \frac{\partial R_1}{\partial Q_1} = a - bQ_2 - 2bQ_1$$

A similar analysis yields the marginal revenue for firm 2.

Notice that the marginal revenue for each Cournot oligopolist depends not only on the firm's own output, but also on the other firm's output. In particular, when firm 2 increases its output, firm 1's marginal revenue falls. This is because the increase in output by firm 2 lowers the market price, resulting in lower marginal revenue for firm 1.

Since each firm's marginal revenue depends on its own output *and* that of the rival, the output where a firm's marginal revenue equals marginal cost depends on the other firm's output level. If we equate firm 1's marginal revenue with its marginal cost and then solve for firm 1's output as a function of firm 2's output, we obtain an algebraic expression for firm 1's reaction function. Similarly, by equating firm 2's marginal revenue with marginal cost and performing some algebra, we obtain firm 2's reaction function. The results of these computations are summarized as follows.

Formula: Reaction Functions for Cournot Duopoly. For the linear (inverse) demand function

$$P = a - b(Q_1 + Q_2)$$

and cost functions,

$$C_1(Q_1) = c_1Q_1$$
$$C_2(Q_2) = c_2Q_2$$

the reaction functions are

$$Q_1 = r_1(Q_2) = \frac{a - c_1}{2b} - \frac{1}{2}Q_2$$
$$Q_2 = r_2(Q_1) = \frac{a - c_2}{2b} - \frac{1}{2}Q_1$$

To see how the preceding formulas are derived, note that firm 1 sets output such that

$$MR_1(Q_1, Q_2) = MC_1$$

For the linear (inverse) demand and cost functions, this means that

$$a - bQ_2 - 2bQ_1 = c_1$$

Solving this equation for Q_1 in terms of Q_2 yields

$$Q_1 = r_1(Q_2) = \frac{a - c_1}{2b} - \frac{1}{2}Q_2$$

The reaction function for firm 2 is computed similarly.

For a video walkthrough of this problem, visit www.mhhe.com/baye10e

DEMONSTRATION PROBLEM 9–4

Suppose the inverse demand function for two Cournot duopolists is given by

$$P = 10 - (Q_1 + Q_2)$$

and their costs are zero.

1. What is each firm's marginal revenue?
2. What are the reaction functions for the two firms?
3. What are the Cournot equilibrium outputs?
4. What is the equilibrium price?

ANSWER:

1. Using the formula for marginal revenue under Cournot duopoly, we find that

$$MR_1(Q_1, Q_2) = 10 - Q_2 - 2Q_1$$
$$MR_2(Q_1, Q_2) = 10 - Q_1 - 2Q_2$$

2. Similarly, the reaction functions are

$$Q_1 = r_1(Q_2) = \frac{10}{2} - \frac{1}{2}Q_2$$
$$= 5 - \frac{1}{2}Q_2$$
$$Q_2 = r_2(Q_1) = \frac{10}{2} - \frac{1}{2}Q_1$$
$$= 5 - \frac{1}{2}Q_1$$

3. To find the Cournot equilibrium, we must solve the two reaction functions for the two unknowns:

$$Q_1 = 5 - \frac{1}{2}Q_2$$
$$Q_2 = 5 - \frac{1}{2}Q_1$$

Inserting Q_2 into the first reaction function yields

$$Q_1 = 5 - \frac{1}{2}\left[5 - \frac{1}{2}Q_1\right]$$

Solving for Q_1 yields

$$Q_1 = \frac{10}{3}$$

To find Q_2, we plug $Q_1 = 10/3$ into firm 2's reaction function to get

$$Q_2 = 5 - \frac{1}{2}\left(\frac{10}{3}\right)$$
$$= \frac{10}{3}$$

4. Total industry output is

$$Q = Q_1 + Q_2 = \frac{10}{3} + \frac{10}{3} = \frac{20}{3}$$

The price in the market is determined by the (inverse) demand for this quantity:

$$P = 10 - (Q_1 + Q_2)$$
$$= 10 - \frac{20}{3}$$
$$= \frac{10}{3}$$

Regardless of whether Cournot oligopolists produce homogeneous or differentiated products, industry output is lower than the socially efficient level. This inefficiency arises because the equilibrium price exceeds marginal cost. The amount by which price exceeds marginal cost depends on the number of firms in the industry as well as the degree of product differentiation. The equilibrium price declines toward marginal cost as the number of firms rises. When the number of firms is arbitrarily large, the equilibrium price in a homogeneous product Cournot market is arbitrarily close to marginal cost, and industry output approximates that under perfect competition (there is no deadweight loss).

Isoprofit Curves

Now that you have a basic understanding of Cournot oligopoly, we will examine how to graphically determine the firm's profits. Recall that the profits of a firm in an oligopoly depend not only on the output it chooses to produce but also on the output produced by other firms in the oligopoly. In a duopoly, for instance, increases in firm 2's output will reduce the price of the output. This is due to the law of demand: As more output is sold in the market, the price consumers are willing and able to pay for the good declines. This will, of course, alter the profits of firm 1.

The basic tool used to summarize the profits of a firm in Cournot oligopoly is an **isoprofit curve**, which defines the combinations of outputs of all firms that yield a given firm the same level of profits.

isoprofit curve
A function that defines the combinations of outputs produced by all firms that yield a given firm the same level of profits.

Figure 9–4 presents the reaction function for firm 1 (r_1), along with three isoprofit curves (labeled π_0, π_1, and π_2). Four aspects of Figure 9–4 are important to understand:

1. Every point on a given isoprofit curve yields firm 1 the same level of profits. For instance, points F, A, and G all lie on the isoprofit curve labeled π_0; thus, each of these points yields profits of exactly π_0 for firm 1.
2. Isoprofit curves that lie closer to firm 1's monopoly output Q_1^M are associated with higher profits for that firm. For instance, isoprofit curve π_2 implies higher profits than does π_1, and π_1 is associated with higher profits than π_0. In other words, as we move down firm 1's reaction function from point A to point C, firm 1's profits increase.
3. The isoprofit curves for firm 1 reach their peak where they intersect firm 1's reaction function. For instance, isoprofit curve π_0 peaks at point A, where it intersects r_1; π_1 peaks at point B, where it intersects r_1; and so on.
4. The isoprofit curves do not intersect one another.

With an understanding of these four aspects of isoprofit curves, we now provide further insights into managerial decisions in a Cournot oligopoly. Recall that one assumption of Cournot oligopoly is that each firm takes as given the output decisions of rival firms and simply chooses its output to maximize profits given other firms' output. This is illustrated in

Figure 9–4

Isoprofit Curves for Firm 1

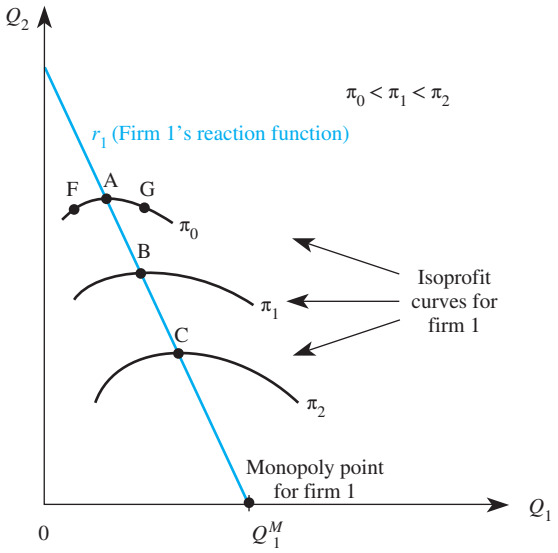
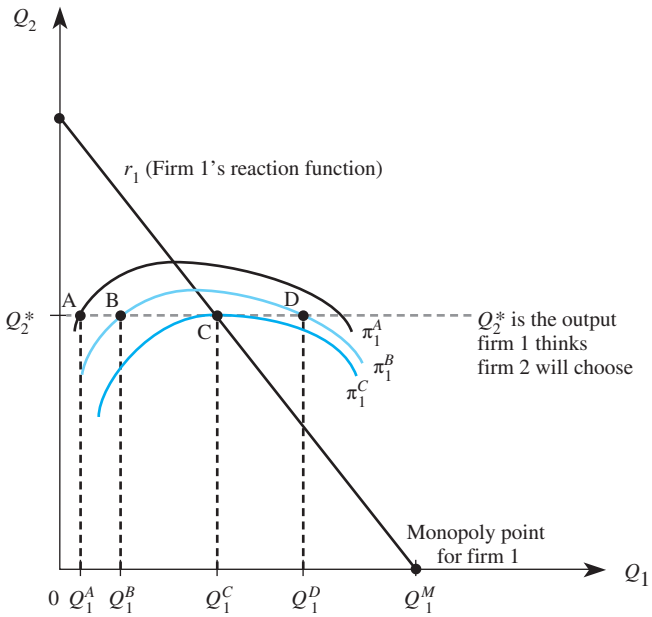


Figure 9–5, where we assume firm 2's output is given by Q_2^*. Since firm 1 believes firm 2 will produce this output regardless of what firm 1 does, it chooses its output level to maximize profits when firm 2 produces Q_2^*. One possibility is for firm 1 to produce Q_1^A units of output, which would correspond to point A on isoprofit curve π_1^A. However, this decision does not maximize profits because by expanding output to Q_1^B, firm 1 moves to a higher isoprofit curve (π_1^B, which corresponds to point B). Notice that profits can be further increased if firm 1 expands output to Q_1^C, which is associated with isoprofit curve π_1^C.

It is not profitable for firm 1 to increase output beyond Q_1^C, given that firm 2 produces Q_2^*. To see this, suppose firm 1 expanded output to, say, Q_1^D. This would result in a combination of outputs that corresponds to point D, which lies on an isoprofit curve that yields lower

Figure 9–5

Firm 1's Best Response to Firm 2's Output



profits. We conclude that the profit-maximizing output for firm 1 is Q_1^C whenever firm 2 produces Q_2^* units. This should not surprise you: This is exactly the output that corresponds to firm 1's reaction function.

To maximize profits, firm 1 pushes its isoprofit curve as far down as possible (as close as possible to the monopoly point), until it is just tangential to the given output of firm 2. This tangency occurs at point C in Figure 9–5.

DEMONSTRATION PROBLEM 9–5

Graphically depict isoprofit curves for firm 2, and explain the relation between points on the isoprofit curves and firm 2's reaction function.

ANSWER:

Isoprofit curves for firm 2 are the mirror image of those for firm 1. Representative isoprofit curves are depicted in Figure 9–6. Points G, A, and F lie on the same isoprofit curve and thus yield the same level of profits for firm 2. These profits are π_1, which are less than those of curves π_2 and π_3. As the isoprofit curves get closer to the monopoly point, the level of profits for firm 2 increases. The isoprofit curves begin to bend backward at the point where they intersect the reaction function.

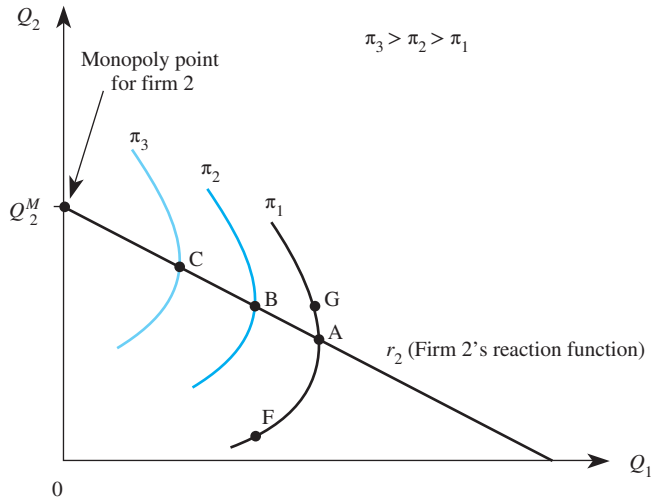


Figure 9–6
Firm 2's Reaction Function and Isoprofit Curves

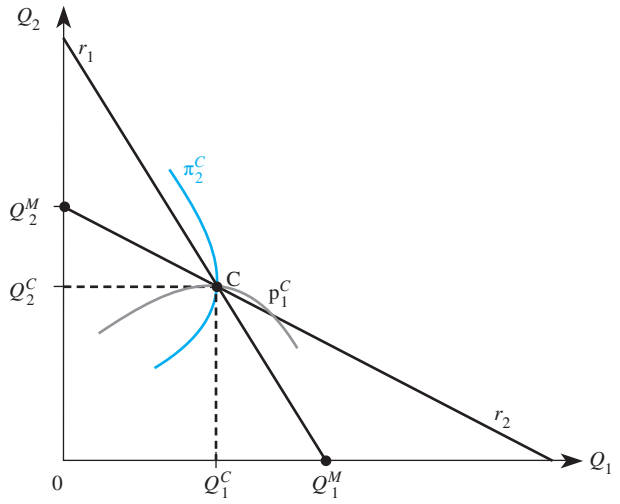
We can use isoprofit curves to illustrate the profits of each firm in a Cournot equilibrium. Recall that Cournot equilibrium is determined by the intersection of the two firms' reaction functions, such as point C in Figure 9–7. Firm 1's isoprofit curve through point C is given by π_1^C, and firm 2's isoprofit curve is given by π_2^C.

Changes in Marginal Costs

In a Cournot oligopoly, the effect of a change in marginal cost is very different from that in a Sweezy oligopoly. To see why, suppose the firms initially are in equilibrium at point E in Figure 9–8, where firm 1 produces Q_1^* units and firm 2 produces Q_2^* units. Now suppose firm 2's marginal cost declines. At the given level of output, marginal revenue remains unchanged but marginal cost is reduced. This means that for firm 2, marginal revenue exceeds the lower marginal cost, and it is optimal to produce more output for any given level of Q_1. Graphically,

Figure 9–7

Cournot Equilibrium

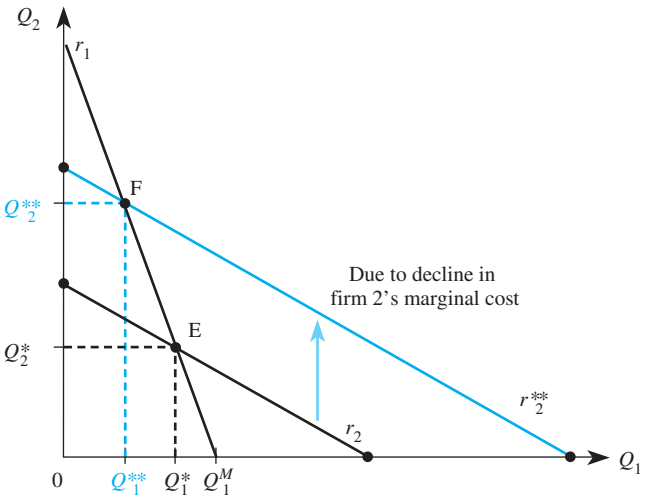


this shifts firm 2's reaction function up from r_2 to r_2^{**}, leading to a new Cournot equilibrium at point F. Thus, the reduction in firm 2's marginal cost leads to an increase in firm 2's output, from Q_2^* to Q_2^{**}, and a decline in firm 1's output from Q_1^* to Q_1^{**}. Firm 2 enjoys a larger market share due to its improved cost situation.

The reason for the difference between the preceding analysis and the analysis of Sweezy oligopoly is the difference in the way a firm perceives how other firms will respond to a change in its decisions. These differences lead to differences in the way a manager should optimally respond to a reduction in the firm's marginal cost. If the manager believes other firms will follow price reductions but not price increases, the Sweezy model applies. In this instance, we learned that it may be optimal to continue to produce the same level of output even if marginal cost declines. If the manager believes other firms will maintain their existing output levels if the firm expands output, the Cournot model applies. In this case, it is optimal to expand output if marginal cost declines. The most important ingredient in making managerial decisions in markets characterized by interdependence is obtaining an accurate grasp of how other firms in the market will respond to the manager's decisions.

Figure 9–8

Effect of Decline in Firm 2's Marginal Cost on Cournot Equilibrium



Collusion

Whenever a market is dominated by only a few firms, firms can benefit at the expense of consumers by "agreeing" to restrict output or, equivalently, to charge higher prices. Such an act by firms is known as *collusion*. In the next chapter, we will devote considerable attention to collusion; for now, it is useful to use the model of Cournot oligopoly to show why such an incentive exists.

In Figure 9–9, point C corresponds to a Cournot equilibrium; it is the intersection of the reaction functions of the two firms in the market. The equilibrium profits of firm 1 are given by isoprofit curve π_1^C and those of firm 2 by π_2^C. Notice that the shaded lens-shaped area in Figure 9–9 contains output levels for the two firms that yield higher profits for both firms than they earn in a Cournot equilibrium. For example, at point D each firm produces less output and enjoys greater profits since each of the firms' isoprofit curves at point D is closer to the respective monopoly point. In effect, if each firm agreed to restrict output, the firms could charge higher prices and earn higher profits. The reason is easy to see. Firm 1's profits would be highest at point A, where it is a monopolist. Firm 2's profits would be highest at point B, where it is a monopolist. If each firm "agreed" to produce an output that in total equaled the monopoly output, the firms would end up somewhere on the line connecting points A and B. In other words, any combination of outputs along line AB would maximize total industry profits.

The outputs on the line segment containing points E and F in Figure 9–9 thus maximize total industry profits, and since they are inside the lens-shaped area, they also yield both firms higher profits than would be earned if the firms produced at point C (the Cournot equilibrium). If the firms colluded by restricting output and splitting the monopoly profits, they would end up at a point like D, earning higher profits of π_1^{collude} and π_2^{collude}. At this point, the corresponding market price and output are identical to those arising under monopoly: Collusion leads to a price that exceeds marginal cost, an output below the socially optimal level, and a deadweight loss. However, the colluding firms enjoy higher profits than they would earn if they competed as Cournot oligopolists.

It is not easy for firms to reach such a collusive agreement, however. We will analyze this point in greater detail in the next chapter, but we can use our existing framework to see why

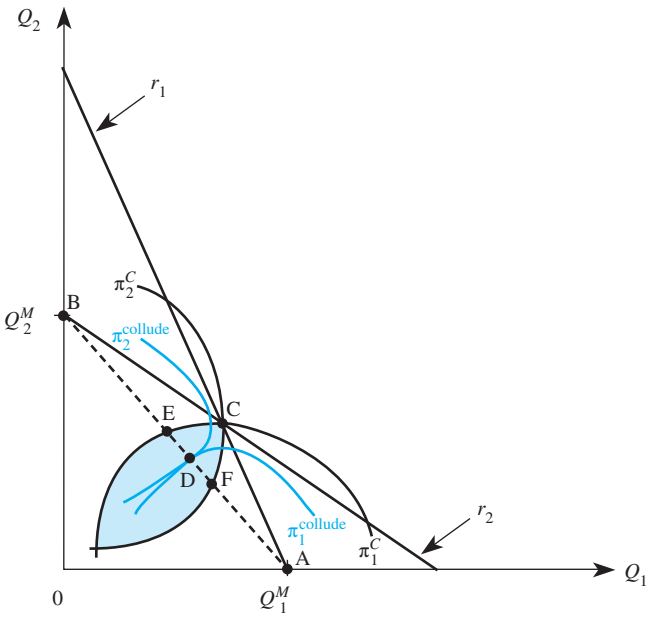
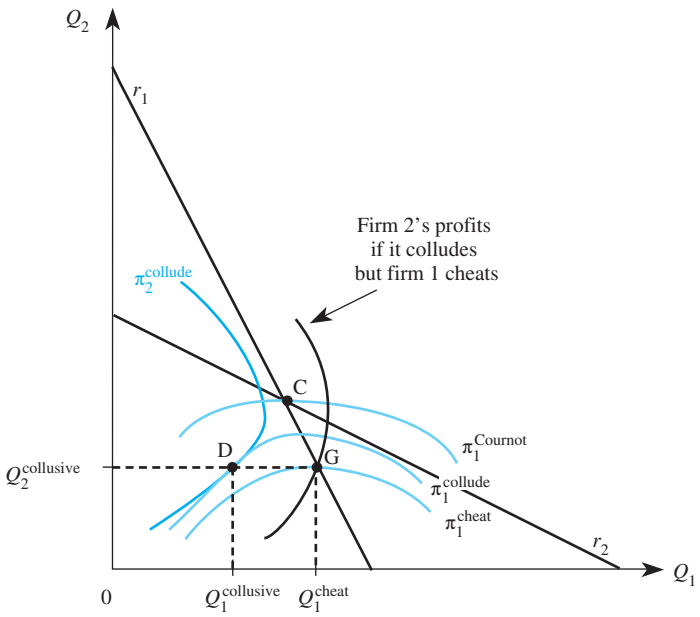


Figure 9–9
The Incentive to Collude in a Cournot Oligopoly

Figure 9–10

The Incentive to Renege on Collusive Agreements in Cournot Oligopoly



collusion is sometimes difficult. Suppose firms agree to collude, with each firm producing the collusive output associated with point D in Figure 9–10 to earn collusive profits. Given that firm 2 produces $Q_2^{collusive}$, firm 1 has an incentive to "cheat" on the collusive agreement by expanding output to point G. At this point, firm 1 earns even higher profits than it would by colluding since $\pi_1^{cheat} > \pi_1^{collude}$. This suggests that a firm can gain by inducing other firms to restrict output and then expanding its own output to earn higher profits at the expense of its collusion partners. Because firms know this incentive exists, it is often difficult for them to reach collusive agreements in the first place. This problem is amplified by the fact that firm 2 in Figure 9–10 earns less at point G (where firm 1 cheats) than it would have earned at point C (the Cournot equilibrium).

INSIDE BUSINESS 9–1

OPEC Members Can't Help but Cheat

The Organization of Petroleum Exporting Countries (OPEC) routinely meets to set quotas for oil production by its member countries. The world's major oil-producing countries compete as Cournot oligopolists that choose the quantity of oil to supply to the market each day. The quotas set by the OPEC members represent a collusive agreement designed to reduce global oil production and raise profits above those that would result in a competitive equilibrium. However, as shown earlier in Figure 9–10, each member country has a strong incentive to "cheat" by bolstering its production, given that the other members are maintaining the agreed-upon low production levels. Consequently, it should be no surprise that OPEC has a long history of its members cheating on their agreements by exceeding their quotas. In 2010, a global surge in demand for oil provided even greater incentives to cheat, resulting in a six-year high in "overproduction" by member countries relative to the agreed-upon level. OPEC overproduction continued to be a problem into 2017, with even greater downward pressure on global prices coming from increased U.S. production.

SOURCE: "OPEC Still Overproducing: Scapegoats U.S. Shale," OilPrice.com, July 12, 2017; G. Smith and M. Habiby, "OPEC Cheating Most Since 2004 as $100 Oil Heralds More Supply," Bloomberg.com, December 13, 2010.

Stackelberg Oligopoly

Up until this point, we have analyzed oligopoly situations that are symmetric in that firm 2 is the "mirror image" of firm 1. In many oligopoly markets, however, firms differ from one another. In a **Stackelberg oligopoly**, firms differ with respect to when they make decisions. Specifically, one firm (the leader) is assumed to make an output decision before the other firms. Given knowledge of the leader's output, all other firms (the followers) take as given the leader's output and choose outputs that maximize profits. Thus, in a Stackelberg oligopoly, each follower behaves just like a Cournot oligopolist. In fact, the leader does not take the followers' outputs as given but instead chooses an output that maximizes profits given that each follower will react to this output decision according to a Cournot reaction function.

Stackelberg oligopoly
An industry in which (1) there are few firms serving many consumers, (2) firms produce either differentiated or homogeneous products, (3) a single firm (the leader) chooses an output before rivals select their outputs, (4) all other firms (the followers) take the leader's output as given and select outputs that maximize profits given the leader's output, and (5) barriers to entry exist.

An industry is characterized as a Stackelberg oligopoly if

1. There are few firms serving many consumers.
2. The firms produce either differentiated or homogeneous products.
3. A single firm (the leader) chooses an output before all other firms choose their outputs.
4. All other firms (the followers) take as given the output of the leader and choose outputs that maximize profits given the leader's output.
5. Barriers to entry exist.

To illustrate how a Stackelberg oligopoly works, let us consider a situation where there are only two firms. Firm 1 is the *leader* and thus has a "first-mover" advantage; that is, firm 1 produces before firm 2. Firm 2 is the *follower* and maximizes profit given the output produced by the leader.

Because the follower produces after the leader, the follower's profit-maximizing level of output is determined by its reaction function. This is denoted by r_2 in Figure 9–11. However, the leader knows the follower will react according to r_2. Consequently, the leader must choose the level of output that will maximize its profits given that the follower reacts to whatever the leader does.

How does the leader choose the output level to produce? Since it knows the follower will produce along r_2, the leader simply chooses the point on the follower's reaction curve that corresponds to the highest level of profits. Because the leader's profits increase as the

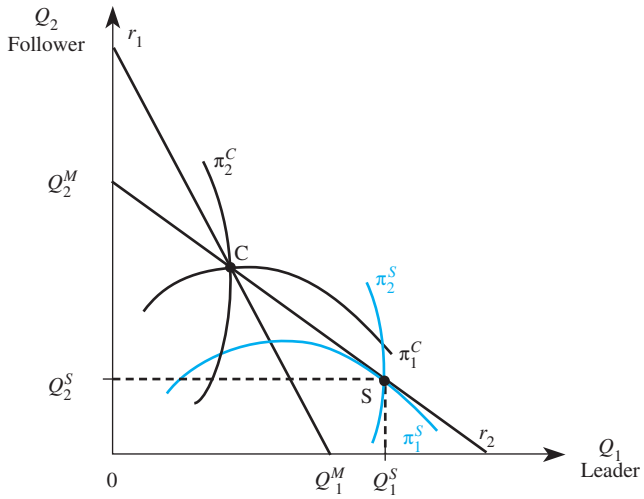


Figure 9–11
Stackelberg Equilibrium

isoprofit curves get closer to the monopoly output, the resulting choice by the leader will be at point S in Figure 9–11. This isoprofit curve, denoted π_1^S, yields the highest profits consistent with the follower's reaction function. It is tangential to firm 2's reaction function. Thus, the leader produces Q_1^S. The follower observes this output and produces Q_2^S, which is the profit-maximizing response to Q_1^S. The corresponding profits of the leader are given by π_1^S, and those of the follower by π_2^S. Notice that the leader's profits are higher than they would be in Cournot equilibrium (point C), and the follower's profits are lower than in Cournot equilibrium. By getting to move first, the leader earns higher profits than would otherwise be the case.

The algebraic solution for a Stackelberg oligopoly can also be obtained, provided firms have information about market demand and costs. In particular, recall that the follower's decision is identical to that of a Cournot model. For instance, with homogeneous products, linear demand, and constant marginal cost, the output of the follower is given by the reaction function

$$Q_2 = r_2(Q_1) = \frac{a - c_2}{2b} - \frac{1}{2}Q_1$$

which is simply the follower's Cournot reaction function. However, the leader in the Stackelberg oligopoly takes into account this reaction function when it selects Q_1. With a linear inverse demand function and constant marginal costs, the leader's profits are

$$\pi_1 = \left\{a - b\left[Q_1 + \left(\frac{a - c_2}{2b} - \frac{1}{2}Q_1\right)\right]\right\}Q_1 - c_1Q_1$$

The leader chooses Q_1 to maximize this profit expression. It turns out that the value of Q_1 that maximizes the leader's profits is

$$Q_1 = \frac{a + c_2 - 2c_1}{2b}$$

INSIDE BUSINESS 9–2

Commitment in Stackelberg Oligopoly

In the Stackelberg oligopoly model, the leader obtains a first-mover advantage by committing to produce a large quantity of output. The follower's best response, upon observing the leader's choice, is to produce less output. Thus, the leader gains market share and profit at the expense of his rival. Evidence from the real world as well as experimental laboratories suggests that the benefits of commitment in Stackelberg oligopolies can be sizeable—provided it is not too costly for the follower to observe the leader's output.

For example, the South African communications company Telkom once enjoyed a 177 percent increase in its net profits, thanks to a first-mover advantage it obtained by getting the jump on its rival. Telkom committed to the Stackelberg output by signing long-term contracts with 90 percent of South Africa's companies. By committing to this high output, Telkom ensured that its rival's best response was a low level of output.

The classic Stackelberg model assumes that the follower costlessly observes the leader's quantity. In practice, however, it is sometimes costly for the follower to gather information about the quantity of output produced by the leader. Professors Morgan and Várdy have conducted a variety of laboratory experiments to investigate whether these "observation costs" reduce the leader's ability to secure a first-mover advantage. The results of their experiments indicate that when the observation costs are small, the leader captures the bulk of the profits and maintains a first-mover advantage. As the second-mover's observation costs increase, the profits of the leader and follower become more equal.

SOURCES: Neels Blom, "Telkom Makes Life Difficult for Any Potential Rival," *Business Day* (Johannesburg), June 9, 2004; J. Morgan, and F. Várdy, "An Experimental Study of Commitment in Stackelberg Games with Observation Costs," *Games and Economic Behavior* 20, no. 2 (November 2004), pp. 401–23.

Formula: Equilibrium Outputs in Stackelberg Oligopoly. For the linear (inverse) demand function

$$P = a - b(Q_1 + Q_2)$$

and cost functions

$$C_1(Q_1) = c_1 Q_1$$
$$C_2(Q_2) = c_2 Q_2$$

the follower sets output according to the Cournot reaction function

$$Q_2 = r_2(Q_1) = \frac{a - c_2}{2b} - \frac{1}{2}Q_1$$

The leader's output is

$$Q_1 = \frac{a + c_2 - 2c_1}{2b}$$

A CALCULUS ALTERNATIVE

To maximize profits, firm 1 sets output so as to maximize

$$\pi_1 = \left\{a - b\left[Q_1 + \left(\frac{a - c_2}{2b} - \frac{1}{2}Q_1\right)\right]\right\}Q_1 - c_1 Q_1$$

The first-order condition for maximizing profits is

$$\frac{d\pi_1}{dQ_1} = a - 2bQ_1 - \left(\frac{a - c_2}{2}\right) + bQ_1 - c_1 = 0$$

Solving for Q_1 yields the profit-maximizing level of output for the leader:

$$Q_1 = \frac{a + c_2 - 2c_1}{2b}$$

The formula for the follower's reaction function is derived in the same way as that for a Cournot oligopolist.

DEMONSTRATION PROBLEM 9–6

Suppose the inverse demand function for two firms in a homogeneous-product Stackelberg oligopoly is given by

$$P = 50 - (Q_1 + Q_2)$$

and cost functions for the two firms are

$$C_1(Q_1) = 2Q_1$$
$$C_2(Q_2) = 2Q_2$$

Firm 1 is the leader, and firm 2 is the follower.

1. What is firm 2's reaction function?
2. What is firm 1's output?
3. What is firm 2's output?
4. What is the market price?

ANSWER:

1. Using the formula for the follower's reaction function, we find
$$Q_2 = r_2(Q_1) = 24 - \frac{1}{2}Q_1$$
2. Using the formula given for the Stackelberg leader, we find
$$Q_1 = \frac{50 + 2 - 4}{2} = 24$$
3. By plugging the answer to part 2 into the reaction function in part 1, we find the follower's output to be
$$Q_2 = 24 - \frac{1}{2}(24) = 12$$
4. The market price can be found by adding the two firms' outputs together and plugging the answer into the inverse demand function:
$$P = 50 - (12 + 24) = 14$$

In general, price exceeds marginal cost in a Stackelberg oligopoly, meaning industry output is below the socially efficient level. This translates into a deadweight loss, but the deadweight loss is lower than that arising under pure monopoly.

Bertrand Oligopoly

To further highlight the fact that there is no single model of oligopoly a manager can use in all circumstances and to illustrate that oligopoly power does not always imply firms will make positive profits, we will next examine Bertrand oligopoly. The treatment here assumes the firms sell identical products and that consumers are willing to pay the (finite) monopoly price for the good.

Bertrand oligopoly
An industry in which (1) there are few firms serving many consumers, (2) firms produce identical products at a constant marginal cost, (3) firms compete in price and react optimally to competitors' prices, (4) consumers have perfect information and there are no transaction costs, and (5) barriers to entry exist.

An industry is characterized as a **Bertrand oligopoly** if

1. There are few firms in the market serving many consumers.
2. The firms produce identical products at a constant marginal cost.
3. Firms engage in price competition and react optimally to prices charged by competitors.
4. Consumers have perfect information and there are no transaction costs.
5. Barriers to entry exist.

From the viewpoint of the manager, Bertrand oligopoly is undesirable: It leads to zero economic profits even if there are only two firms in the market. From the viewpoint of consumers, Bertrand oligopoly is desirable: It leads to precisely the same outcome as a perfectly competitive market.

To explain more precisely the preceding assertions, consider a Bertrand duopoly. Because consumers have perfect information, and zero transaction costs, and because the products are identical, all consumers will purchase from the firm charging the lowest price. For concreteness, suppose firm 1 charges the monopoly price. By slightly undercutting this price, firm 2 would capture the entire market and make positive profits, while firm 1 would sell nothing. Therefore, firm 1 would retaliate by undercutting firm 2's lower price, thus recapturing the entire market.

INSIDE BUSINESS 9–3

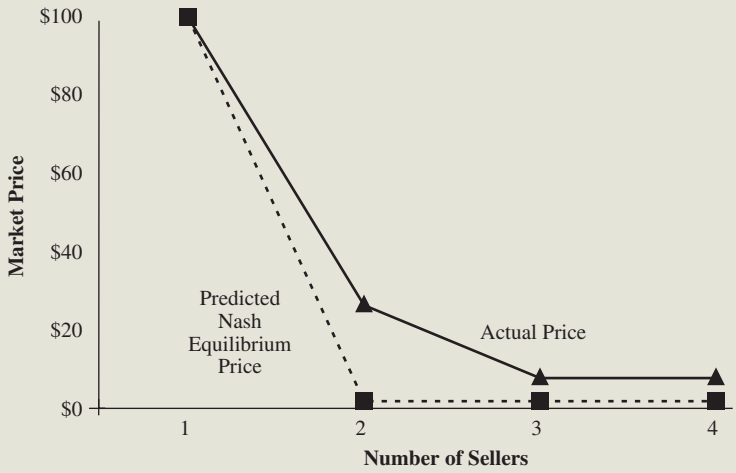
Price Competition and the Number of Sellers: Evidence from Online and Laboratory Markets

Does competition really force homogeneous-product Bertrand oligopolists to price at marginal cost? Two studies – one experimental and one using market data – arrive at a very similar conclusion: the answer critically depends on the number of sellers in the market.

Professors Baye, Morgan, and Scholten examined 4 million daily price observations for thousands of products sold at a leading price comparison site. Price comparison sites, such as Shopper.com and Kelkoo.com, permit online shoppers to obtain a list of prices that different firms charge for homogeneous products. Theory would suggest that—in online markets where firms sell identical products and consumers have excellent information about firms' prices—firms will fall victim to the "Bertrand trap." Contrary to this expectation, the authors found that the "gap" between the two lowest prices charged for identical products sold online averaged 22 percent when only two firms sold the product, but declined to less than 3 percent when more than 20 firms listed prices for the homogeneous products. Expressed differently, real-world firms appear to be able to escape from the Bertrand trap when there are relatively few sellers but fall victim to the trap when there are more competitors.

Professors Dufwenberg and Gneezy provide experimental evidence that corroborates this finding. These authors conducted a sequence of experiments with subjects who competed in a homogeneous product pricing game in which marginal cost was $2 and the monopoly (collusive) price was $100. In the experiments, sellers offering the lowest price "win" and earned real cash. As the accompanying figure shows, theory predicts that a monopolist would price at $100 and that prices would fall to $2 in markets with two, three, or four sellers. In reality, the average market price (the winning price) was about $27 when there were only two sellers, and declined to about $9 in sessions with three or four sellers. In practice, prices (and profits) rapidly decline as the number of sellers increases—but not nearly as sharply as predicted by theory.

SOURCES: Martin Dufwenberg and Uri Gneezy, "Price Competition and Market Concentration: An Experimental Study," *International Journal of Industrial Organization* 18 (2000), pp. 7–22; Michael R. Baye, John Morgan, and Patrick Scholten, "Price Dispersion in the Small and in the Large: Evidence from an Internet Price Comparison Site," *Journal of Industrial Economics* 52 (2004), pp. 463–96.



When would this "price war" end? When each firm charged a price that equaled marginal cost: $P_1 = P_2 = MC$. Given the price of the other firm, neither firm would choose to lower its price, for then its price would be below marginal cost and it would make a loss. Also, no firm would want to raise its price, for then it would sell nothing. In short, Bertrand oligopoly and

homogeneous products lead to a situation where each firm charges marginal cost and economic profits are zero. Since $P = MC$, homogeneous-product Bertrand oligopoly results in a socially efficient level of output. Indeed, total market output corresponds to that in a perfectly competitive industry, and there is no deadweight loss.

Chapters 10 and 11 provide strategies that managers can use to mitigate the "Bertrand trap"—the cut-throat competition that ensues in homogeneous-product Bertrand oligopoly. As we will see, the key is to either raise switching costs or eliminate the perception that the firms' products are identical. The product differentiation induced by these strategies permits firms to price above marginal cost without losing customers to rivals. The appendix to this chapter illustrates that, under differentiated-product price competition, reaction functions are upward sloping and equilibrium occurs at a point where prices exceed marginal cost. This explains, in part, why firms such as Kellogg's and General Mills spend millions of dollars on advertisements designed to persuade consumers that their competing brands of corn flakes are not identical. If consumers did not view the brands as differentiated products, these two makers of breakfast cereal would have to price at marginal cost.

COMPARING OLIGOPOLY MODELS

To see further how each form of oligopoly affects firms, it is useful to compare the models covered in this chapter in terms of individual firm outputs, prices in the market, and profits per firm. To accomplish this, we will use the same market demand and cost conditions for each firm when examining results for each model. The inverse market demand function we will use is

$$P = 1{,}000 - (Q_1 + Q_2)$$

The cost function of each firm is identical and given by

$$C_i(Q_i) = 4Q_i$$

so the marginal cost of each firm is 4. We will now see how outputs, prices, and profits vary according to the type of oligopolistic interdependence that exists in the market.

Cournot

We will first examine Cournot equilibrium. The profit function for the individual Cournot firm given the preceding inverse demand and cost functions is

$$\pi_i = [1{,}000 - (Q_1 + Q_2)]Q_i - 4Q_i$$

The reaction functions of the Cournot oligopolists are

$$Q_1 = r_1(Q_2) = 498 - \frac{1}{2}Q_2$$

$$Q_2 = r_2(Q_1) = 498 - \frac{1}{2}Q_1$$

Solving these two reaction functions for Q_1 and Q_2 yields the Cournot equilibrium outputs, which are $Q_1 = Q_2 = 332$. Total output in the market thus is 664, which leads to a price of \$336. Plugging these values into the profit function reveals that each firm earns profits of \$110,224.

Stackelberg

With these demand and cost functions, the output of the Stackelberg leader is

$$Q_1 = \frac{a + c_2 - 2c_1}{2b} = \frac{1{,}000 + 4 - 2(4)}{2} = 498$$

The follower takes this level of output as given and produces according to its reaction function:

$$Q_2 = r_2(Q_1) = \frac{a - c_2}{2b} - \frac{1}{2}Q_1 = \frac{1{,}000 - 4}{2} - \frac{1}{2}(498) = 249$$

Total output in the market thus is 747 units. Given the inverse demand function, this output yields a price of $253. Total market output is higher in a Stackelberg oligopoly than in a Cournot oligopoly. This leads to a lower price in the Stackelberg oligopoly than in the Cournot oligopoly. The profits for the leader are $124,002, while the follower earns only $62,001 in profits. The leader does better in a Stackelberg oligopoly than in a Cournot oligopoly due to its first-mover advantage. However, the follower earns lower profits in a Stackelberg oligopoly than in a Cournot oligopoly.

Bertrand

The Bertrand equilibrium is simple to calculate. Recall that firms that engage in Bertrand competition end up setting price equal to marginal cost. Therefore, with the given inverse demand and cost functions, price equals marginal cost ($4) and profits are zero for each firm. Total market output is 996 units. Given symmetric firms, each firm gets half of the market.

Collusion

Finally, we will determine the collusive outcome, which results when the firms choose output to maximize total industry profits. When firms collude, total industry output is the monopoly level, based on the market inverse demand curve. Since the market inverse demand curve is

$$P = 1{,}000 - Q$$

the associated marginal revenue is

$$MR = 1{,}000 - 2Q$$

Notice that this marginal revenue function assumes the firms act as a single profit-maximizing firm, which is what collusion is all about. Setting marginal revenue equal to marginal cost (which is $4) yields

$$1{,}000 - 2Q = 4$$

or $Q = 498$. Thus, total industry output under collusion is 498 units, with each firm producing half. The price under collusion is

$$P = 1{,}000 - 498 = \$502$$

Each firm earns profits of $124,002.

Comparison of the outcomes in these different oligopoly situations reveals the following: The highest market output is produced in a Bertrand oligopoly, followed by Stackelberg, then Cournot, and finally collusion. Profits are highest for the Stackelberg leader and the colluding firms, followed by Cournot, then the Stackelberg follower. The Bertrand oligopolists earn the lowest level of profits. If you become a manager in an oligopolistic market, it is important to

INSIDE BUSINESS 9–4

Using a Spreadsheet to Calculate Cournot, Stackelberg, and Collusive Outcomes

Available at www.mhhe.com/baye10e, there are three files named *CournotSolver.xls*, *StackelbergSolver.xls*, and *CollusionSolver.xls*. With a few clicks of a mouse, you can use these files to calculate the profit-maximizing price and quantity and the maximum profits for the following oligopoly situations.

COURNOT DUOPOLY

In a Cournot duopoly, each firm believes the other will hold its output constant as it changes its own output. Therefore, the profit-maximizing output level for firm 1 depends on firm 2's output. Each firm will adjust its profit-maximizing output level until the point where the two firms' reaction functions are equal. This point corresponds to the Cournot equilibrium. At the Cournot equilibrium, neither firm has an incentive to change its output, given the output of the other firm. Step-by-step instructions for computing the Cournot equilibrium outputs, price, and profits are included in the file named *CournotSolver.xls*.

STACKELBERG DUOPOLY

The Stackelberg duopoly model assumes that one firm is the leader while the other is a follower. The leader has a first-mover advantage and selects its profit-maximizing output level, knowing that the follower will move second and thus react to this decision according to a Cournot reaction function. Given the leader's output decision, the follower takes the leader's output as given and chooses its profit-maximizing level of output. Step-by-step instructions for computing the Stackelberg equilibrium outputs, price, and profits are included in the file named *StackelbergSolver.xls*.

COLLUSIVE DUOPOLY (THE MONOPOLY SOLUTION)

Under collusion, duopolists produce a total output that corresponds to the monopoly output. In a symmetric situation, the two firms share the market equally, each producing one-half of the monopoly output. Step-by-step instructions for computing the collusive (monopoly) output, price, and profits are included in the file named *CollusionSolver.xls*.

recognize that your optimal decisions and profits will vary depending on the type of oligopolistic interaction that exists in the market.

CONTESTABLE MARKETS

Thus far, we have emphasized strategic interaction among existing firms in an oligopoly. Strategic interaction can also exist between existing firms and potential entrants into a market. To illustrate the importance of this interaction and its similarity to Bertrand oligopoly, let us suppose a market is served by a single firm, but there is another firm (a potential entrant) free to enter the market whenever it chooses.

contestable market
A market in which (1) all firms have access to the same technology, (2) consumers respond quickly to price changes, (3) existing firms cannot respond quickly to entry by lowering their prices, and (4) there are no sunk costs.

Before we continue our analysis, let us make more precise what we mean by *free entry*. What we have in mind here is what economists refer to as a **contestable market**. A market is contestable if

1. All producers have access to the same technology.
2. Consumers respond quickly to price changes.
3. Existing firms cannot respond quickly to entry by lowering price.
4. There are no sunk costs.

If these four conditions hold, incumbent firms (existing firms in the market) have no market power over consumers. That is, the equilibrium price corresponds to marginal cost, and firms earn zero economic profits. This is true even if there is only one existing firm in the market.

The reason for this result follows. If existing firms charged a price in excess of what they required to cover costs, a new firm could immediately enter the market with the same technology and charge a price slightly below the existing firms' prices. Since the incumbents cannot quickly respond by lowering their prices, the entrant would get all the incumbents' customers by charging the lower price. Because the incumbents know this, they have no alternative but to charge a low price equal to the cost of production to keep out the entrant. Thus, if a market is perfectly contestable, incumbents are disciplined by the threat of entry by new firms.

An important condition for a contestable market is the absence of sunk costs. In this context, **sunk costs** are defined as costs a new entrant must bear that cannot be recouped upon exiting the market. For example, if an entrant pays $100,000 for a truck to enter the market for moving services, but receives $80,000 for the truck upon exiting the market, $20,000 represents the sunk cost of entering the market. Similarly, if a firm pays a nonrefundable fee of $20,000 for the nontransferable right to lease a truck for a year to enter the market, this reflects a sunk cost associated with entry. Or if a small firm must incur a loss of $2,000 per month for six months while waiting for customers to "switch" to that company, it incurs $12,000 of sunk costs.

sunk cost
A cost that is forever lost after it has been paid.

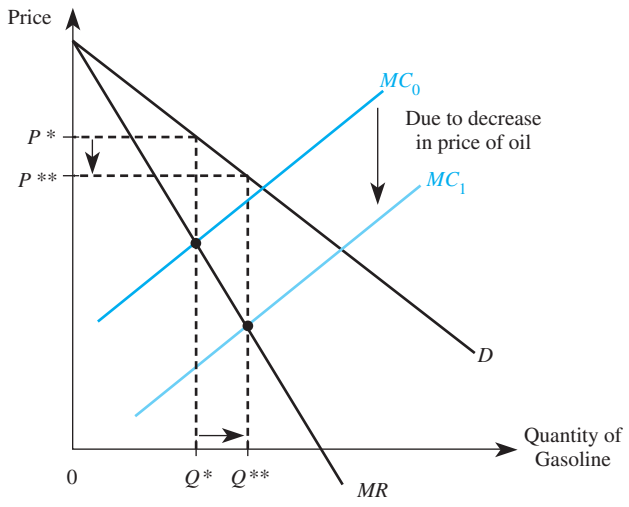
Sunk costs are important for the following reason: Suppose incumbent firms are charging high prices, and a new entrant calculates that it could earn $70,000 by entering the market and charging a lower price than the existing firms. This calculation is, of course, conditional upon the existing firms continuing to charge their present prices. Suppose that to enter, the firm must pay sunk costs of $20,000. If it enters the market and the incumbent firms keep charging the high price, entry is profitable; indeed, the firm will make $70,000. However, if the incumbents do not continue charging the high price but instead lower their prices, the entrant can be left with no customers. The incumbents cannot lower their prices quickly, so the entrant may earn some profits early on; however, it likely will not earn enough profit to offset its sunk costs before the incumbents lower their prices. In this instance, the entrant would need to earn enough profit immediately after entering to cover its sunk cost of $20,000. In short, if a potential entrant must pay sunk costs to enter a market and has reason to believe incumbents will respond to entry by lowering their prices, it may find it unprofitable to enter even though prices are high. The end result is that with sunk costs, incumbents may not be disciplined by potential entry, and higher prices may prevail. Chapters 10 and Module Group A provide more detailed coverage of strategic interactions between incumbents and potential entrants.

ANSWERING THE headLINE

Although the price of crude oil fell, in a few areas there were no declines in the price of gasoline. The headline asks whether this is evidence of collusion by gasoline stations in those areas. To answer this question, notice that oil is an input in producing gasoline. A reduction in the price of oil leads to a reduction in the marginal cost of producing gasoline—say, from MC_0 to MC_1. If gasoline stations were colluding, a reduction in marginal cost would lead the firms to lower the price of gasoline. To see this, recall that under collusion, both the industry output and the price are set at the monopoly level and price. Thus, if firms were colluding when marginal cost was MC_0, the output that would maximize collusive profits would occur where $MR = MC_0$ in Figure 9–12. Thus, Q^* and P^* in Figure 9–12 denote the collusive output and price when marginal cost is MC_0. A reduction in the marginal cost of producing gasoline would shift down the marginal cost curve to MC_1, leading to a greater collusive output (Q^{**}) and a lower price (P^{**}). Thus, collusion cannot explain why some gasoline firms failed to lower their prices. Had these firms been colluding, they would have found it profitable to lower gasoline prices when the price of oil fell.

Figure 9–12

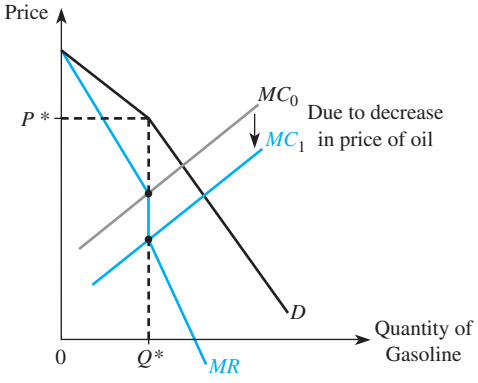
Reduction in Marginal Cost Lowers the Collusive Price



Since collusion is not the reason gasoline prices in some areas did not fall when the marginal cost of gasoline declined, one may wonder what could explain the pricing behavior in these markets. One explanation is that these gasoline producers are Sweezy oligopolists. A Sweezy oligopolist operates on the assumption that if she raises her price, her competitors will ignore the change. However, if she lowers her price, all will follow suit and lower their prices. Figure 9–13 reveals that Sweezy oligopolists will not decrease gasoline prices when marginal cost falls from MC_0 to MC_1. They know they cannot increase their profits or market share by lowering their price because all of their competitors will lower prices if they do.

Figure 9–13

Price Rigidity in Sweezy Oligopoly



SUMMARY

In this chapter, we examined several models of markets that consist of a small number of strategically interdependent firms. These models help explain several possible types of behavior when a market is characterized by oligopoly. You should now be familiar with the Sweezy, Cournot, Stackelberg, and Bertrand models.

In the Cournot model, a firm chooses quantity based on its competitors' given levels of output. Each firm earns some economic profits. Bertrand competitors, on the other hand, set prices given their rivals' prices. They end up charging a price equal to their marginal cost and earn zero economic profits. Sweezy oligopolists believe their

competitors will follow price decreases but will ignore price increases, leading to extremely stable prices even when costs change in the industry. Finally, Stackelberg oligopolies have a follower and a leader. The leader knows how the follower will behave, and the follower simply maximizes profits given what the leader has chosen. This leads to profits for each firm but much higher profits for the leader than for the follower.

The next chapter will explain in more detail how managers go about reaching equilibrium in oligopoly. For now, it should be clear that your decisions will affect others in your market and their decisions will affect you as well.

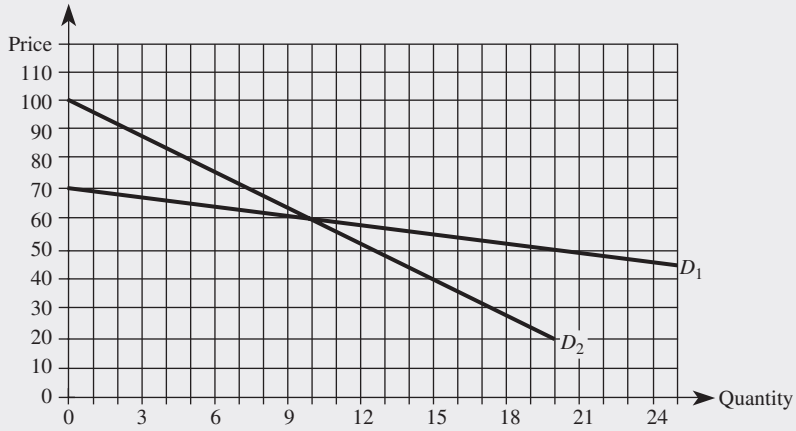
KEY TERMS AND CONCEPTS

Bertrand oligopoly
best-response (or reaction) function
collusion
contestable markets
Cournot equilibrium
Cournot oligopoly
duopoly
follower
isoprofit curve
leader
oligopoly
Stackelberg oligopoly
sunk costs
Sweezy oligopoly

CONCEPTUAL AND COMPUTATIONAL QUESTIONS

connect

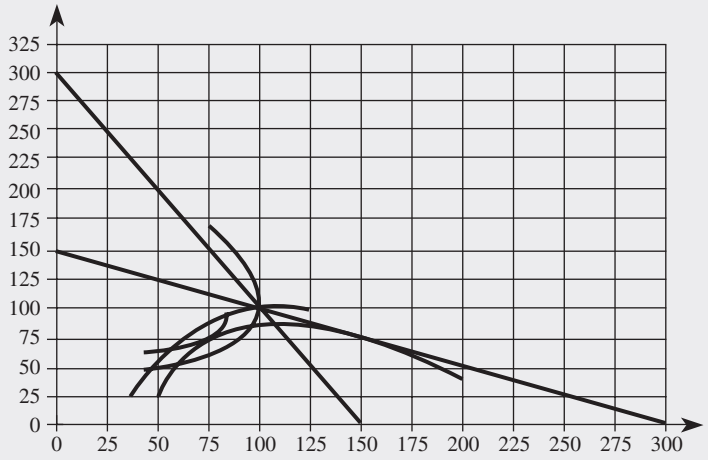
1. The graph that accompanies this question illustrates two demand curves for a firm operating in a differentiated-product oligopoly. Initially, the firm charges a price of $60 and produces 10 units of output. One of the demand curves is relevant when rivals match the firm's price changes; the other demand curve is relevant when rivals do not match price changes. *(LO1, LO2)*



   a. Which demand curve is relevant when rivals will match any price change?
   b. Which demand curve is relevant when rivals will *not* match any price change?
   c. Suppose the manager believes that rivals will match price cuts but will not match price increases.
      (1) What price will the firm be able to charge if it produces 20 units?
      (2) How many units will the firm sell if it charges a price of $70?
      (3) For what range in marginal cost will the firm continue to charge a price of $60?

2. Analysts have estimated inverse market demand in a homogeneous-product Cournot duopoly to be $P = 200 - 3(Q_1 + Q_2)$. They estimate costs to be $C_1(Q_1) = 26Q_1$ and $C_2(Q_2) = 32Q_2$. *(LO1, LO3)*
   a. Determine the reaction function for each firm.
   b. Calculate each firm's equilibrium output.
   c. Calculate the equilibrium market price.
   d. Calculate the profit each firm earns in equilibrium.

3. The following diagram illustrates the reaction functions and isoprofit curves for a homogeneous-product duopoly in which each firm produces at constant marginal cost. *(LO1, LO2, LO3)*



a. If your rival produces 50 units of output, what is your optimal level of output?
b. In equilibrium, how much will each firm produce in a Cournot oligopoly?
c. In equilibrium, what is the output of the leader and follower in a Stackelberg oligopoly?
d. How much output would be produced if the market were monopolized?
e. Suppose you and your rival agree to a collusive arrangement in which each firm produces half of the monopoly output.
(1) What is your output under the collusive arrangement?
(2) What is your optimal output if you believe your rival will live up to the agreement?

connect Excel Exercises

4. The inverse demand for a homogeneous-product Stackelberg duopoly is $P = 16{,}000 - 4Q$. The cost structures for the leader and the follower, respectively, are $C_L(Q_L) = 4{,}000Q_L$ and $C_F(Q_F) = 6{,}000Q_F$. *(LO2, LO3)*
a. What is the follower's reaction function?
b. Determine the equilibrium output level for both the leader and the follower.
c. Determine the equilibrium market price.
d. Determine the profits of the leader and the follower.

connect Excel Exercises

5. Consider a Bertrand oligopoly consisting of four firms that produce an identical product at a marginal cost of $140. Analysts estimate that the inverse market demand for this product is $P = 400 - 5Q$. *(LO2)*
a. Determine the equilibrium level of output in the market.
b. Determine the equilibrium market price.
c. Determine the profits of each firm.

6. Provide a real-world example of a market that approximates each oligopoly setting, and explain your reasoning. *(LO2)*
a. Cournot oligopoly.
b. Stackelberg oligopoly.
c. Bertrand oligopoly.

7. Two firms compete in a market to sell a homogeneous product with inverse demand function $P = 600 - 3Q$. Each firm produces at a constant marginal cost of $300 and has no fixed costs. Use this information to compare the output levels and profits in settings characterized by Cournot, Stackelberg, Bertrand, and collusive behavior. *(LO1, LO2, LO3)*

8. Consider a homogeneous-product duopoly where each firm initially produces at a constant marginal cost of $200 and there are no fixed costs. Determine what would happen to each firm's equilibrium output and profits if firm 2's marginal cost increased to $210 but firm 1's marginal cost remained constant at $200 in each of the following settings: *(LO1, LO2, LO3)*
   a. Cournot duopoly.
   b. Sweezy oligopoly.
9. Determine whether each of the following scenarios best reflects features of Sweezy, Cournot, Stackelberg, or Bertrand duopoly: *(LO2)*
   a. Neither manager expects her own output decision to impact the other manager's output decision.
   b. Each manager charges a price that is a best response to the price charged by the rival.
   c. The manager of one firm gets to observe the output of the rival firm before making its own output decision.
   d. The managers perceive that rivals will match price reductions but not price increases.
10. Suppose a single firm produces all of the output in a contestable market. Analysts determine that the market inverse demand function is $P = 150 - 2Q$, and the firm's cost function is $C(Q) = 4Q$. Determine the firm's equilibrium price and corresponding profits. *(LO4)*

PROBLEMS AND APPLICATIONS



11. Ford executives announced that the company would extend its most dramatic consumer incentive program in the company's long history—the Ford Drive America Program. The program provides consumers with either cash back or zero percent financing for new Ford vehicles. As the manager of a Ford franchise, how would you expect this program to impact your firm's bottom line? Explain. *(LO1, LO2)*
12. You are the manager of BlackSpot Computers, which competes directly with Condensed Computers to sell high-powered computers to businesses. From the two businesses' perspectives, the two products are indistinguishable. The large investment required to build production facilities prohibits other firms from entering this market, and existing firms operate under the assumption that the rival will hold output constant. Analysts have determined that the inverse market demand for computers is $P = 5{,}900 - Q$, and both firms produce at a marginal cost of $800 per computer. Currently, BlackSpot earns revenues of $4.25 million and profits (net of investment, R&D, and other fixed costs) of $890,000. The engineering department at BlackSpot has been steadily working on developing an assembly method that would dramatically reduce the marginal cost of producing these high-powered computers and has found a process that allows it to manufacture each computer at a marginal cost of $500. How will this technological advance impact your production and pricing plans? How will it impact BlackSpot's bottom line? *(LO1, LO2, LO3)*
13. The Hull Petroleum Company and Inverted V are retail gasoline franchises that compete in a local market to sell gasoline to consumers. Hull and Inverted V are located across the street from each other and can observe the prices posted on each other's marquees. Demand for gasoline in this market is $Q = 120 - 5P$, and both franchises obtain gasoline from their supplier at $3.00 per gallon. On the day that both franchises opened for business, each owner was observed changing the price of gasoline advertised on its marquee more than 10 times; the owner of Hull lowered its price to slightly undercut Inverted V's price, and the owner of Inverted V lowered its advertised price to beat Hull's price. Since then, prices appear to have stabilized. Under current conditions,

how many gallons of gasoline are sold in the market, and at what price? Would your answer differ if Hull had service attendants available to fill consumers' tanks but Inverted V was only a self-service station? Explain. *(LO1, LO2)*

14. You are the manager of the only firm worldwide that specializes in exporting fish products to Japan. Your firm competes against a handful of Japanese firms that enjoy a significant first-mover advantage. Recently, one of your Japanese customers has called to inform you that the Japanese legislature is considering imposing a quota that would reduce the number of pounds of fish products you are permitted to ship to Japan each year. Your first instinct is to call the trade representative of your country to lobby against the import quota. Is following through with your first instinct necessarily the best decision? Explain. *(LO2)*
15. The opening statement on the website of the Organization of Petroleum Exporting Countries (OPEC) says its members seek " . . . to secure an efficient, economic and regular supply of petroleum to consumers, a steady income to producers and a fair return on capital for those investing in the petroleum industry." To achieve this goal, OPEC attempts to coordinate and unify petroleum policies by raising or lowering its members' collective oil production. However, increased production by the United States, Russia, Oman, Mexico, Norway, and other non-OPEC countries has placed downward pressure on the price of crude oil. To achieve its goal of stable and fair oil prices, what must OPEC do to maintain the price of oil at its desired level? Do you think this will be easy for OPEC to do? Explain. *(LO1, LO2)*
16. Semi-Salt Industries began its operation in 1975 and remains the only firm in the world that produces and sells commercial-grade polyglutamate. While virtually anyone with a degree in college chemistry could replicate the firm's formula, due to the relatively high cost, Semi-Salt has decided not to apply for a patent. Despite the absence of patent protection, Semi-Salt has averaged accounting profits of 5.5 percent on investment since it began producing polyglutamate—a rate comparable to the average rate of interest that large banks paid on deposits over this period. Do you think Semi-Salt is earning monopoly profits? Why? *(LO4)*
17. You are the manager of a firm that competes against four other firms by bidding for government contracts. While you believe your product is better than the competition's, the government purchasing agent views the products as identical and purchases from the firm offering the best price. Total government demand is $Q = 1{,}500 - 5P$, and all five firms produce at a constant marginal cost of \$120. For security reasons, the government has imposed restrictions that permit a maximum of five firms to compete in this market; thus, entry by new firms is prohibited. A member of Congress is concerned because no restrictions have been placed on the price that the government pays for this product. In response, she has proposed legislation that would award each existing firm 20 percent of a contract for 700 units at a contracted price of \$160 per unit. Would you support or oppose this legislation? Explain. *(LO2)*
18. The market for a standard-sized cardboard container consists of two firms: CompositeBox and Fiberboard. As the manager of CompositeBox, you enjoy a patented technology that permits your company to produce boxes faster and at a lower cost than Fiberboard. You use this advantage to be the first to choose its profit-maximizing output level in the market. The inverse demand function for boxes is $P = 1{,}200 - 6Q$, CompositeBox's costs are $C_C(Q_C) = 60Q_C$, and Fiberboard's costs are $C_F(Q_F) = 120Q_F$. Ignoring antitrust considerations, would it be profitable for your firm to merge with Fiberboard? If not, explain why not; if so, put together an offer that would permit you to profitably complete the merger. *(LO1, LO2, LO3)*
19. You are the manager of Taurus Technologies, and your sole competitor is Spyder Technologies. The two firms' products are viewed as identical by most consumers. The relevant cost functions are $C(Q_i) = 4Q_i$, and the inverse market demand curve for

this unique product is given by $P = 160 - 2Q$. Currently, you and your rival simultaneously (but independently) make production decisions, and the price you fetch for the product depends on the total amount produced by each firm. However, by making an unrecoverable fixed investment of $200, Taurus Technologies can bring its product to market before Spyder finalizes production plans. Should you invest the $200? Explain. *(LO1, LO2, LO3)*

20. During the 1980s, most of the world's supply of lysine was produced by a Japanese company named Ajinomoto. Lysine is an essential amino acid that is an important livestock feed component. At this time, the United States imported most of the world's supply of lysine—more than 30,000 tons—to use in livestock feed at a price of $1.65 per pound. The worldwide market for lysine, however, fundamentally changed in 1991 when U.S.-based Archer Daniels Midland (ADM) began producing lysine—a move that doubled worldwide production capacity. Experts conjectured that Ajinomoto and ADM had similar cost structures and that the marginal cost of producing and distributing lysine was approximately $0.70 per pound. Despite ADM's entry into the lysine market, suppose demand remained constant at $Q = 208 - 80P$ (in millions of pounds). Shortly after ADM began producing lysine, the worldwide price dropped to $0.70. By 1993, however, the price of lysine shot back up to $1.65. Use the theories discussed in this chapter to provide a potential explanation for what happened in the lysine market. Support your answer with appropriate calculations. *(LO1, LO2)*
21. PC Connection and CDW are two online retailers that compete in an Internet market for digital cameras. While the products they sell are similar, the firms attempt to differentiate themselves through their service policies. Over the last couple of months, PC Connection has matched CDW's price cuts but has not matched its price increases. Suppose that when PC Connection matches CDW's price changes, the inverse demand curve for CDW's cameras is given by $P = 1{,}500 - 3Q$. When it does not match price changes, CDW's inverse demand curve is $P = 900 - 0.50Q$. Based on this information, determine CDW's inverse demand and marginal revenue functions over the last couple of months. Over what range will changes in marginal cost have no effect on CDW's profit-maximizing level of output? *(LO1, LO2)*
22. Jones is the manager of an upscale clothing store in a shopping mall that contains only two such stores. While these two competitors do not carry the same brands of clothes, they serve a similar clientele. Jones was recently notified that the mall is going to implement a 10 percent across-the-board increase in rents to all stores in the mall, effective next month. Should Jones raise her prices 10 percent to offset the increase in monthly rent? Explain carefully. *(LO2)*
23. In an attempt to increase tax revenues, legislators in several states have introduced legislation that would increase state excise taxes. Examine the impact of such an increase on the equilibrium prices paid and quantities consumed by consumers in markets characterized by (a) Sweezy oligopoly, (b) Cournot oligopoly, and (c) Bertrand oligopoly, and determine which of these market settings is likely to generate the greatest increase in tax revenues. *(LO1, LO2)*
24. In the late 1990s, Vanguard Airlines operated as a low-cost carrier, offering low prices and limited services, out of Kansas City, Missouri. Not long after its inception, Vanguard began offering a significant number of flights based out of Midway International Airport in Chicago, Illinois, as well. When Vanguard expanded to Midway, incumbent airlines, such as Delta, quickly responded to its low fares by offering many competing flights at comparably low prices. The intense price competition ultimately caused Vanguard to exit Midway in 2000 and file for bankruptcy in 2002. At varying points in time, the airline industry has been described as a contestable market; does the example of Vanguard support or refute this characterization of the airline industry? Explain. *(LO4)*

25. You are a new entrant in a market with just one incumbent, who sells a roughly equivalent product. You initially take on the follower role when it comes to choosing the amount of your product to manufacture. In researching your market, you've collected substantial data on prices and quantities and asked your firm's analysts to determine as closely as possible the inverse demand curve for the market. They've reported back to you the following table:

    Price regressed on Quantity:

	Coefficients	Standard Error	*t*-Stat	*P*-value	Lower 95%	Upper 95%
Intercept	13693.75	516.34	26.52	4.69E-79	12677.45	14710.05
Quantity	−2.14	0.101	−21.18	1.55E-60	−2.34	−1.95

    a. Write down the estimated inverse demand curve for the market, and comment on whether it is precisely estimated.
    b. Suppose your marginal costs are $2,000 and the incumbent produces 4,000 units. What is the profit maximizing quantity you should produce?
    c. Suppose your marginal costs are $2,000 and the incumbent's marginal costs are $1,500. What will be the market price if you and the incumbent produce at your respective profit maximizing levels?

26. Your firm competes in a local duopoly. You've hired consultants to examine how your rival responds to changes in your prices. To do this, over a period of time, your consultants helped your firm to experiment with different price points and observe your rival's response. The data they collected are in *Q09-26.xls*.
    a. Using these data, determine how your competitor's price responds to yours.
    b. Based on your findings in part *a*, with what model of oligopoly are these data most consistent?
    c. What additional information or findings would help confirm your answer to part *b*? Explain.

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APPENDIX

DIFFERENTIATED-PRODUCT BERTRAND OLIGOPOLY

The model of Bertrand oligopoly presented in the text is based on Bertrand's classic treatment of the subject, which assumes oligopolists produce identical products. Because oligopolists that produce differentiated products may engage in price competition, this appendix presents a model of differentiated-product Bertrand oligopoly.

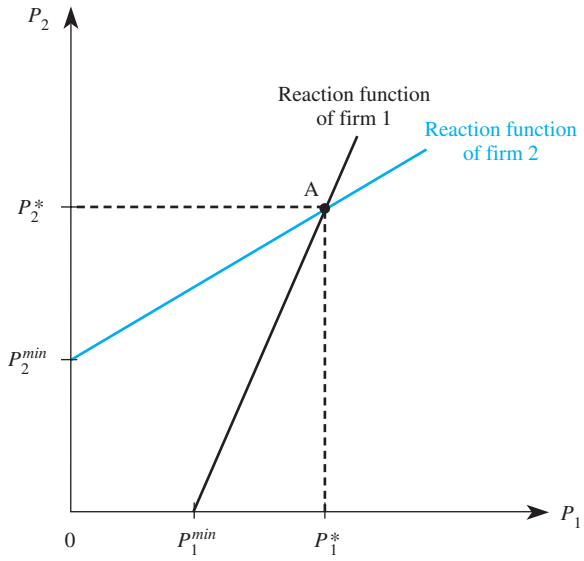
Suppose two oligopolists produce slightly differentiated products and compete by setting prices. In this case, one firm cannot capture all of its rival's customers by undercutting the rival's price; some consumers will have a preference for a firm's product even if the rival is charging a lower price. Thus, even if firm 2 were to "give its products away for free" (charge a zero price), firm 1 generally would find it profitable to charge a positive price. Moreover, as firm 2 raised its price, some of its customers would defect to firm 1, and thus the demand for firm 1's product would increase. This would raise firm 1's marginal revenue, making it profitable for the firm to increase its price.

In a differentiated-product price-setting oligopoly, the reaction function of firm 1 defines firm 1's profit-maximizing price given the price charged by firm 2. Based on this reasoning, firm 1's reaction function is upward sloping, as illustrated in Figure 9–14. To see this, note that if firm 2 sets its price at zero, firm 1 will find it profitable to set its price at $P_1^{min} > 0$ since some consumers will prefer its product to the rival's. Effectively, P_1^{min} is the price that maximizes firm 1's profits when it sells only to its brand-loyal customers (customers who do not want the other product, even for free). If the rival raises its price to, say, P_2^*, some of firm 2's customers will decide to switch to firm 1's product. Consequently, when firm 2 raises its price to P_2^*, firm 1 will raise its price to P_1^* to maximize profits given the higher demand. In fact, each point along firm 1's reaction function defines the profit-maximizing price charged by firm 1 for each price charged by firm 2. Notice that firm 1's reaction function is upward sloping, unlike in the case of Cournot oligopoly.

Firm 2's reaction function, which defines the profit-maximizing price for firm 2 given the price charged by firm 1, also is illustrated in Figure 9–14. It is upward sloping for the same reason firm 1's reaction function is upward sloping; in fact, firm 2's reaction function is the mirror image of firm 1's.

Figure 9–14

Reaction Functions in a Differentiated-Product Bertrand Oligopoly



In a differentiated-product Bertrand oligopoly, equilibrium is determined by the intersection of the two firms' reaction functions, which corresponds to point A in Figure 9–14. To see that point A is indeed an equilibrium, note that the profit-maximizing price for firm 1 when firm 2 sets price at P_2^* is P_1^*. Similarly, the profit-maximizing price for firm 2 when firm 1 sets price at P_1^* is P_2^*.

In a differentiated-product Bertrand oligopoly, firms charge prices that exceed marginal cost. The reason they are able to do so is that the products are not perfect substitutes. As a firm raises its price, it loses some customers to the rival firm, but not all of them. Thus, the demand function for an individual firm's product is downward sloping, similar to the case in monopolistic competition. But unlike in monopolistic competition, the existence of entry barriers prevents other firms from entering the market. This allows the firms in a differentiated-product Bertrand oligopoly to potentially earn positive economic profits in the long run.

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10 Game Theory: Inside Oligopoly

LEARNING OBJECTIVES

After completing this chapter, you will be able to:

- **LO1** Apply normal form and extensive form representations of games to formulate decisions in strategic environments that include pricing, advertising, coordination, bargaining, innovation, product quality, monitoring employees, and entry.
- **LO2** Distinguish among dominant, secure, Nash, mixed, and subgame perfect equilibrium strategies, and identify such strategies in various games.
- **LO3** Identify whether cooperative (collusive) outcomes may be supported as a Nash equilibrium in a repeated game, and explain the roles of trigger strategies, the interest rate, and the presence of an indefinite or uncertain final period in achieving such outcomes.

headLINE

Bring Back Complimentary Drinks!

Shortly before its merger with American Airlines, US Airways began charging domestic coach class passengers $2 for soft drinks. One year later, the company abandoned the strategy. Sources in the industry attribute the company's decision to return to the "industry standard of complimentary drinks" to a variety of factors, including the depressed economy and the fact that US Airways was the only large network carrier to charge passengers for soft drinks. History repeated itself: In 2017 American Airlines banned basic economy passengers from boarding with carry-on bags, but abandoned this policy in 2018.

Why do you think US Airways abandoned its $2 drink strategy in 2009, and American Airlines abandoned its carry-on ban in 2018?

SOURCES: Leslie Josephs, "Squeezed by Competition, American Airlines Is Giving In on One of Its Stingiest Cheap-Seat Restrictions: A Ban on Carry-on Bags," *CNBC.com*, July 28, 2018; Harry R. Weber, "US Airways Won't Charge for Sodas After All," *AP Newswire*, February 25, 2009; Michael R. Baye from US Airways, personal communication, February 23, 2009.

INTRODUCTION

In this chapter, we continue our analysis of strategic interaction. As we saw in Chapter 9, when only a few firms compete in a market, the actions of one firm will have a drastic impact on its rivals. For example, the pricing and output decisions of one firm in an oligopoly generally will affect the profits of other firms in the industry. Consequently, to maximize profits a manager must take into account the likely impact of his or her decisions on the behavior of other managers in the industry.

In this chapter we will delve more deeply into managerial decisions that arise in the presence of interdependence. We will develop general tools that will assist you in making a host of decisions in oligopolistic markets, including what prices to charge, how much advertising to use, whether to introduce new products, and whether to enter a new market. The basic tool we will use to examine these issues is *game theory*. Game theory is a very useful tool for managers. In fact, we will see that game theory can be used to analyze decisions within a firm, such as those related to monitoring and bargaining with workers.

OVERVIEW OF GAMES AND STRATEGIC THINKING

Perhaps when you think of a game, a trivial game like tic-tac-toe or checkers comes to mind. Game theory is actually a much more general framework to aid in decision making when your payoff depends on the actions taken by other players.

In a game, the players are individuals who make decisions. For example, in an oligopolistic market consisting of two firms, each of which must make a pricing decision, the firms (or, more precisely, the firms' managers) are the players. The planned decisions of the players are called *strategies*. The payoffs to the players are the profits or losses that result from the strategies. Due to interdependence, the payoff to a player depends not only on that player's strategy but also on the strategies employed by other players.

In the analysis of games, the order in which players make decisions is important. In a **simultaneous-move game**, each player makes decisions without knowledge of the other players' decisions. In a **sequential-move game**, one player makes a move after observing the other player's move. Tic-tac-toe, chess, and checkers are examples of sequential-move games (since players alternate moves), whereas matching pennies, dueling, and rock-paper-scissors are examples of simultaneous-move games. In the context of oligopoly games, if two firms must set prices without knowledge of each other's decisions, it is a simultaneous-move game; if one firm sets its price after observing its rival's price, it is a sequential-move game.

It is also important to distinguish between one-shot games and repeated games. In a **one-shot game**, the underlying game is played only once. In a **repeated game**, the underlying game is played more than once. For example, if you agree to play one, and only one, game of chess with a "rival," you are playing a one-shot game. If you agree to play chess two times with a rival, you are playing a repeated game.

Before we formally show how game theory can help managers solve business decisions, it is instructive to provide an example. Imagine that two gasoline stations are located side by side on the same block so that neither firm has a location advantage over the other. Consumers view the gasoline at each station as perfect substitutes and will purchase from the station that offers the lower price. The first thing in the morning, the manager of a gas station must phone the attendant to tell him what price to put on the sign. Since she must do so without knowledge of the rival's price, this "pricing game" is a simultaneous-move game. This type of game often is called the *Bertrand duopoly game*.

simultaneous-move game
Game in which each player makes decisions without knowledge of the other players' decisions.

sequential-move game
Game in which one player makes a move after observing the other player's move.

one-shot game
Game in which the underlying game is played only once.

repeated game
Game in which the underlying game is played more than once.

Given the structure of the game, if the manager of station A calls in a higher price than the manager of station B, consumers will not buy any gas from station A. The manager of station A, therefore, is likely to reason, "I think I'll charge $9.50 per gallon. But if station B thinks I will charge $9.50, they will charge $9.49, so I'd better charge $9.48. But if manager B thinks I think she'll charge $9.49, she will try to 'trick' me by charging $9.47. So I'd better charge $9.46. But if she thinks I think she thinks . . . . " Perhaps you have gone through a similar thought process in trying to decide what to study for an exam ("The professor won't test us on this, but if he thinks we think he won't, he'll ask it to get us . . . ").

Game theory is a powerful tool for analyzing situations such as these. First, however, we must examine the foundations of game theory. We will begin with the study of simultaneous-move, one-shot games.

SIMULTANEOUS-MOVE, ONE-SHOT GAMES

This section presents the basic tools used to analyze simultaneous-move, one-shot games. Recall that in a simultaneous-move game, players must make decisions without knowledge of the decisions made by other players. The fact that a game is "one-shot" simply means that the players will play the game only once.

Knowledge of simultaneous-move, one-shot games is important to managers making decisions in an environment of interdependence. For example, it can be used to analyze situations where the profits of a firm depend not only on the firm's action but on the actions of rival firms as well. Before we look at specific applications of simultaneous-move, one-shot games, let us examine the general theory used to analyze such decisions.

Theory

strategy
In game theory, a decision rule that describes the actions a player will take at each decision point.

normal-form game
A representation of a game indicating the players, their possible strategies, and the payoffs resulting from alternative strategies.

We begin with two key definitions. First, a **strategy** is a decision rule that describes the actions a player will take at each decision point. Second, the **normal-form game** indicates the players in the game, the possible strategies of the players, and the payoffs to the players that will result from alternative strategies.

Perhaps the best way to understand precisely what is meant by *strategy* and *normal-form game* is to examine a simple example. The normal form of a simultaneous-move game is presented in Table 10–1. There are two players, whom we will call A and B to emphasize that the theory is completely general; that is, the players can be any two entities that are engaged in a situation of strategic interaction. If you wish, you may think of the players as the managers of two firms competing in a duopoly.

Player A has two possible strategies: He can choose *up* or *down*. Similarly, the feasible strategies for player B are *left* or *right*. This illustrates that the players may have different strategic options. Again, by calling the strategies *up*, *down*, and so on, we emphasize that these

Table 10–1
A Normal-Form Game

		Player B	
	Strategy	**Left**	**Right**
Player A	**Up**	10, 20	15, 8
	Down	−10, 7	10, 10

actions can represent virtually any decisions. For instance, *up* might represent raising the price and *down* lowering price, or *up* a high level of advertising and *down* a low level of advertising.

Finally, the payoffs to the two players are given by the entries in each cell of the matrix. The first entry refers to the payoff to player A, and the second entry denotes the payoff to player B. An important thing to notice about the description of the game is that the payoff to player A crucially depends on the strategy player B chooses. For example, if A chooses *up* and B chooses *left*, the resulting payoffs are 10 for A and 20 for B. Similarly, if player A's strategy is *up* while B's strategy is *right*, A's payoff is 15 while B's payoff is 8.

Since the game in Table 10–1 is a simultaneous-move, one-shot game, the players get to make one, and only one, decision and must make their decisions at the same time. For player A, the decision is simply *up* or *down*. Moreover, the players cannot make conditional decisions; for example, A can't choose *up* if B chooses *right* or *down* if B chooses *left*. The fact that the players make decisions at the same time precludes each player from basing his or her decisions on what the other player does.

What is the optimal strategy for a player in a simultaneous-move, one-shot game? As it turns out, this is a very complex question and depends on the nature of the game being played. There is one instance, however, in which it is easy to characterize the optimal decision—a situation that involves a dominant strategy. A strategy is a **dominant strategy** if it results in the highest payoff regardless of the action of the opponent.

dominant strategy
A strategy that results in the highest payoff to a player regardless of the opponent's action.

In Table 10–1, the dominant strategy for player A is *up*. To see this, note that if player B chooses *left*, the best choice by player A is *up* since 10 units of profits are better than the –10 he would earn by choosing *down*. If B chose *right*, the best choice by A would be *up* since 15 units of profits are better than the 10 he would earn by choosing *down*. In short, regardless of whether player B's strategy is *left* or *right*, the best choice by player A is *up*. *Up* is a dominant strategy for player A.

Play Your Dominant Strategy PRINCIPLE

Check to see if you have a dominant strategy. If you have one, play it.

In simultaneous-move, one-shot games where a player has a dominant strategy, the optimal decision is to choose the dominant strategy. By doing so, you will maximize your payoff regardless of what your opponent does. In some games a player may not have a dominant strategy.

DEMONSTRATION PROBLEM 10–1

In the game presented in Table 10–1, does player B have a dominant strategy?

ANSWER:

Player B does not have a dominant strategy. To see this, note that if player A chose *up*, the best choice by player B would be *left* since 20 is better than the payoff of 8 she would earn by choosing *right*. But if A chose *down*, the best choice by B would be *right* since 10 is better than the payoff of 7 she would realize by choosing *left*. Thus, there is no dominant strategy for player B; the best choice by B depends on what A does.

secure strategy
A strategy that guarantees the highest payoff given the worst possible scenario.

What should a player do in the absence of a dominant strategy? One possibility would be to play a **secure strategy**—a strategy that guarantees the highest payoff given the worst possible scenario. As we will see in a moment, this approach is not generally the optimal way to play

a game, but it is useful to explain the reasoning that underlies this strategy. By using a secure strategy, a player maximizes the payoff that would result in the "worst-case scenario." In other words, to find a secure strategy, a player examines the worst payoff that could arise for each of his or her actions and chooses the action that has the highest of these worst payoffs.

DEMONSTRATION PROBLEM 10–2

What is the secure strategy for player B in the game presented in Table 10–1?

ANSWER:

The secure strategy for player B is *right*. By choosing *left* B can guarantee a payoff of only 7, but by choosing *right* she can guarantee a payoff of 8. Thus, the secure strategy by player B is *right*.

While useful, the notion of a secure strategy suffers from two shortcomings. First, it is a very conservative strategy and should be considered only if you have a good reason to be extremely averse to risk. Second, it does not take into account the optimal decisions of your rival and thus may prevent you from earning a significantly higher payoff. In particular, player B in Table 10–1 should recognize that a dominant strategy for player A is to play *up*. Thus, player B should reason as follows: "Player A will surely choose *up* since *up* is a dominant strategy. Therefore, I should not choose my secure strategy (*right*) but instead choose *left*." Assuming player A indeed chooses the dominant strategy (*up*), player B will earn 20 by choosing *left*, but only 8 by choosing the secure strategy (*right*).

PRINCIPLE

Put Yourself in Your Rival's Shoes

If you do not have a dominant strategy, look at the game from your rival's perspective. If your rival has a dominant strategy, anticipate that he or she will play it.

Nash equilibrium
A condition describing a set of strategies in which no player can improve her payoff by unilaterally changing her own strategy, given the other players' strategies.

A very natural way of formalizing the "end result" of such a thought process is captured in the definition of Nash equilibrium. A set of strategies constitute a **Nash equilibrium** if, given the strategies of the other players, no player can improve her payoff by unilaterally changing her own strategy. The concept of Nash equilibrium is very important because it represents a situation where every player is doing the best he or she can, given what other players are doing.

DEMONSTRATION PROBLEM 10–3

In the game presented in Table 10–1, what are the Nash equilibrium strategies for players A and B?

ANSWER:

The Nash equilibrium strategy for player A is *up*, and for player B it is *left*. To see this, suppose A chooses *up* and B chooses *left*. Would either player have an incentive to change his or her strategy? No. Given that player A's strategy is *up*, the best player B can do is choose *left*. Given that B's strategy is *left*, the best A can do is choose *up*. Hence, given the strategies (*up*, *left*), each player is doing the best he or she can given the other player's decision.

Why aren't any of the other strategy combinations—(*up*, *right*), (*down*, *right*), and (*down*, *left*)—a Nash equilibrium? This is because, for each combination, at least one player would like to change his or her strategy given the strategy of the other player. Consider each in turn. The strategies (*up*, *right*)

are not a Nash equilibrium because, given Player A is playing *up*, Player B would do better by playing *left* instead of *right*. The strategies (*down*, *right*) are not a Nash equilibrium because, given Player B is playing *right*, Player A would do better by playing *up* instead of *down*. The strategies (*down*, *left*) are not a Nash equilibrium because both players could do better: given Player A is playing *down*, Player B would do better by playing *right* instead of *left*; and given Player B is playing *left*, Player A would do better by playing *up* instead of *down*.

INSIDE BUSINESS 10–1

Hollywood's (not so) Beautiful Mind: Nash or "Opie" Equilibrium?

Director Ron Howard scored a home run by strategically releasing *A Beautiful Mind* just in time to win four Golden Globe Awards in 2002. The film—based loosely on the life of Nobel Laureate John Forbes Nash Jr., whose "Nash equilibrium" revolutionized economics and game theory—won best dramatic picture and best screenplay. Actor Russell Crowe also won a Golden Globe for his portrayal of the brilliant man whose battle with delusions, mental illness, and paranoid schizophrenia almost kept him from winning the 1994 Nobel Prize in Economics. While some know Ron Howard for his accomplishments as a director, he is best known as the kid who played Opie Taylor and Richie Cunningham in the popular *Andy Griffith* and *Happy Days* TV shows. For this reason, Eddie Murphy once dubbed him "Little Opie Cunningham" in a *Saturday Night Live* skit.

While *A Beautiful Mind* is an enjoyable film, its portrait of Nash's life is at odds with Sylvia Nasar's carefully documented and best-selling book with the same title. More relevant to students of game theory, the film does not accurately illustrate the concept for which Nash is renowned. Translation: Don't rent the movie as a substitute for learning how to use Nash's equilibrium concept to make business decisions.

Hollywood attempts to illustrate Nash's insight into game theory in a bar scene in which Nash and his buddies are eyeing one stunningly beautiful blonde woman and several of her brunette friends. When considering which woman they would like to approach, all of the men prefer to approach the blonde woman. Nash ponders the situation and says, "If we all go for the blonde, we block each other. Not a single one of us is going to get her. So then we go for her friends. But they will all give us the cold shoulder because nobody likes to be second choice. But what if no one goes for the blonde? We don't get in each other's way, and we don't insult the other girls. That's the only way we win." The camera shows a shot of the blonde woman sitting all alone at the bar while the men dance happily with the brunettes. The scene concludes with Nash rushing off to write a paper on his new concept of equilibrium.

What's wrong with this scene? Recall that a Nash equilibrium is a situation where *no player* can gain by changing his decision, given the decisions of the other players. In Hollywood's game, the men are players and their decisions are which of the women to pursue. If the other men opt for the brunettes, the blonde is all alone just waiting to dance. This means that the remaining man's best response, given the decisions of the others, is to pursue the lonely blonde! Hollywood's dance scene does not illustrate a Nash equilibrium, but the exact opposite: a situation where any one of the men could unilaterally gain by switching to the blonde, given that the other men are dancing with brunettes! What is the correct term for Hollywood's dance scene in which the blonde is left all alone? Personally, we like the term "Opie equilibrium" because it honors the director of the film and sounds much more upbeat than "disequilibrium."

Hollywood also uses the dance scene to spin its view that "Adam Smith was wrong." In particular, since the men are better off dancing with the brunettes than all pursuing the blonde, viewers are to conclude that it is never socially efficient for individuals to pursue their own selfish desires. While Module Group B of this text shows a number of situations where markets may fail, Hollywood's illustration is not one of them. Its "Opie equilibrium" outcome is actually *socially inefficient* because none of the men get to enjoy the company of the stunning blonde. In contrast, a real Nash equilibrium to the game entails one man dancing with the blonde and the others dancing with brunettes. Any Nash equilibrium to Hollywood's game not only has the property that each man is selfishly maximizing his own satisfaction, given the strategies of the others, but the outcome is also *socially efficient* because it doesn't squander a dance with the blonde.

Applications of One-Shot Games

Pricing Decisions

Let us now see how game theory can help formalize the optimal managerial decisions in a Bertrand duopoly. Consider the game presented in Table 10–2, where two firms face a situation where they must decide whether to charge low or high prices. The first number in each cell represents firm A's profits and the second number represents firm B's profits. For example, if firm A charges a high price while firm B charges a low price, A loses 10 units of profits while B earns 50 units of profits.

While the numbers in Table 10–2 are arbitrary, their relative magnitude is consistent with the nature of Bertrand competition. In particular, note that the profits of both firms are higher when both charge high prices than when they both charge low prices because, in each instance, consumers have no incentive to switch to the other firm. On the other hand, if one firm charges a high price and the other firm undercuts that price, the lower-priced firm will gain all the other firm's customers and thus earn higher profits at the expense of the competitor.

We are considering a one-shot play of the game in Table 10–2, that is, a situation where the firms meet once, and only once, in the market. Moreover, the game is a simultaneous-move game in that each firm makes a pricing decision without knowledge of the decision made by the other firm. In a one-shot play of the game, the Nash equilibrium strategies are for each firm to charge the low price. The reason is simple. If firm B charges a high price, firm A's best choice is to charge a low price since 50 units of profits are better than the 10 units it would earn if A charged the high price. Similarly, if firm B charges the low price, firm A's best choice is to charge the low price since 0 units of profits are preferred to the 10 units of losses that would result if A charged the high price. Similar arguments hold from firm B's perspective. Firm A is always better off charging the low price regardless of what firm B does, and B is always better off charging the low price regardless of what A does. Hence, charging a low price is a dominant strategy for both firms. To summarize, in the one-shot version of this game, each firm's best strategy is to charge a low price regardless of the other firm's action. The outcome of the game is that both firms charge low prices and earn profits of zero.

Clearly, profits are less than the firms would earn if they colluded and "agreed" to both charge high prices. For example, in Table 10–2 we see that each firm would earn profits of 10 units if both charged high prices. This is a classic result in economics and is called a *dilemma* because the Nash equilibrium outcome is inferior (from the viewpoint of the firms) to the situation where they both "agree" to charge high prices.

Why can't firms collude and agree to charge high prices? One answer is that collusion is illegal in the United States; firms are not allowed to meet and "conspire" to set high prices. There are other reasons, however. Suppose the managers did secretly meet and agree to charge high prices. Would they have an incentive to live up to their promises? Consider firm A's point of view. If it "cheated" on the collusive agreement by lowering its price, it would

Table 10–2

A Pricing Game

		Firm B	
	Strategy	**Low Price**	**High Price**
Firm A	**Low price**	0, 0	50, −10
	High price	−10, 50	10, 10

INSIDE BUSINESS 10–2

Cola Wars in India

One of the most well-known examples of duopoly price competition is Coca-Cola versus PepsiCo. Although there are many firms competing in the cola industry, the dominance in market share by Coke and Pepsi results in each firm's profits being heavily influenced by the pricing decision of the other. The pricing "game" between Coke and Pepsi is not unlike the one illustrated in Table 10-2. Each firm has a strong incentive to charge low prices regardless of its opponent's pricing decision, often leading to low prices and low profits, as compared to the outcome when both charge high prices.

Not long ago, Coke announced it was lowering its price for a 200-ml bottle in India to a uniform 8 rupees across the entire country. This price drop was made in anticipation of the summer spike in demand for cola. If Coke views the summer market as a one-shot game with Pepsi, charging this low price is likely its dominant strategy. In fact, Pepsi was expected to quickly follow suit by cutting its prices, again consistent with the prediction for a one-shot game.

While the one-shot game in Table 10-2 is quite effective in explaining the recent price war between Coke and Pepsi in India, we know that these two firms actually face each other many times in many markets. In 2003, both firms engaged in a similar price war in India, only to later jointly raise prices after seeing significant damage to their profits. Later in this chapter, you will see how the repeated nature of the price war between Coke and Pepsi can allow them to keep prices high over extended periods of time, despite the temptation to cut prices in any given period.

SOURCES: S. Sharma, "Coca-Cola Cuts Prices, Pepsi May Follow Suit," *The Economic Times*, February 15, 2012; S. Srivastava, "Why Coke May Have Triggered a New Price War This Season," *Forbes India*, June 30, 2012.

increase its profits from 10 to 50. Thus, firm A has an incentive to induce firm B to charge a high price so that it can "cheat" to earn higher profits. Of course, firm B recognizes this incentive, which precludes the agreement from being reached in the first place.

However, suppose the manager of firm A is "honest" and would never cheat on a promise to charge a high price. (She is "honest" enough to keep her word to the other manager, but not so honest as to obey the law against collusion.) What happens to firm A if the manager of firm B cheats on the collusive agreement? If B cheats, A experiences losses of $10. When firm A's stockholders ask the manager why they lost $10 when the rival firm earned profits of $50, how can the manager answer? She cannot admit she was cheated on in a collusive agreement, for doing so might send her to jail for having violated the law. Whatever her answer, she risks being fired or sent to prison.

Advertising and Quality Decisions

Our framework for analyzing simultaneous-move, one-shot games can also be used to analyze advertising and quality decisions. In oligopolistic markets, firms advertise and/or increase their product quality in an attempt to increase the demand for their products. While both quality and advertising can be used to increase the demand for a product, our discussion will use advertising as a placeholder for both quality and advertising.

An important issue in evaluating the consequences of advertising is to recognize where the increase in demand comes from. In most oligopolistic markets, advertising increases the demand for a firm's product by taking customers away from other firms in the industry. An increase in one firm's advertising increases its profits at the expense of other firms in the market; there is interdependency among the advertising decisions of firms.

A classic example of such a situation is the breakfast cereal industry, which is highly concentrated. By advertising its brand of cereal, a particular firm does not induce many consumers to eat cereal for lunch and dinner; instead, it induces customers to switch to its brand

from another brand. This can lead to a situation where each firm advertises just to "cancel out" the effects of other firms' advertising, resulting in high levels of advertising, no change in industry or firm demand, and low profits.

For a video walkthrough of this problem, visit www.mhhe.com/baye10e

DEMONSTRATION PROBLEM 10–4

Suppose your firm competes against another firm for customers. You and your rival know your products will be obsolete at the end of the year and must simultaneously determine whether or not to advertise. In your industry, advertising does not increase total industry demand but instead induces consumers to switch among the products of different firms. Thus, if both you and your rival advertise, the two advertising campaigns will simply offset each other, and you will each earn $4 million in profits. If neither of you advertises, you will each earn $10 million in profits. However, if one of you advertises and the other one does not, the firm that advertises will earn $20 million and the firm that does not advertise will earn $1 million in profits. Is your profit-maximizing choice to advertise or not to advertise? How much money do you expect to earn?

ANSWER:

The description of the game corresponds to the matrix presented in Table 10–3. The game is a one-shot game. Note that the dominant strategy for each firm is to advertise, and thus the unique Nash equilibrium for the game is for each firm to advertise. The profit-maximizing choice by your firm, therefore, is to advertise. You can expect to earn $4 million. Collusion would not work because this is a one-shot game; if you and your rival "agreed" not to advertise (in the hope of making $10 million each), each of you would have an incentive to cheat on the agreement.

Table 10–3

An Advertising Game

		Firm B	
	Strategy	**Advertise**	**Don't Advertise**
Firm A	**Advertise**	$4, $4	$20, $1
	Don't Advertise	$1, $20	$10, $10

Coordination Decisions

Thus far, our analysis of oligopoly has focused on situations where firms have competing objectives: One firm can gain only at the expense of other firms. Not all games have this structure, however.

Imagine a world where producers of electrical appliances have a choice of which type of electrical outlets to put on appliances: 90-volt, four-prong outlets or 120-volt, two-prong outlets. In an environment where different appliances require different outlets, a consumer who desires several appliances would have to spend a considerable sum wiring the house to accommodate all the appliances. This would reduce the amount the consumer has available for buying appliances and therefore would adversely affect the profits of appliance manufacturers. In contrast, if the appliance manufacturers can "coordinate" their decisions (i.e., produce appliances that require the same types of wiring), they will earn higher profits.

Table 10–4 presents a hypothetical example of what is called a *coordination game*. Two firms must decide whether to produce appliances requiring 120-volt or 90-volt outlets. If each firm produces appliances requiring 120-volt outlets, each firm will earn profits of $100.

Table 10–4

A Coordination Game

		Firm B	
	Strategy	**120-Volt Outlets**	**90-Volt Outlets**
Firm A	**120-Volt Outlets**	$100, $100	$0, $0
	90-Volt Outlets	$0, $0	$100, $100

Similarly, if each firm produces appliances requiring 90-volt outlets, each firm will earn $100. However, if the two firms produce appliances requiring different types of outlets, each firm will earn zero profits due to the lower demand that will result from consumers' need to spend more money wiring their houses.

What would you do if you were the manager of firm A in this example? If you do not know what firm B is going to do, you have a very tough decision. All you can do is "guess" what B will do. If you think B will produce 120-volt appliances, you should produce 120-volt appliances as well. If you think B will produce 90-volt appliances, you should do likewise. You will thus maximize profits by doing what firm B does. Effectively, both you and firm B will do better by "coordinating" your decisions.

The game in Table 10–4 has two Nash equilibria. One Nash equilibrium is for each firm to produce 120-volt appliances; the other is for each firm to produce 90-volt appliances. The question is how the firms will get to one of these equilibria. If the firms could "talk" to each other, they could agree to produce 120-volt systems. Alternatively, the government could set a standard that electrical outlets be required to operate on 120-volt, two-prong outlets. In effect, this would allow the firms to "coordinate" their decisions. Notice that once they agree to produce 120-volt appliances, there is no incentive to cheat on this agreement. The game in Table 10–4 is not analogous to the pricing or advertising games analyzed earlier; it is a game of coordination rather than a game of conflicting interests.

Monitoring Employees

Game theory can also be used to analyze interactions between workers and the manager. In Chapter 6, we discussed the principal–agent problem and argued that there can be conflicting goals between workers and managers. Managers desire workers to work hard, while workers enjoy leisure.

In our discussion of manager–worker principal–agent problems in Chapter 6, we noted that one way a manager can reduce workers' incentives to shirk is to engage in "random" spot checks of the workplace. Game theory provides a way of seeing why this can work. Consider a game between a worker and a manager. The manager has two possible actions: (1) monitor the worker or (2) don't monitor the worker. The worker has two choices: (1) work or (2) shirk. These possible actions and resulting payoffs are depicted in Table 10–5.

Table 10–5

A Game with No Nash Equilibrium

		Worker	
	Strategy	**Work**	**Shirk**
Manager	**Monitor**	–1, 1	1, –1
	Don't Monitor	1, –1	–1, 1

The interpretation of this normal-form game is as follows: If the manager monitors while the worker works, the worker "wins" and the manager "loses." The manager has spent time monitoring a worker who was already working. In this case, suppose the manager's payoff is −1 and the worker's payoff is 1. The payoffs are the same if the manager does not monitor the worker and the worker shirks; the worker wins because she gets away with shirking.

In contrast, if the manager monitors while the worker shirks, the manager wins 1 and the worker who gets caught loses 1. Similarly, if the worker works and the manager does not monitor, the manager wins 1 and the worker loses 1. The numbers in Table 10–5 are, of course, purely hypothetical, but they are consistent with the relative payoffs that arise in such situations.

Notice that the game in Table 10–5 does not have a Nash equilibrium, at least in the usual sense of the term. To see this, suppose the manager's strategy is to monitor the worker. Then the best choice of the worker is to work. But if the worker works, the manager does better by changing his strategy: choosing not to monitor. Thus, "monitoring" is not part of a Nash equilibrium strategy. The paradox, however, is that "not monitoring" isn't part of a Nash equilibrium either. To see why, suppose the manager's strategy is "don't monitor." Then the worker will maximize her payoff by shirking. Given that the worker shirks, the manager does better by changing the strategy to "monitor" to increase his payoff from −1 to 1. Thus, we see that "don't monitor" is not part of a Nash equilibrium strategy either.

The thing to notice in this example is that both the worker and the manager want to keep their actions "secret"; if the manager knows what the worker is doing, it will be curtains for the worker, and vice versa. In such situations, players find it in their interest to engage in a **mixed (randomized) strategy**. What this means is that players "randomize" over their available strategies; for instance, the manager flips a coin to determine whether or not to monitor. By doing so, the worker cannot predict whether the manager will be present to monitor her and, consequently, cannot outguess the manager.

mixed (randomized) strategy
A strategy whereby a player randomizes over two or more available actions in order to keep rivals from being able to predict his or her action.

Those of you who have taken multiple-choice tests have had firsthand experience with randomized strategies. If your professor made *a* the correct answer more often than *b*, *c*, or *d*, you could gain by answering *a* in those instances when you did not know the correct answer. This would enable you to earn a higher grade than you deserved based on your knowledge of subject matter. To prevent this strategy from working for you, professors randomize which option is the correct answer so that you cannot systematically guess the correct answer on an exam.

Nash Bargaining

The final application of simultaneous-move, one-shot games we will consider is a simple bargaining game. In a *Nash bargaining* game, two players "bargain" over some object of value. In a simultaneous-move, one-shot bargaining game, the players have only one chance to reach an agreement, and the offers made in bargaining are made simultaneously.

To be concrete, suppose management and a labor union are bargaining over how much of a $100 surplus to give to the union. Suppose, for simplicity, that the $100 can be split only into $50 increments. The players have one shot to reach an agreement. The parties simultaneously write the amount they desire on a piece of paper (0, 50, or 100). If the sum of the amounts each party asks for does not exceed $100, the players get the specified amounts. But if the sum of the amounts requested exceeds $100, bargaining ends in a stalemate. Let's suppose that the delays caused by this stalemate cost both the union and management $1.

Table 10–6 presents the normal form of this hypothetical bargaining game. If you were management, what amount would you ask for? Suppose you wrote down $100. Then the only way you would get any money is if the union asked for zero. Notice that if management asked

Table 10–6

A Bargaining Game

		Union		
	Strategy	**0**	**50**	**100**
Management	**0**	0, 0	0, 50	0, 100
	50	50, 0	50, 50	−1, −1
	100	100, 0	−1, −1	−1, −1

for $100 and the union asked for $0, neither party would have an incentive to change its amounts; we would be in Nash equilibrium.

Before concluding that you should ask for $100, think again. Suppose the union wrote down $50. Management's best response to this move would be to ask for $50. And given that management asked for $50, the union would have no incentive to change its amount. Thus, a 50–50 split of the $100 also would be a Nash equilibrium.

Finally, suppose management asked for $0 and the union asked for the entire $100. This too would constitute a Nash equilibrium. Neither party could improve its payoff by changing its strategy given the strategy of the other.

Thus, there are three Nash equilibrium outcomes to this bargaining game. One outcome splits the money evenly among the parties, while the other two outcomes give all the money to either the union or management.

This example illustrates that the outcomes of simultaneous-move bargaining games are difficult to predict because there are generally multiple Nash equilibria. This multiplicity of equilibria leads to inefficiencies when the parties fail to "coordinate" on an equilibrium. In Table 10–6, for instance, six of the nine potential outcomes are inefficient in that they result in total payoffs that are less than the amount to be divided. Three of these outcomes entail negative payoffs due to stalemate. Unfortunately, stalemate is common in labor disputes: Agreements often fail or are delayed because the two sides ask for more (in total) than there is to split.

Experimental evidence suggests that bargainers often perceive a 50–50 split to be "fair." Consequently, many players in real-world settings tend to choose strategies that result in such a split even though there are other Nash equilibria. Clearly, for the game in Table 10–6, if you expect the union to ask for $50, you, as management, should ask for $50.

DEMONSTRATION PROBLEM 10–5

Suppose a $1 bill is to be divided between two players according to a simultaneous-move, one-shot bargaining game. Is there a Nash equilibrium to the bargaining game if the smallest unit in which the money can be divided is $0.01? Assume that if the players ask for more in total than is available, they go home empty-handed.

ANSWER:

Yes, in fact there are many Nash equilibria. Any amount the players ask for that sums to exactly 100 cents constitutes a Nash equilibrium. As examples, one player asks for $0.01 and the other asks for $0.99; one player asks for $0.02 and the other asks for $0.98; and so on. In each case, neither party can gain by asking for more, given what the other player has asked for.

INFINITELY REPEATED GAMES

Based on our analysis of one-shot pricing and advertising games, one might be led to believe that collusion is impossible in an industry. This conclusion is erroneous, however, and stems from the fact that firms in some industries do not play a one-shot game. Instead, they compete week after week, year after year. In these instances, the appropriate mode of analysis is to consider a situation where a game is repeated over time. In this section, we analyze a situation where players perpetually interact.

infinitely repeated game
A game that is played over and over again forever and in which players receive payoffs during each play of the game.

An **infinitely repeated game** is a game that is played over and over again forever. Players receive payoffs during each repetition of the game.

Theory

When a game is played again and again, players receive payoffs during each repetition of the game. Due to the time value of money, a dollar earned during the first repetition of the game is worth more than a dollar earned in later repetitions; players must appropriately discount future payoffs when they make current decisions. For this reason, we will review the key aspects of present value analysis before we begin examining repeated games.

Review of Present Value

The value of a firm is the present value of all future profits earned by the firm. If the interest rate is i, π_0 represents profits today, π_1 profits one year from today, π_2 profits two years from today, and so on, the value of a firm that will be in business for T years is

$$PV_{Firm} = \pi_0 + \frac{\pi_1}{1+i} + \frac{\pi_2}{(1+i)^2} + \cdots + \frac{\pi_T}{(1+i)^T} = \sum_{t=0}^{T} \frac{\pi_t}{(1+i)^t}$$

If the profits earned by the firm are the same in each period ($\pi_t = \pi$ for each period t) and the horizon is infinite ($T = \infty$), this formula simplifies to

$$PV_{Firm} = \left(\frac{1+i}{i}\right)\pi$$

As we will see, this formula is very useful in analyzing decisions in infinitely repeated games.

Supporting Collusion with Trigger Strategies

Now consider the simultaneous-move Bertrand pricing game presented in Table 10–7. The Nash equilibrium in a one-shot play of this game is for each firm to charge low prices and earn zero profits. Let us suppose the firms play the game in Table 10–7 day after day, week after week, for all eternity. Thus, we are considering an infinitely repeated Bertrand pricing game, not a one-shot game. In this section, we will examine the impact of repeated play on the equilibrium outcome of the game.

Table 10–7
A Pricing Game That Is Repeated

		Firm B	
	Price	**Low**	**High**
Firm A	**Low**	0, 0	50, −40
	High	−40, 50	10, 10

When firms repeatedly face a payoff matrix such as that in Table 10–7, it is possible for them to "collude" without fear of being cheated on. They do this by using trigger strategies. A **trigger strategy** is a strategy that is contingent on the past plays of players in a game. A player who adopts a trigger strategy continues to choose the same action until some other player takes an action that "triggers" a different action by the first player.

trigger strategy
A strategy that is contingent on the past play of a game and in which some particular past action "triggers" a different action by a player.

To see how trigger strategies can be used to support collusive outcomes, suppose firm A and firm B secretly meet and agree to the following arrangement: "We will each charge the high price, provided neither of us has ever 'cheated' in the past (i.e., charged the low price in any previous period). If one of us cheats and charges the low price, the other player will 'punish' the deviator by charging the low price in every period thereafter." Thus, if firm A cheats, it pulls a "trigger" that leads firm B to charge the low price forever after, and vice versa. It turns out that if both firms adopt such a trigger strategy, there are conditions under which neither firm has an incentive to cheat on the collusive agreement. Before we show this formally, let us examine the basic intuition.

If neither firm in Table 10–7 cheats on the collusive agreement, each firm will earn $10 each period forever. But if one firm plays according to the agreement, the other firm could cheat and earn an immediate profit of $50 instead of $10. Thus, there is still the immediate benefit to a firm of cheating on the agreement. However, because the firms compete repeatedly over time, there is a future cost of cheating. According to the agreement, if a firm ever cheats, the other firm will charge a low price in all future periods. Thus, the best the firm that cheated can do is earn $0 in the periods after cheating instead of the $10 it would have earned had it not broken the agreement.

In short, the benefit of cheating today on the collusive agreement is earning $50 instead of $10 today. The cost of cheating today is earning $0 instead of $10 in each future period. If the present value of the cost of cheating exceeds the one-time benefit of cheating, it does not pay for a firm to cheat, and high prices can be sustained.

Now let us formalize this idea. Suppose the firms agree to the collusive plan just outlined, and firm A believes firm B will live up to the agreement. Does firm A have an incentive to cheat and charge a low price? If firm A cheats by charging a low price, its profits will be $50 today but $0 in all subsequent periods since cheating today will lead firm B to charge a low price in all future periods. The best choice of firm A when firm B charges the low price in these future periods is to charge the low price to earn $0. Thus, if firm A cheats today, the present value of its profits are

$$PV_{Firm\,A}^{Cheat} = \$50 + 0 + 0 + 0 + 0 + \cdots$$

If firm A does not cheat, it earns $10 each period forever. Thus, the present value of the profits of firm A if it "cooperates" (does not cheat) are

$$PV_{Firm\,A}^{Coop} = 10 + \frac{10}{1+i} + \frac{10}{(1+i)^2} + \frac{10}{(1+i)^3} + \cdots = \frac{10(1+i)}{i}$$

where i is the interest rate. Firm A has no incentive to cheat if the present value of its earnings from cheating is less than the present value of its earnings from not cheating. For the numbers in this example, there is no incentive to cheat if

$$PV_{Firm\,A}^{Cheat} = 50 \leq \frac{10(1+i)}{i} = PV_{Firm\,A}^{Coop}$$

which is true if $i \leq 1/4$. In other words, if the interest rate is less than 25 percent, firm A will lose more (in present value) by cheating than it will gain. Since firm B's incentives are

symmetric, the same is true for firm B. Thus, when oligopolistic firms compete repeatedly over time, it is possible for them to collude and charge high prices to earn $10 each period. This benefits firms at the expense of consumers and also leads to a deadweight loss. This explains why there are laws against collusion.

More generally, we may state the following principle:

PRINCIPLE

Sustaining Cooperative Outcomes with Trigger Strategies

Suppose a one-shot game is infinitely repeated and the interest rate is i. Further, suppose the "cooperative" one-shot payoff to a player is π_{Coop}, the maximum one-shot payoff if the player cheats on the collusive outcome is π_{Cheat}, the one-shot Nash equilibrium payoff is π_N, and

$$\frac{\pi^{Cheat} - \pi^{Coop}}{\pi^{Coop} - \pi^{N}} \leq \frac{1}{i}$$

Then the cooperative (collusive) outcome can be sustained in the infinitely repeated game with the following trigger strategy: "Cooperate provided no player has ever cheated in the past. If any player cheats, 'punish' the player by choosing the one-shot Nash equilibrium strategy forever after."

The condition written in the preceding principle has a very intuitive interpretation. It can be rewritten as

$$\pi^{Cheat} - \pi^{Coop} \leq \frac{1}{i}(\pi^{Coop} - \pi^{N})$$

The left-hand side of this equation represents the one-time gain of breaking the collusive agreement today. The right-hand side represents the present value of what is given up in the future by cheating today. Provided the one-time gain is less than the present value of what would be given up by cheating, players find it in their interest to live up to the agreement.

DEMONSTRATION PROBLEM 10–6

Suppose firm A and firm B repeatedly face the situation presented in Table 10–7 and the interest rate is 40 percent. The firms agree to charge a high price each period, provided neither firm has cheated on this agreement in the past.

1. What are firm A's profits if it cheats on the collusive agreement?
2. What are firm A's profits if it does not cheat on the collusive agreement?
3. Does an equilibrium result where the firms charge the high price each period?

ANSWER:

1. If firm B lives up to the collusive agreement but firm A cheats, firm A will earn $50 today and zero forever after.
2. If firm B lives up to the collusive agreement and firm A does not cheat, the present value of firm A's profits is

$$10 + \frac{10}{1 + .4} + \frac{10}{(1 + .4)^2} + \frac{10}{(1 + .4)^3} + \cdots = \frac{10(1 + .4)}{.4} = 35$$

3. Since $50 > 35$, the present value of firm A's profits is higher if A cheats on the collusive agreement than if it does not cheat. Since the payoff matrix is symmetric, each firm has an incentive to cheat on the collusive agreement, even if it believes the other firm will not cheat. In equilibrium, each firm will charge the low price each period to earn profits of $0 each period.

In summary, in a one-shot game there is no tomorrow; any gains must be had today or not at all. In an infinitely repeated game there is always a tomorrow, and firms must weigh the benefits of current actions against the future costs of those actions. The principal result of infinitely repeated games is that when the interest rate is low, firms may find it in their interest to collude and charge high prices, unlike in the case of a one-shot game. The basic reason for this important result is this: If a player deviates from the "collusive strategy," he or she is punished in future periods long enough to wipe out the gains from having deviated from the collusive outcome. The threat of punishment makes cooperation work in repeated games. In one-shot games there is no tomorrow, and threats have no bite.

Factors Affecting Collusion in Pricing Games

It is easier to sustain collusive arrangements via the punishment strategies outlined earlier when firms know (1) who their rivals are, so they know whom to punish should the need arise; (2) who their rivals' customers are, so that if punishment is necessary they can take away those customers by charging lower prices; and (3) when their rivals deviate from the collusive arrangement, so they know when to begin the punishments. Furthermore, they must (4) be able to successfully punish rivals for deviating from the collusive agreement—otherwise the threat of punishment would not work. These factors are related to several variables reflected in the structure and conduct of the industry.

Number of Firms

Collusion is easier when there are few firms rather than many. If there are n firms in the industry, the total amount of monitoring that must go on to sustain the collusive arrangement is $n \times (n - 1)$. For example, let the firms be indexed by A, B, C, ... If there are only two firms in the industry, then to punish a firm for deviating, each firm must know whether its rival has deviated and, if so, where its customers are so it can punish the rival by getting some of its customers. To do this, each must keep an eye on its rival. With two firms, this information may be obtained if A monitors B and B monitors A.

The total number of monitors needed in the market grows very rapidly as the number of firms increases. For example, if there are five firms, each firm must monitor four other firms, so the total number of monitors needed in the market is $5 \times 4 = 20$. The cost of monitoring rivals reduces the gains to colluding. If the number of firms is "large enough," the monitoring costs become so high relative to collusive profits that it does not pay to monitor the actions of other firms. Under these circumstances, the "threat" used to sustain the collusive outcome is not credible, and the collusion fails. This is one reason why it is easier for two firms to collude than it is for, say, four firms to do so.

Firm Size

Economies of scale exist in monitoring. Monitoring and policing costs constitute a much greater share of total costs for small firms than for larger firms. Thus, it may be easier for a large firm to monitor a small firm than for a small firm to monitor a large firm. For example, a large firm (with, say, 20 outlets) can monitor the prices charged by a small competitor (with one outlet) by simply checking prices at the one store. But to check the prices of its rival, the smaller firm must hire individuals to monitor 20 outlets.

History of the Market

One key issue not addressed thus far is how firms reach an understanding to collude. One way is for the firms to explicitly meet and verbally warn their rivals not to steal their

INSIDE BUSINESS 10–3

Collusion in Canadian Gasoline Markets

Not long ago, the Canadian Competition Bureau implemented wire taps to monitor cartels of gas stations in Canada that were actively engaged in price-fixing schemes. After careful examination of many phone calls, analysts determined that each cartel was structured around a leader, which controlled a large fraction of stations in its respective market. Regional leaders controlled the timing and magnitude of price increases. With the assistance of a group of stations, these leaders also actively monitored the behavior of competitors to ensure all cartel members followed the instructions. For price decreases, the largest firm in the province—Ultramar—took the lead. Ultramar advertised a low-price guarantee, instructed firms to wait for its call before matching any of its price cuts, and dissuaded them from dropping below its price by threatening a price war.

In this example, we see cartels that are led by large firms using explicit methods of communication (phone calls) along with a persistent monitoring and punishment mechanism. This may seem like a winning formula to achieve higher profits, but before you decide to adopt similar methods, it is important to note how these cartels ended up. Many firms and individuals were charged with violating Canadian competition law, leading to numerous guilty pleas along with substantial fines. In the United States, it is illegal to conspire to engage in such practices as well.

SOURCE: R. Clark and J. F. Houde, "The Effect of Explicit Communication on Pricing: Evidence from the Collapse of a Gasoline Cartel," *Journal of Industrial Economics* 62, no. 2 (2014).

customers, or else they will be punished. Alternatively, firms might not meet at all but instead gain an understanding over time of the way the game is played and thus achieve "tacit collusion." *Tacit collusion* occurs when the firms do not explicitly conspire to collude but accomplish collusion indirectly. For example, in many instances firms learn from experience how other firms will behave in a market. If a firm observes over time that it is "punished" each time it charges a low price or attempts to steal customers from a rival, it eventually will learn that it does not pay to charge low prices. In these instances, tacit collusion will be the likely outcome.

In contrast, if a firm learns over time that its opponents are unable to successfully punish it for undercutting prices, tacit collusion will be unlikely to result. If firms never carry out their threats, the history of the industry will be such that collusion by threat of reprisal is not an equilibrium. But if firms observe that rivals indeed carry out their threats, this "history" ultimately will result in collusion.

Punishment Mechanisms

The pricing mechanisms firms use also affect their ability to punish rivals that do not cooperate. For example, in a posted-price market, where a single price is posted and charged to all of a firm's customers, the cost of punishing an opponent is higher than in markets in which different customers are quoted different prices. The reason is as follows: If a single price is charged to all customers, a firm that wishes to punish a rival by stealing its customers not only has to charge a low price to the rival's customers but also must lower its price to its own customers. This is essentially what a retailer must do to get customers away from another retailer. In contrast, in an industry in which different prices are quoted to different customers, a firm can punish its rival by charging the rival's customers a low price while continuing to charge its own customers a higher price. This, of course, substantially reduces the cost of engaging in punishment.

An Application of Infinitely Repeated Games to Product Quality

The theory of infinitely repeated games can be used to analyze the desirability of firm policies such as warranties and guarantees. Effectively, a game occurs between consumers and firms: Consumers desire durable, high-quality products at a low price, while firms wish to maximize profits. In a one-shot game, any profits made by the firm must be made today; there is no prospect for repeat business. Thus, in a one-shot game, a firm may have an incentive to sell shoddy products. This is particularly true if consumers cannot determine the quality of the products prior to purchase.

To see this, consider the normal-form game in Table 10–8. Here the game is between a consumer and a firm. The consumer has two strategies: buy the product or don't buy it. The firm can produce a low-quality product or a high-quality product. In a one-shot play of the game, the Nash equilibrium strategy is for the firm to produce a low-quality product and for consumers to shun the product. To see this, note that if the consumer decided to buy the product, the firm would benefit by selling a low-quality product since profits of 10 are better than the 1 it would earn by producing a high-quality product. Given a low-quality product, the consumer chooses not to buy since 0 is better than losing 10 by purchasing a shoddy product. But since the consumer chooses not to buy, it does not pay for the firm to produce a high-quality product. In a one-shot game, the consumer chooses not to buy the product because he or she knows the firm will "take the money and run."

The story differs if the game is infinitely repeated. Suppose the consumer tells the firm, "I'll buy your product and will continue to buy it if it is of good quality. But if it turns out to be shoddy, I'll tell all my friends never to purchase anything from you again." Given this strategy by the consumer, what is the best thing for the firm to do? If the interest rate is not too high, the best alternative is to sell a high-quality product. The reason is simple. By selling a shoddy product, the firm earns 10 instead of 1 that period. This is, in effect, "the gain to cheating" (selling a poor-quality product). The cost of selling a shoddy product, however, is to earn zero forever after, as the firm's reputation is ruined by having sold such a product. When the interest rate is low, the one-time gain will be more than offset by the lost future sales. It will not pay for the firm to "cheat" by selling shoddy merchandise.

The lesson to be drawn from this example is twofold. First, if your firm desires to be a "going concern," that is, infinitely lived, it does not pay to "cheat" customers if the one-time gain is more than offset by lost future sales. Notice that this is true even if your firm cannot be sued or if there are no government regulations against selling shoddy merchandise.

Second, you should recognize that any production process is likely to have "bad runs," in which some low-quality products are produced out of honest error. Notice in this example that even if the firm "tried" to produce high-quality merchandise but, due to an inadvertent error, one unit was defective, that error could ruin the firm. To guard against this, many firms offer

Table 10–8

A Product Quality Game

		Firm	
	Strategy	**Low-Quality Product**	**High-Quality Product**
Consumer	**Don't Buy**	0, 0	0, −10
	Buy	−10, 10	1, 1

INSIDE BUSINESS 10–4

Multimarket Contact and Price Competition

In the United States, many firms have a national presence, competing for customers in hundreds of markets across the country. When the same firms compete in multiple markets, they are said to have multimarket contact. Such interaction across many markets may soften price competition. The economist Corwin Edwards provided the intuition in senate testimony as follows:

> When one large conglomerate enterprise competes with another, the two are likely to encounter each other in a considerable number of markets. The multiplicity of their contact may blunt the edge of their competition. A prospect of advantage from vigorous competition in one market may be weighed against the danger of retaliatory forays by the competitor in other markets. Each conglomerate competitor may adopt a live-and-let-live policy to stabilize the whole structure of the competitive relationship.

Put simply, consider two firms competing in two separate markets, A and B. If one firm lowers its price in market A, it risks the prospect of its competitor retaliating by lowering its price not just in market A but in market B as well. While multimarket contact need not always soften price competition, several researchers have found such a relationship for industries such as airlines, hotels, and hospitals.

SOURCES: M. Schmitt, "Multimarket Contact in the Hospital Industry," *American Economic Journal: Economic Policy* 10, no. 3 (2018); W. Evans and I. Kessides, "Living by the 'Golden Rule': Multimarket Contact in the U.S. Airline Industry," *Quarterly Journal of Economics* 109, no. 2 (1994); N. Fernández and P. L. Marin, "Market Power and Multimarket Contact: Some Evidence from the Spanish Hotel Industry," *Journal of Industrial Economics* 46, no. 3 (1998), pp. 301–15.

guarantees that the product will be of high quality. That way, if an error occurs in production, the consumer can obtain a new item, be satisfied, and not "punish" the firm by spreading the news that it sells shoddy merchandise.

FINITELY REPEATED GAMES

So far we have considered two extremes: games that are played only once and games that are played infinitely many times. This section summarizes important implications of games that are repeated a finite number of times, that is, games that eventually end. We will consider two classes of **finitely repeated games**: (1) games in which players do not know when the game will end and (2) games in which players know when it will end.

finitely repeated game
Games in which players do not know when the game will end; and games in which players know when it will end.

Games with an Uncertain Final Period

Suppose two duopolists repeatedly play the pricing game in Table 10–9 until their products become obsolete, at which point the game ends. Thus, we are considering a finitely repeated game. Suppose the firms do not know the exact date at which their products will

Table 10–9
A Pricing Game That Is Finitely Repeated

		Firm B	
	Price	**Low**	**High**
Firm A	**Low**	0, 0	50, −40
	High	−40, 50	10, 10

become obsolete. Thus, there is uncertainty regarding the final period in which the game will be played.

Suppose the probability that the game will end after a given play is θ, where $0 < \theta < 1$. Thus, when a firm makes today's pricing decision, there is a chance that the game will be played again tomorrow; if the game is played again tomorrow, there is a chance that it will be played again the next day; and so on. For example, if $\theta = 1/2$, there is a 50–50 chance the game will end after one play, a $1/4$ chance it will end after two plays, a $1/8$ chance that it will end after three plays, or, more generally, a $\left(\frac{1}{2}\right)^t$ chance that the game will end after t plays of the game. It is as if a coin is flipped at the end of every play of the game, and if the coin comes up heads, the game terminates. The game terminates after t plays if the first heads occurs after t consecutive tosses of the coin.

It turns out that when there is uncertainty regarding precisely when the game will end, the finitely repeated game in Table 10–9 exactly mirrors our analysis of infinitely repeated games. To see why, suppose the firms adopt trigger strategies, whereby each agrees to charge a high price provided the other has not charged a low price in any previous period. If a firm deviates by charging a low price, the other firm will "punish" it by charging a low price until the game ends. For simplicity, let us assume the interest rate is zero so that the firms do not discount future profits.

Given such trigger strategies, does firm A have an incentive to cheat by charging a low price? If A cheats by charging a low price when B charges a high price, A's profits are \$50 today but zero in all remaining periods of the game. This is because cheating today "triggers" firm B to charge a low price in all future periods, and the best A can do in these periods is to earn \$0. Thus, if firm A cheats today, it earns

$$\Pi_{Firm\,A}^{Cheat} = \$50$$

regardless of whether the game ends after one play, two plays, or whenever.

If firm A does not cheat, it earns \$10 today. In addition, there is a probability of $1 - \theta$ that the game will be played again, in which case the firm will earn another \$10. There is also a probability of $(1 - \theta)^2$ that the game will not terminate after two plays, in which case A will earn yet another \$10. Carrying out this reasoning for all possible dates at which the game terminates, we see that firm A can expect to earn

$$\Pi_{Firm\,A}^{Coop} = 10 + (1 - \theta)10 + (1 - \theta)^2 10 + (1 - \theta)^3 10 + \cdots = \frac{10}{\theta}$$

if it does not cheat. In this equation, θ is the probability the game will terminate after one play. Notice that when $\theta = 1$, firm A is certain the game will end after one play; in this case, A's profits if it cooperates are \$10. But if $\theta < 1$, the probability the game will end after one play is less than 1 (there is a chance they will play again), and the profits of cooperating are greater than \$10.

The important thing to notice is that when the game is repeated a finite but uncertain number of times, the benefits of cooperating look exactly like the benefits of cooperating in an infinitely repeated game, which are

$$PV_{Firm\,A}^{Coop} = 10 + \frac{10}{1 + i} + \frac{10}{(1 + i)^2} + \frac{10}{(1 + i)^3} + \cdots = \frac{10(1 + i)}{i}$$

where i is the interest rate. In a repeated game with an uncertain end point, $1 - \theta$ plays the role of $1/(1 + i)$; players discount the future not because of the interest rate but because they are not certain future plays will occur.

In a finitely repeated game with an unknown end point, firm A has no incentive to cheat if it expects to earn less from cheating than from not cheating. For the numbers in our example, firm A has no incentive to cheat if

$$\Pi_{Firm\ A}^{Cheat} = 50 \leq \frac{10}{\theta} = \Pi_{Firm\ A}^{Coop}$$

which is true if $\theta \leq 1/5$. In other words, if after each play of the game the probability the game will end is less than 20 percent, firm A will lose more by cheating than it will gain. Since firm B's incentives are symmetric, the same is true for B. Thus, when oligopolistic firms compete a finite but uncertain number of times, it is possible for them to collude and charge high prices—to earn $10 each period—just as they can when they know the game will be played forever. The key is that there must be a sufficiently high probability that the game will be played in subsequent periods. In the extreme case where $\theta = 1$, players are certain they will play the game only once. In this case, the profits of cheating ($50) are much greater than the profits of cooperating ($10), and collusion cannot work. This should come as no surprise to you; when $\theta = 1$, the game is really a one-shot game, and the dominant strategy for each firm is to charge the low price.

DEMONSTRATION PROBLEM 10–7

Two local wedding photographers repeatedly play the following simultaneous-move online advertising game. If both advertise, each earns profits of $0 thousand. If neither advertises, each earns profits of $10 thousand. If one advertises and the other does not, the one that advertises earns $20 thousand and the other loses $1 thousand. If there is a 10 percent chance that a recession hits in any given year (driving the firms out of business), can the firms "collude" by agreeing not to advertise? Assume the interest rate is 0.

ANSWER:

The normal form of the one-shot game that is to be repeated an uncertain number of times is presented in Table 10–10. Suppose the players have adopted a trigger strategy, whereby each agrees not to advertise provided the other firm has not advertised in any previous period. If a firm deviates by advertising, the other firm will "punish" the offender by advertising until the game ends. If firm A cheats on the agreement, its profits are $20 thousand today but $0 in all subsequent periods until the game terminates. If firm A does not cheat, it can expect to earn

$$\Pi_{Firm\ A}^{Coop} = 10 + (.90)10 + (.90)^2 10 + (.90)^3 10 + \cdots = \frac{10}{.10} = 100$$

Since $20 < $100, firm A has no incentive to cheat. The incentives for firm B are symmetric. Thus, the firms can collude by using this type of trigger strategy.

Table 10–10

An Online Advertising Game

		Firm B	
	Strategy	**Advertise**	**Don't Advertise**
Firm A	**Advertise**	0, 0	20, −1
	Don't Advertise	−1, 20	10, 10

Repeated Games with a Known Final Period: The End-of-Period Problem

Now suppose a game is repeated some known finite number of times. For simplicity, we will suppose the game in Table 10–11 is repeated two times. However, the arguments that follow apply even when a game is repeated a larger number of times (e.g., 1,000 times), provided the players know precisely when the game will end and the game has only one Nash equilibrium.

The important thing about repeating the game in Table 10–11 two times is that in the second play of the game there is no tomorrow, and thus each firm has an incentive to use the same strategy during that period that it would use in a one-shot version of the game. Because there is no possibility of playing the game in the third period, the players cannot punish their rival for actions it takes in the second period. For this game, this implies that each player will charge a low price in period 2; even if firm B thought firm A would "cooperate" by charging a high price during the second period, A would maximize its profits by charging a low price during the last period. There is nothing B could do in the future to "punish" A for doing so. In fact, A would be very happy if B charged a high price in the second period; if it did, A could charge a low price and earn profits of $50.

Of course, firm B knows firm A has an incentive to charge a low price in period 2 (the last period) and will likewise want to charge a low price in this period. Because both players know their opponent will charge a low price in the second period, the first period is essentially the last period. There is a tomorrow, but it is the last period, and each player knows what the opponent will do in the last period. Thus, in period 1, each player has an incentive to choose the same strategy as in a one-shot version of the game (i.e., charge a low price) since they cannot be punished in period 2 for their actions in period 1. In short, the Nash equilibrium for the two-shot version of the game in Table 10–11 is to charge a low price each period. Each player earns zero profits during each of the two periods.

In fact, collusion cannot work even if the game is played for 3 periods, 4 periods, or even 1,000 periods, provided the firms know precisely when the game will end. The key reason firms cannot collude in a finitely repeated known-end-point version of the game in Table 10–11 is that eventually a point will come when both players are certain there is no tomorrow. At that point, any promises to "cooperate" made during previous periods will be broken because there is no way a player can be punished tomorrow for having broken the promise. Effectively, a player has an incentive to break a promise in the second-to-the-last period since there is no effective punishment during the last period. Because all the players know this, there is effectively no tomorrow in the third period from the last. This type of "backward unraveling" continues until the players realize no effective punishment can be used during any period. The players charge low prices in every period, right up to the known last period.

Table 10–11

A Pricing Game

		Firm B	
	Price	**Low**	**High**
Firm A	**Low**	0, 0	50, −40
	High	−40, 50	10, 10

DEMONSTRATION PROBLEM 10–8

You and a rival will play the game in Table 10–11 two times. Suppose your strategy is to charge a high price each period provided your opponent never charged a low price in any previous period. How much will you earn? Assume the interest rate is zero.

ANSWER:

Given your strategy, your opponent's best strategy is to charge a high price the first period and a low price the second period. To see why, note that if she charges a high price each period, she will earn 10 in the first period and 10 in the second period, for a total of 20 units of profit. She does better by charging a high price the first period (earning 10 units) and a low price the second period (earning 50 units), for a total of 60 units of profit. You will earn 10 units in the first period but lose 40 units in the second period, for a total loss of 30 units. Since each of you knows exactly when the game will end, trigger strategies will not enhance your profits.

Applications of the End-of-Period Problem

When players know precisely when a repeated game will end, what is known as the *end-of-period problem* arises. In the final period there is no tomorrow, and there is no way to "punish" a player for doing something "wrong" in the last period. Consequently, in the last period, players will behave just as they would in a one-shot game. In this section, we will examine some implications of the end-of-period problem for managerial decisions.

Resignations and Quits

As we discussed in Chapter 6, one reason workers find it in their interest to work hard is that they are implicitly threatened with the prospect of being fired if they get caught not working. As long as the benefits of shirking are less than the cost to workers of getting fired, workers will find it in their interest to work hard.

When a worker announces that she or he plans to quit, say, tomorrow, the cost of shirking to the worker is considerably reduced. Specifically, since the worker does not plan to work tomorrow anyway, the benefits of shirking on the last day generally will exceed the expected costs. In other words, since the worker does not plan to show up tomorrow, the "threat" of being fired has no bite.

What can the manager do to overcome this problem? One possibility is to "fire" the worker as soon as he or she announces the plan to quit. While in some instances there are legal restrictions against this practice, there is a more fundamental reason why a firm should not adopt such a policy. If you, as a manager, adopt a strategy of firing workers as soon as they notify you they plan to quit, how will workers respond? The best strategy for a worker would be to wait and tell you at the end of the day he or she plans to quit! By keeping the plan to quit a secret, the worker gets to work longer than he or she would otherwise. Notice that the worker's incentive to shirk is just as strong as it would be if you did not adopt this policy. Consequently, you will not solve the end-of-period problem, but instead will be continually "surprised" by worker resignations, with no lead time to find new workers to replace them.

A better managerial strategy is to provide some rewards for good work that extend beyond the termination of employment with your firm. For instance, you can emphasize to workers that you are very well connected and will be pleased to write a letter of recommendation should a worker need one in the future. By doing this, you send a signal to workers that quitting is not really the end of the game. If a worker takes advantage of the end-of-period

problem, you, being well connected, can "punish" the worker by informing other potential employers of this fact.

The "Snake-Oil" Salesman

In old TV westerns, "snake-oil" salesmen move from town to town, selling bottles of an elixir that is promised to cure every disease known to humankind. Unfortunately, buyers of the "medicine" soon learn that it is worthless and that they have been had. Nonetheless, these salesmen make a livelihood selling the worthless substance because they continue moving from town to town. By moving about, they ensure that buyers cannot "punish" them for selling worthless bottles of fluid. In contrast, if a local merchant were to sell worthless medicine, customers could have punished him or her by refusing to buy from the merchant in the future. As we saw earlier, this threat can be used to induce firms to sell products of good quality. But in the days of the snake-oil salesman, no such threat was possible.

For punishments to work, there must be some way to link the past, present, and future as it relates to the seller. The inadequate communication networks of the Old West precluded consumers from spreading the word about the snake-oil salesman to future customers; thus, the loss of his "reputation" was not a threat to him. However, over time consumers learned from past experience not to trust such salesmen, and when a new salesman came to town, they would "run him out."

Perhaps you have learned from experience that "sidewalk vendors" sell inferior merchandise. The reason, as you should now recognize, is that consumers have no way of tracking such vendors down in the event the merchandise is inferior. These salespeople indeed take advantage of the end-of-period problem.

MULTISTAGE GAMES

An alternative class of games is called *multistage games*. Multistage games differ from the class of games examined earlier in that timing is very important. In particular, the multistage framework permits players to make sequential rather than simultaneous decisions.

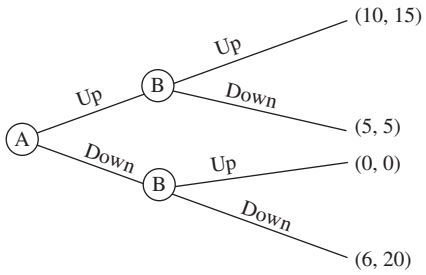
Theory

To understand how multistage games differ from one-shot and infinitely repeated games, it is useful to introduce the extensive form of a game. An **extensive-form game** summarizes who the players are, the information available to the players at each stage of the game, the strategies available to the players, the order of the moves of the game, and the payoffs that result from the alternative strategies.

extensive-form game
A representation of a game that summarizes the players, the information available to them at each stage, the strategies available to them, the sequence of moves, and the payoffs resulting from alternative strategies.

Once again, the best way to understand the extensive-form representation of a game is by way of example. Figure 10–1 depicts the extensive form of a game. The circles are called *decision nodes*, and each circle indicates that at that stage of the game the particular player must choose a move. The single point (denoted A) at which all of the lines originate is the beginning of the game, and the numbers at the ends of the branches represent the payoffs at the end of the game. For example, in this game player A moves first. A's feasible strategies are *up* or *down*. Once player A moves, it is player B's turn. Player B must then decide whether to move *up* or *down*. If both players move *up*, player A receives a payoff of 10 and player B receives a payoff of 15. If player A moves *up* and player B moves *down*, both players receive a payoff of 5. Thus, the first number in parentheses reflects the payoff to player A (the first mover in the game), while the second number refers to the payoff of player B (the second mover).

Figure 10–1
A Sequential-Move Game in Extensive Form



As in simultaneous-move games, each player's payoff depends not only on his or her action but on the action of the other player as well. For example, if player A moves *down* and player B moves *up*, the resulting payoff to A is 0. But if player B moves *down* when player A moves *down*, A receives 6.

There is, however, an important difference between the sequential-move game depicted in Figure 10–1 and the simultaneous-move games examined in the previous sections. Since player A must make a decision before player B, A cannot make actions conditional on what B does. Thus, A can choose only *up* or *down*. In contrast, B gets to make a decision after A. Consequently, a strategy for player B will specify an action for both of his decision nodes. If player A chooses *up*, player B can choose either *up* or *down*. If A chooses *down*, B can choose either *up* or *down*. Thus, one example of a strategy for B is to choose *up* if A chooses *up* and *down* if A chooses *down*. Notice that player B's strategy is allowed to depend on what player A has done since this is a sequential-move game and B moves second. In contrast, there is no conditional "if " in player A's strategy.

To illustrate how strategies work in sequential-move games, suppose player B's strategy is: "Choose *down* if player A chooses *up*, and *down* if player A chooses *down.*" Given this strategy, what is the best choice by player A? If A chooses *up*, she earns 5 since B will choose *down*. If A chooses *down*, she earns 6 because B will choose *down*. Given a choice between earning 5 and 6, player A prefers 6 and therefore will choose *down*.

Given that player A chooses *down*, does player B have an incentive to change his strategy? B's strategy specifies that he chooses *down* if A chooses *down*. By choosing down, B earns 20, whereas he earns 0 by choosing *up*. We thus see that player B has no incentive to change his strategy given that player A chose *down*.

Since neither player has an incentive to change his or her strategies, we have found a Nash equilibrium to the game in Figure 10–1. These strategies are:

Player A: *down.*

Player B: *down* if player A chooses *up*, and *down* if player A chooses *down*.

The payoffs that result in this equilibrium are 6 for player A and 20 for player B.

You should ask yourself whether this is a reasonable outcome for the game. In particular, notice that the highest payoff for player A results when A chooses *up* and B chooses *up* as well. Why didn't player A choose *up*? Because player B "threatened" to choose *down* if A chose *up*. Should player A believe this threat? If she chooses *up*, player B's best choice is *up* since the payoff of 15 is better for B than the payoff of 5 that results from choosing *down*. But if B chooses *up*, A earns 10. This is higher than the payoff that resulted in the Nash equilibrium we examined earlier.

What do we make of all this? There is, in fact, another Nash equilibrium to this game. In particular, suppose player B's strategy is "Choose *up* if player A chooses *up*; choose

down if player A chooses *down*." Given this strategy by player B, player A earns 10 by choosing *up* and 6 by choosing *down*. Clearly the best response by A to this strategy by B is *up*. Given that player A chooses *up*, player B has no incentive to change his strategy, and thus we have another Nash equilibrium. In this Nash equilibrium, player A earns 10 and player B earns 15.

Which of these two Nash equilibrium outcomes is the more reasonable? The answer is the second one. The reason is as follows: In the first Nash equilibrium, player A chooses *down* because player B threatened to play *down* if A chooses *up*. But player A should recognize that this threat is really not credible. If this stage of the game (decision node) were in fact reached, player B would have an incentive to renege on his threat to choose *down*. Choosing *down* at this stage of the game would result in lower profits for B than he would earn by choosing *up*. Player B therefore has no incentive to do what he said he would do. In the jargon of game theory, the Nash equilibrium in which player A earns 6 and player B earns 20 is not a subgame perfect equilibrium. A set of strategies constitutes a **subgame perfect equilibrium** if (1) it is a Nash equilibrium and (2) at each stage of the game (decision node), neither player can improve her payoff by changing her own strategy. Thus, a subgame perfect equilibrium is a Nash equilibrium that involves only credible threats. For the game in Figure 10–1, the only subgame perfect equilibrium involves player A choosing *up* and player B choosing *up* when player A chooses *up*.

subgame perfect equilibrium
A condition describing a set of strategies that constitutes a Nash equilibrium and allows no player to improve his own payoff at any stage of the game by changing strategies.

The analysis in this section typically is difficult for students to grasp on the first or second reading, so we encourage you to review this section if you are not clear on the concepts presented. Before you do so, or move on to the next section, let us provide a fable that may help you understand the notion of a subgame perfect equilibrium.

A teenager is given the following instructions by her father: "If you're not home by midnight, I'll burn down the house and you will lose everything you own." If the teenager believes her father, it will certainly be in her best interest to return before midnight since she does not want to lose everything she owns. And if the teenager returns before midnight, the

INSIDE BUSINESS 10–5

Entry Strategies in International Markets: Sprinkler or Waterfall?

International marketing strategists are often confronted with a dilemma regarding entry into new markets: Should we adopt a "waterfall strategy" in which we enter several countries sequentially? Or is it best to adopt a "sprinkler" strategy and enter multiple countries simultaneously?

The main advantage of a sprinkler strategy is that it permits a firm to quickly enter several markets at the same time, thereby establishing a foothold in different countries ahead of rivals. The disadvantages are that it often prevents firms from taking advantage of learning curve effects and tends to spread resources too thin. In contrast, a waterfall strategy leads to slower international penetration but permits firms to tailor products to particular markets and to learn from experiences in other markets.

The optimal penetration strategy, of course, depends on the benefits and costs of these strategies. Sprinkler strategies are typically optimal when markets are homogeneous, learning curve effects are small, and country-specific investments are low. Waterfall strategies tend to work best when significant country-specific investments are needed.

Professors Fischer, Clement, and Shankar have provided evidence that the order of entry is an important factor in determining optimal strategies for entering international markets. Based on pharmaceutical data from Europe, they find that, if there are already more than three existing firms in the market, sequential entry into different countries is best.

SOURCE: Marc Fischer, Michel Clement, and Venkatesh Shankar, "International Market Entry Strategy: A Source of Late Mover Advantage," University of Maryland, March 2004.

father never has to burn down the house; there is no cost to the father of threatening to do so. The threat of the father and the return of the daughter before midnight are Nash equilibrium strategies. However, they are not subgame perfect equilibrium strategies. The father's threat to burn down the house, which is what led the teenager to choose to return before midnight, is not credible. The father will not find it in his interest to burn down his own house if his daughter returns late. If the daughter knows this, she knows that the threat is not credible and will not let it affect whether or not she returns home before midnight. Thus, since the Nash equilibrium is obtained by a threat that is not credible, it is not a subgame perfect equilibrium.

Applications of Multistage Games

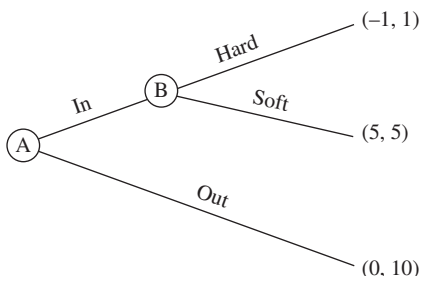
The Entry Game

To illustrate the use of the theory of multistage games in a market setting, consider the extensive-form game presented in Figure 10–2. Here, firm B is an existing firm in the market and firm A is a potential entrant. Firm A must decide whether to enter the market (*in*) or stay out (*out*). If A decides to stay out of the market, firm B continues its existing behavior and earns profits of $10 million, while A earns $0. But if A decides to enter the market, B must decide whether to engage in a price war (*hard*) or to simply share the market (*soft*). By choosing *hard*, firm B ensures that firm A incurs a loss of $1 million, but B makes only $1 million in profits. On the other hand, if firm B chooses *soft* after A enters, A takes half of the market and each firm earns profits of $5 million.

It turns out that there are two Nash equilibria for this game. The first occurs where firm B threatens to choose *hard* if A enters the market, and thus A stays *out* of the market. To see that these strategies indeed comprise a Nash equilibrium, note the following: Given that firm B's strategy is to choose *hard* if firm A enters, A's best choice is not to enter. Given that A doesn't enter, B may as well threaten to choose *hard* if A enters. Thus, neither firm has an incentive to change its strategy; firm A earns $0, and firm B earns profits of $10 million.

However, this Nash equilibrium involves a threat that is not credible. The reason firm A chooses not to enter is that firm B threatens to choose *hard* if A enters. Does B have an incentive to carry through its threat of choosing *hard* if firm A enters? The answer is no. Given that firm A enters the market, firm B will earn $5 million by choosing *soft* but only $1 million by choosing *hard*. If firm A enters, it is not in firm B's best interest to play *hard*. Thus, the outcome in which firm A stays out of the market because firm B threatens to choose *hard* if it enters is a Nash equilibrium, but it is not a subgame perfect equilibrium. It involves a threat that is not credible, namely, the threat by firm B to engage in a price war if firm A enters.

Figure 10–2
An Entry Game



The other Nash equilibrium for this game is for firm A to choose *in* and firm B to follow this move by playing *soft*. In particular, if firm A enters, firm B's best choice is to play *soft* (by playing *soft*, B earns $5 million instead of the $1 million it would earn by playing *hard*). Given that firm B plays *soft* if firm A enters, A's best choice is to enter (by choosing *in*, A earns $5 million instead of the $0 it would earn by staying out). This is a subgame perfect equilibrium because it is clearly in firm B's self-interest to play *soft* whenever A chooses to enter. Thus, while there are two Nash equilibria for the entry game, there is a unique subgame perfect equilibrium in which firm A chooses *in* and firm B plays *soft*.

Innovation

Our analysis of the entry game reveals an important lesson for future managers: It does not pay to heed threats made by rivals when the threats are not credible. We can also use the theory of sequential, or multistage, games to analyze innovation decisions, as the next problem illustrates.

DEMONSTRATION PROBLEM 10–9

Your firm must decide whether or not to introduce a new product. If you introduce the new product, your rival will have to decide whether or not to clone the new product. If you don't introduce the new product, you and your rival will earn $1 million each. If you introduce the new product and your rival clones it, you will lose $5 million and your rival will earn $20 million (you have spent a lot on research and development, and your rival doesn't have to make this investment to compete with its clone). If you introduce the new product and your rival does not clone, you will make $100 million and your rival will make $0.

1. Set up the extensive form of this game.
2. Should you introduce the new product?
3. How would your answer change if your rival has "promised" not to clone your product?
4. What would you do if patent law prevented your rival from cloning your product?

ANSWER:

1. The new-product game is depicted in Figure 10–3. Note that this is a multistage game in which your firm (A) moves first, followed by your rival (B).

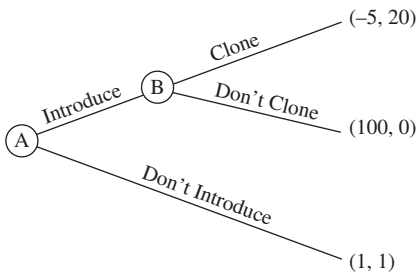


Figure 10–3
An Innovation Game

2. If you introduce the product, B's best choice is to clone, in which case your firm loses $5 million. If you don't introduce the product, you earn $1 million. Thus, your profit-maximizing decision is not to introduce the new product.
3. If you believe your rival's "promise" not to clone, you will earn $100 million by introducing the new product and only $1 million if you do not introduce it. However, B's promise is

not credible; B would love you to spend money developing the product so that B could clone it and earn profits of $20 million. In this case, you stand to lose $5 million. Because the promise is not credible, you had better think twice about letting it affect your behavior.

4. If you can obtain a patent on your new product, B will be forced by law to refrain from cloning. In this case, you should introduce the product to earn $100 million. This illustrates that the ability to patent a new product often induces firms to introduce products that they would not introduce in the absence of a patent system.

Sequential Bargaining

The final application of multistage games that we will consider is a *sequential-move bargaining game*. Specifically, suppose a firm and a labor union are engaged in negotiations over how much of a $100 surplus will go to the union and how much will go to management. Suppose management (M) moves first by offering an amount to the union (U). Given the offer, the union gets to decide to accept or reject the offer. If the offer is rejected, neither party receives anything. If the offer is accepted, the union gets the amount specified and management gets the residual. To simplify matters, suppose management can offer the union one of three amounts: $1, $50, or $99.

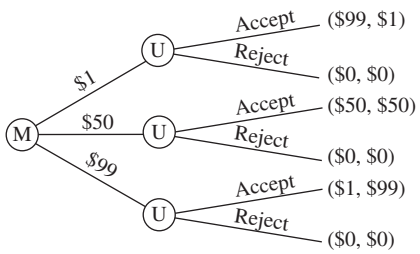
The extensive form of this game is depicted in Figure 10–4. Notice that the union gets to make its decision after it learns of management's offer. For instance, if management offers the union $1 and the union accepts the offer, management gets $99 and the union gets $1. If the union rejects the offer, both parties get $0.

Suppose you are management and the union makes the following statement to you before you make an offer: "Give us $99 or else we will reject the offer." What should you do? If you believe the union, then if you offered it a lower amount, it would reject the offer and you would get nothing. Given the union's strategy, your best choice is to give the union $99 since that action gives you a payoff of $1 instead of $0. And given that you offer the union $99, its best choice is to accept the offer. Thus, one Nash equilibrium outcome of this sequential bargaining process yields $1 for management and $99 for the union.

Does this mean that the optimal action for management is to give the union $99? The answer is no. Notice that this equilibrium is supported by a union threat that is not credible. According to the union, if management offered the union $1, the union would reject the offer. But by rejecting such an offer, the union would earn $0 instead of the $1 it could earn by accepting it. Thus, it is not in the union's best interest to reject the offer.

In fact, the unique subgame perfect equilibrium for this sequential bargaining game is for management to offer the union $1 and for the union to accept the offer. To see this, notice that if management offered the union $1, the union's best choice would be to accept since $1 is preferred to the $0 it would earn by rejecting the offer. In this sequential-move bargaining game, the unique subgame perfect equilibrium results in management getting $99 and the union getting $1.

Figure 10–4
A Sequential-Move Bargaining Game



DEMONSTRATION PROBLEM 10–10

Consider the bargaining game just described, but suppose the order of play is reversed: The union gets to make an offer and then management decides whether to accept or reject it. What is the subgame perfect equilibrium outcome of this bargaining process?

ANSWER:

The profit-maximizing choice by management to any offer is to accept it if that yields more than the $0 management would earn by rejecting the offer. Therefore, the subgame perfect equilibrium is for the union to offer management $1 and keep $99 for itself. Given this offer, management's best choice is to accept it. Any threat by management to refuse an offer of $1 or $50 would not be credible.

This section has illustrated a remarkable feature of two-stage sequential bargaining games. Effectively, the first mover in the bargaining game makes a take-it-or-leave-it offer. The second mover can accept the offer or reject it and receive nothing. The player making the take-it-or-leave-it offer extracts virtually all the amount bargained over. The following example illustrates this principle.

Suppose a consumer wishes to buy a car that the dealer values at $10,000. The consumer values the car at $12,000. Effectively, the bargaining game is over the $2,000 difference between the consumer's valuation and the dealer's cost. Suppose the consumer makes the following take-it-or-leave-it offer to the dealer: "I'll pay you $10,001 for the car. If you don't accept it, I will buy a car from the dealer down the road." If the dealer believes the consumer's threat to terminate the bargaining process if the offer is rejected, he will accept the offer; the dealer prefers earning $1 to earning $0 by not selling the car. The consumer buys the car at $1 over the dealer's cost.

In contrast, suppose the order of the bargaining process is reversed, and the dealer tells the consumer: "Another buyer wants the car. Pay me $11,999, or I'll sell it to the other customer." In this case, if the buyer believes the dealer's threat to sell to another buyer is credible and has no other options, her best choice is to buy the car since it costs $1 less than her valuation. In this case, the dealer makes a handsome profit.

In concluding this section, we note that several aspects of reality often complicate sequential-bargaining processes. First, the players do not always know the true payoffs to other players. For instance, if a car buyer does not know the dealer's cost of a car, he or she cannot make a take-it-or-leave-it offer and be assured of getting the car. Similarly, if a dealer does not know the maximum price a consumer will pay for a car, she or he cannot be assured of making a sale by making a take-it-or-leave-it offer. In bargaining processes, it is worthwhile to invest some time in learning about your opponent. This explains why there is a market for publications that specialize in providing information to consumers about the dealer cost of automobiles.

Second, an important assumption in the bargaining process analyzed in this section is that bargaining terminates as soon as the second player rejects or accepts an offer. If this were not the case, the person making the decision to accept or reject the offer might reason as follows: "If I reject the offer, perhaps the other party will make a new, more attractive offer." Effectively, this changes the game and can change the players' underlying decisions. On the other hand, a player who can credibly commit to making a take-it-or-leave-it offer will do very well in the bargaining game. But if the commitment is not credible, he or she may end up "eating crow" when the other party makes a counteroffer that the first player would prefer over walking away from the bargaining table.

ANSWERING THE headLINE

While a number of factors might have contributed to US Airways' decision to stop charging $2 for soft drinks, the strategy failed primarily because the airline was the only major carrier to charge passengers for soft drinks. This damaged US Airways' image and led some of its customers to switch to more friendly carriers. These negative effects of the company's unilateral strategy to charge passengers $2 for drinks swamped any revenues (or cost savings) it gained by collecting cash from passengers. US Airways learned the hard way that offering complimentary drinks is the dominant strategy in the brutal game it plays with other carriers. The same is true for American Airlines' later attempt to force basic economy passengers to pay to check bags instead of carry them on the aircraft.

The payoff matrix in Table 10–12 contains some hypothetical numbers that illustrate these points. Notice that if US Airways and its rivals all offer complimentary drinks, each of the airlines earns a zero payoff. If US Airways and its rivals all charge $2 for drinks, US Airways and its rivals earn an extra $4 million. But when US Airways charges $2 for drinks and the other carriers offer complimentary drinks, US Airways gives up $5 million and its rivals gain $5 million. Looking at the payoff matrix in Table 10–12, it is clear that US Airways' dominant strategy is to offer complimentary drinks. While US Airways probably hoped that other carriers would follow if it started charging $2 for drinks, it was not in its rivals' interests to do so. If managers at US Airways (and American Airlines) had put themselves in their rivals' shoes, perhaps they would have realized that the dominant strategy of the other carriers in this game is to offer complimentary drinks (and carry-on bags) and never have traveled along this unprofitable path in the first place.

Table 10–12

The Complimentary Drink Game

		Rivals	
	Strategy	**Complimentary Drinks**	**$2 Drinks**
US Airways	**Complimentary Drinks**	0, 0	5, –5
	$2 Drinks	–5, 5	4, 4

SUMMARY

This chapter opened with the study of Nash equilibrium in one-shot, simultaneous-move games. We learned that the resulting payoffs are sometimes lower than would arise if players colluded. The reason higher payoffs cannot be achieved in one-shot games is that each participant has an incentive to cheat on a collusive agreement. In many games, what primarily motivates firms to cheat is the fact that cheating is a dominant strategy. Dominant strategies, when they exist, determine the optimal decision in a one-shot game.

We also examined solutions to games that are infinitely repeated. The use of trigger strategies in these games enables players to enter and enforce collusive agreements when the interest rate is low. By adopting strategies that punish cheaters over long periods of time, collusive agreements can be self-enforcing when the game is infinitely repeated. Other factors that affect collusion are the number of firms, the history in the market, the ability of firms to monitor one another's behavior, and the ability to punish cheaters. Similar features of repeated

interaction also help consumers and businesses continue trading with each other and keep product quality high.

Finally, we covered finitely repeated games with both uncertain and known terminal periods, as well as sequential-move entry and bargaining games. When the interaction among parties is for a known time period, problems with cheating in the last period can unravel cooperative agreements that would have been supported by trigger strategies in infinitely repeated games or games with an uncertain end point. In sequential-move games, one must determine whether the threats to induce a particular outcome in the game are credible.

KEY TERMS AND CONCEPTS

coordination game
dominant strategy
end-of-period problem
extensive-form game
finitely repeated game
game theory
infinitely repeated game
mixed (randomized) strategy
multistage game
Nash bargaining
Nash equilibrium
normal-form game
one-shot game
repeated game
secure strategy
sequential bargaining
sequential-move game
simultaneous-move game
strategy
subgame perfect equilibrium
trigger strategy

CONCEPTUAL AND COMPUTATIONAL QUESTIONS

1. Use the following one-shot, normal-form game to answer the following questions. *(LO2)*

		Player 2		
	Strategy	***D***	***E***	***F***
Player 1	***A***	−200, 150	350, 100	−50, 600
	B	200, −300	400, 400	300, 100
	C	−150, 200	−250, 550	750, −350

   a. Find each player's dominant strategy, if it exists.
   b. Find each player's secure strategy.
   c. Find the Nash equilibrium.

2. In a two-player, one-shot, simultaneous-move game, each player can choose strategy *A* or strategy *B*. If both players choose strategy *A*, each earns a payoff of $400. If both players choose strategy *B*, each earns a payoff of $200. If player 1 chooses strategy *A* and player 2 chooses strategy *B*, then player 1 earns $100 and player 2 earns $600. If player 1 chooses strategy *B* and player 2 chooses strategy *A*, then player 1 earns $600 and player 2 earns $100. *(LO2)*
   a. Write this game in normal form.
   b. Find each player's dominant strategy, if it exists.
   c. Find the Nash equilibrium (or equilibria) of this game.
   d. Rank strategy pairs by aggregate payoff (highest to lowest).
   e. Can the outcome with the highest aggregate payoff be sustained in equilibrium? Why or why not?

3. Use the following payoff matrix for a simultaneous-move one-shot game to answer the accompanying questions. *(LO2, LO3)*

		Player 2			
	Strategy	C	D	E	F
Player 1	A	6, 14	7, 11	18, 20	10, 19
	B	12, 5	15, 1	7, 25	16, 17

a. What is player 1's optimal strategy? Why?
b. Determine player 1's equilibrium payoff.

4. Use the following normal-form game to answer the following questions. *(LO2)*

		Player 2	
	Strategy	C	D
Player 1	A	30, 30	70, 0
	B	0, 70	60, 60

a. Identify the one-shot Nash equilibrium.
b. Suppose the players know this game will be repeated exactly three times. Can they achieve payoffs that are better than the one-shot Nash equilibrium? Explain.
c. Suppose this game is infinitely repeated and the interest rate is 6 percent. Can the players achieve payoffs that are better than the one-shot Nash equilibrium? Explain.
d. Suppose the players do not know exactly how many times this game will be repeated, but they do know that the probability the game will end after a given play is θ. If θ is sufficiently low, can players earn more than they could in the one-shot Nash equilibrium?

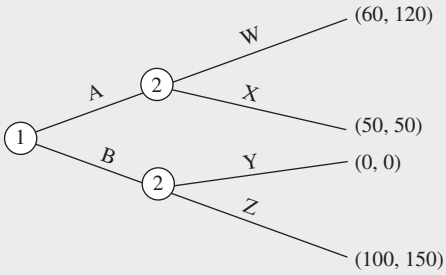
5. Use the following normal-form game to answer the following questions. *(LO2)*

		Player 2	
	Strategy	C	D
Player 1	A	3, $7 - x$	2, 3
	B	4, 4	$7 - x$, 5

a. For what values of x is strategy D (strictly) dominant for player 2?
b. For what values of x is strategy B (strictly) dominant for player 1?
c. For what values of x is (B, D) the only Nash equilibrium of the game?

6. Consider a two-player, sequential-move game where each player can choose to play *right* or *left*. Player 1 moves first. Player 2 observes player 1's actual move and then decides to move *right* or *left*. If player 1 moves *right*, player 1 receives \$0 and player 2 receives \$25. If both players move *left*, player 1 receives –\$5 and player 2 receives \$10. If player 1 moves *left* and player 2 moves *right*, player 1 receives \$20 and player 2 receives \$20. *(LO2)*
a. Write this game in extensive form.
b. Find the Nash equilibrium outcomes to this game.
c. Which of the equilibrium outcomes is most reasonable? Explain.

7. Use the following extensive-form game to answer the following questions. *(LO2)*
   a. List the feasible strategies for player 1 and player 2.
   b. Identify the Nash equilibria to this game.
   c. Find the subgame perfect equilibrium.



8. Use the following payoff matrix for a one-shot game to answer the accompanying questions. *(LO2)*

		Player 2	
	Strategy	***X***	***Y***
Player 1	***A***	25, 25	−100, 5
	B	5, −100	15, 15

   a. Determine the Nash equilibrium outcomes that arise if the players make decisions independently, simultaneously, and without any communication. Which of these outcomes would you consider most likely? Explain.
   b. Suppose player 1 is permitted to "communicate" by uttering one syllable before the players simultaneously and independently make their decisions. What should player 1 utter, and what outcome do you think would occur as a result?
   c. Suppose player 2 can choose its strategy before player 1, that player 1 observes player 2's choice before making her decision, and that this move structure is known by both players. What outcome would you expect? Explain.

9. Use the following payoff matrix to answer the following questions. *(LO2)*

		Player 2	
	Strategies	***C***	***D***
Player 1	***A***	−10, −10	200, −100
	B	−100, 220	140, 180

   Suppose this is a one-shot game:
   a. Determine the dominant strategy for each player. If such strategies do not exist, explain why not.
   b. Determine the secure strategy for each player. If such strategies do not exist, explain why not.
   c. Determine the Nash equilibrium of this game. If such an equilibrium does not exist, explain why not.

10. Using the same payoff matrix as in question 9, suppose this game is infinitely repeated and that the interest rate is sufficiently "low." Identify trigger strategies that permit players 1 and 2 to earn equilibrium payoffs of 140 and 180, respectively, in each period. *(LO3)*

PROBLEMS AND APPLICATIONS



11. While there is a degree of differentiation between major grocery chains like Albertsons and Kroger, the regular offering of sale prices by both firms for many of their products provides evidence that these firms engage in price competition. For markets where Albertsons and Kroger are the dominant grocers, this suggests that these two stores simultaneously announce one of two prices for a given product: a regular price or a sale price. Suppose that when one firm announces the sale price and the other announces the regular price for a particular product, the firm announcing the sale price attracts 1,000 extra customers to earn a profit of $5,000, compared to the $3,000 earned by the firm announcing the regular price. When both firms announce the sale price, the two firms split the market equally (each getting an extra 500 customers) to earn profits of $2,000 each. When both firms announce the regular price, each company attracts only its 1,500 loyal customers and the firms each earn $4,500 in profits. If you were in charge of pricing at one of these firms, would you have a clear-cut pricing strategy? If so, explain why. If not, explain why not and propose a mechanism that might solve your dilemma. (*Hint*: Unlike Walmart, neither of these two firms guarantees "Everyday low prices.") *(LO1, LO2)*

12. Suppose Toyota and Honda must decide whether to make a new breed of side-impact airbags standard equipment on all models. Side-impact airbags raise the price of each automobile by $1,000. If both firms make side-impact airbags standard equipment, each company will earn profits of $2.5 billion. If neither company adopts the side-impact airbag technology, each company will earn $1 billion (due to lost sales to other automakers). If one company adopts the technology as standard equipment and the other does not, the adopting company will earn a profit of $3 billion and the other company will lose $1.5 billion. If you were a decision maker at Honda, would you make side-impact airbags standard equipment? Explain. *(LO1, LO2)*

13. Coca-Cola and PepsiCo are the leading competitors in the market for cola products. In 1960 Coca-Cola introduced Sprite, which today is among the worldwide leaders in the lemon-lime soft drink market and ranks in the top 10 among all soft drinks worldwide. Prior to 1999, PepsiCo did not have a product that competed directly against Sprite and had to decide whether to introduce such a soft drink. By not introducing a lemon-lime soft drink, PepsiCo would continue to earn a $200 million profit, and Coca-Cola would continue to earn a $300 million profit. Suppose that by introducing a new lemon-lime soft drink, one of two possible strategies could be pursued: (1) PepsiCo could trigger a price war with Coca-Cola in both the lemon-lime and cola markets or (2) Coca-Cola could acquiesce and each firm maintain its current 50/50 split of the cola market and split the lemon-lime market 30/70 (PepsiCo/Coca-Cola). If PepsiCo introduced a lemon-lime soft drink and a price war resulted, both companies would earn profits of $100 million. Alternatively, Coca-Cola and PepsiCo would earn $275 million and $227 million, respectively, if PepsiCo introduced a lemon-lime soft drink and Coca-Cola acquiesced and split the markets as listed. If you were a manager at PepsiCo, would you try to convince your colleagues that introducing the new soft drink is the most profitable strategy? Why or why not? *(LO1, LO2)*

14. Suppose a UAW labor contract with General Dynamics is being renegotiated. Some of the many issues on the table include job security, health benefits, and wages. If you are an executive in charge of human resource issues at General Dynamics, would you be better off (*a*) letting the union bear the expense of crafting a document summarizing its desired compensation or (*b*) making the union a take-it-or-leave-it offer? Explain. *(LO1, LO2)*

15. Price comparison services on the Internet (as well as "shopbots") are a popular way for retailers to advertise their products and a convenient way for consumers to simultaneously obtain price quotes from several firms selling an identical product. Suppose that you are the manager of Digital Camera, Inc., a firm that specializes in selling digital cameras to consumers that advertises with an Internet price comparison service. In the market for one particular high-end camera, you have only one rival firm—The Camera Shop—with which you've competed for the last four years by setting prices day after day. Being savvy entrepreneurs, the ease of using the Internet to monitor rival firms' prices has enabled you and your rival to charge extremely high prices for this particular camera. In a recent newspaper article, you read that The Camera Shop has exhausted its venture capital and that no new investors are willing to sink money into the company. As a result, The Camera Shop will discontinue its operations next month. Will this information alter your pricing decisions today? Explain. *(LO1, LO2, LO3)*

16. You are the manager of a firm that manufactures front and rear windshields for the automobile industry. Due to economies of scale in the industry, entry by new firms is not profitable. Toyota has asked your company and your only rival to simultaneously submit a price quote for supplying 100,000 front and rear windshields for its newest version of the Highlander. If both you and your rival submit a low price, each firm supplies 50,000 front and rear windshields and earns a zero profit. If one firm quotes a low price and the other a high price, the low-price firm supplies 100,000 front and rear windshields and earns a profit of $11 million and the high-price firm supplies no windshields and loses $2 million. If both firms quote a high price, each firm supplies 50,000 front and rear windshields and earns a $6 million profit. Determine your optimal pricing strategy if you and your rival believe that the new Highlander is a "special edition" that will be sold only for one year. Would your answer differ if you and your rival were required to resubmit price quotes year after year and if, in any given year, there was a 60 percent chance that Toyota would discontinue the Highlander? Explain. *(LO1, LO2, LO3)*

17. At a time when demand for ready-to-eat cereal was stagnant, a spokesperson for the cereal maker Kellogg's was quoted as saying, " . . . for the past several years, our individual company growth has come out of the other fellow's hide." Kellogg's has been producing cereal since 1906 and continues to implement strategies that make it a leader in the cereal industry. Suppose that when Kellogg's and its largest rival advertise, each company earns $0 in profits. When neither company advertises, each company earns profits of $12 billion. If one company advertises and the other does not, the company that advertises earns $52 billion and the company that does not advertise loses $4 billion. Under what conditions could these firms use trigger strategies to support the collusive level of advertising? *(LO1, LO2, LO3)*

18. You are a pricing manager at Argyle Inc.—a medium-sized firm that recently introduced a new product into the market. Argyle's only competitor is Baker Company, which is significantly smaller than Argyle. The management of Argyle has decided to pursue a short-term strategy of maximizing this quarter's revenues, and you are in charge of formulating a strategy that will permit the firm to do so. After talking with an employee who was recently hired from the Baker Company, you are confident that (*a*) Baker is constrained to charge $10 or $20 for its product, (*b*) Baker's goal is to maximize this quarter's profits, and (*c*) Baker's relevant unit costs are identical to yours. You

have been authorized to price the product at two possible levels ($5 or $10) and know that your relevant costs are $2 per unit. The marketing department has provided the following information about the expected number of units sold (in millions) this quarter at various prices to help you formulate your decision:

Argyle Price	Baker Price	Argyle Quantity (millions of units)	Baker Quantity (millions of units)
$ 5	$10	3	2
5	20	3	1
10	10	1	2
10	20	1	1

Argyle and Baker currently set prices at the same time. However, Argyle can become the first mover by spending $2 million on computer equipment that would permit it to set its price before Baker. Determine Argyle's optimal price and whether you should invest the $2 million. *(LO1, LO2)*

19. You are the manager of GearNet and must decide how many Internet hubs to produce to maximize your firm's profit. GearNet and its only rival (NetWorks) sell dual-speed Internet hubs that are identical from consumers' perspectives. The market price for hubs depends on the total quantity produced by the two firms. A survey reveals that the market price of hubs depends on total market output as follows:

Combined Hub Production of GearNet and NetWorks	Market Price of Hubs (per unit)
500 units	$140
750 units	110
1,000 units	95

GearNet and NetWorks each uses labor, materials, and machines to produce output. GearNet purchases labor and materials on an as-needed basis; its machines were purchased three years ago and are being depreciated according to the straight-line method. GearNet's accounting department has provided the following data about its unit production costs:

	GearNet's Unit Cost for an Output of:	
Item	250 units	500 units
Direct labor	$ 35	$35
Direct materials	25	25
Depreciation charge	120	60

Reports from industry experts suggest that NetWorks' cost structure is similar to GearNet's cost structure and that technological constraints require each firm to

produce either 250 hubs or 500 hubs. Identify the costs that are relevant for your decision, and then determine whether GearNet should produce 250 hubs or 500 hubs. *(LO1, LO2)*

20. Both Google and Amazon are major players in the smart home market, using their own internally developed smart home control system (Google Assistant and Alexa, respectively). Suppose each is considering a new round of investments into their smart home offerings, which could build on their in-house system or be tailored to a new open-source standard system, called Connected Home. Google estimates that it will cost $1.2 billion to build on Google Assistant and $2.0 billion to move to Connected Home. Amazon's projected cost of building on Alexa is $1.1 billion, while the cost of moving to Connected Home is $2.7 billion. As shown in the accompanying table, each company's projected revenues depend not only on the technology it uses, but also on the technology used by its rival.

Projected Revenues for Different Combinations of Smart Home Technologies (in billions)

Technologies (Google–Amazon)	Google's Revenues	Amazon's Revenues
Google Assistant—Alexa	$12.1	$13.5
Google Assistant—Connected Home	12.1	11.6
Connected Home—Alexa	9.8	13.5
Connected Home—Connected Home	16.2	18.3

Construct the normal form of this game. Then, explain the economic forces that give rise to the structure of the payoffs and any difficulties the companies might have in achieving Nash equilibrium in the new market. *(LO1, LO2)*

21. Japanese officials are considering a new tariff on imported pork products from the United States in an attempt to reduce Japan's reliance on U.S. pork. Due to political pressure, the U.S. International Trade Representative's (ITR) office is also considering a new tariff on imported steel from Japan. Officials in both Japan and the United States must assess the social welfare ramifications of their tariff decisions. Reports from a reliable think tank indicate the following: If neither country imposes a new tariff, social welfare in Japan's economy will remain at $10 billion and social welfare in the United States will remain at $50 billion. If both countries impose a new tariff, welfare in the United States declines to $49.1 billion and welfare in Japan declines to $9.5 billion. If Japan does not impose a tariff but the United States does, projected welfare in Japan is $8.9 billion while welfare in the United States is $52.5 billion. Finally, if the United States does not impose a tariff but Japan does, welfare is projected at $48.2 billion in the United States and $11.4 billion in Japan. Determine the Nash equilibrium outcome when policymakers in the two countries simultaneously but independently make tariff decisions in a myopic (one-shot) setting. Is it possible for the two countries to improve their social welfare by "agreeing" to different strategies? Explain. *(LO1, LO2, LO3)*

22. An office manager is concerned with declining productivity. Despite the fact that she regularly monitors her clerical staff four times each day—at 9:00 AM, 11:00 AM, 1:00 PM, and again at 3:00 PM—office productivity has declined 30 percent since she assumed the helm one year ago. Would you recommend that the office manager invest more time monitoring the productivity of her clerical staff? Explain. *(LO1, LO2)*

23. You manage a company that competes in an industry that is comprised of five equal-sized firms. A recent industry report indicates that a tariff on foreign imports would boost industry profits by $30 million—and that it would only take $5 million in expenditures on (legal) lobbying activities to induce Congress to implement such a tariff. Discuss your strategy for improving your company's profits. *(LO1, LO2)*

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11 Pricing Strategies for Firms with Market Power

LEARNING OBJECTIVES

After completing this chapter, you will be able to:

- **LO1** Apply simple elasticity-based markup formulas to determine profit-maximizing prices in environments where a business enjoys market power, including monopoly, monopolistic competition, and Cournot oligopoly.
- **LO2** Formulate pricing strategies that permit firms to extract additional surplus from consumers—including price discrimination, two-part pricing, block pricing, and commodity bundling—and explain the conditions needed for each of these strategies to yield higher profits than standard pricing.
- **LO3** Formulate pricing strategies that enhance profits for special cost and demand structures—such as peak-load pricing, cross-subsidies, and transfer pricing—and explain the conditions needed for each strategy to work.
- **LO4** Explain how price-matching guarantees, brand loyalty programs, and randomized pricing strategies can be used to enhance profits in markets with intense price competition.

headLINE

Mickey Mouse Lets You Ride "for Free" at Disney World

Walt Disney World Theme Parks offer visitors a wide variety of ticket choices. The one thing these ticket options have in common is that they entail a fixed entrance fee and allow customers to take as many rides as they want at no additional charge. For instance, by purchasing a 1-Day ticket for about $120, a customer gains unlimited access to the park of her choice for one day.

Wouldn't Disney earn higher profits if it charged visitors, say, $12.00, each time they went on a ride?

INTRODUCTION

In this chapter, we deal with pricing decisions by firms that have some market power: firms in monopoly, monopolistic competition, and oligopoly. As we learned in Chapter 8, firms in perfect competition have no control over the prices they charge for their products; prices are determined by market forces. Therefore, the pricing decision in perfect competition is simple: Charge the same price other firms in the market charge for their products.

In contrast, firms with market power have some influence over the prices they charge. Therefore, it is important for you, as a manager, to learn some basic pricing strategies for maximizing a firm's profits. This chapter provides practical advice that you can use to implement such pricing strategies, typically using information that is readily available to managers. For instance, we will see how a manager can use publicly available information about demand elasticities to determine the profit-maximizing markup used to set product price.

The optimal pricing decisions will vary from firm to firm depending on the underlying market structure of the industry and the instruments (such as advertising) available. Thus, we will begin with basic pricing strategies firms use in monopoly, monopolistic competition, and oligopoly to set the price that maximizes profits. Then we will develop more sophisticated pricing strategies that enable a firm to extract even greater profits. As you work through this chapter, remember that some of these more advanced pricing strategies would work in some situations but will not be viable in others. You should familiarize yourself not only with how to implement the strategies but also with the conditions under which each type of strategy is feasible.

BASIC PRICING STRATEGIES

In this section, we will examine the most basic pricing strategy used by firms with market power: Charge a single price to all customers such that marginal revenue equals marginal cost. We will begin with a review of the economic basis for such a pricing strategy and then discuss how it can be easily implemented in monopoly, monopolistic competition, and Cournot oligopoly.

Review of the Basic Rule of Profit Maximization

Firms with market power face a downward-sloping demand for their products. This means that by charging a higher price, the firm reduces the amount it will sell. Thus, there is a trade-off between selling many units at a low price and selling only a few units at a high price.

In Chapter 8 we learned how the manager of a firm with market power balances off these two forces: Output is set at the point where marginal revenue (MR) equals marginal cost (MC). The profit-maximizing price is the maximum price per unit that consumers will pay for this level of output. The following problem summarizes what we learned in Chapter 8 about the profit-maximizing pricing decision of a firm with market power.

DEMONSTRATION PROBLEM 11–1

Suppose the (inverse) demand for a firm's product is given by

$$P = 10 - 2Q$$

and the cost function is

$$C(Q) = 2Q$$

What is the profit-maximizing level of output and price for this firm?

ANSWER:

For this (inverse) demand function, marginal revenue is

$$MR = 10 - 4Q$$

and marginal cost is

$$MC = 2$$

Setting $MR = MC$ yields

$$10 - 4Q = 2$$

Thus, the profit-maximizing level of output is $Q = 2$. Substituting this into the inverse demand function yields the profit-maximizing price

$$P = 10 - 2(2) = \$6$$

A Simple Pricing Rule for Monopoly and Monopolistic Competition

As we saw in the previous section, in instances where a manager has estimates of the demand and cost functions for the firm's product, calculation of the profit-maximizing price is straightforward. In some cases, a manager lacks access to an estimated form of demand or cost functions. This is particularly true of managers of small firms that do not have research departments or funds to hire economists to estimate demand and cost functions.

Fortunately, all is not lost in these instances. It turns out that given minimal information about demand and costs, a manager can do a reasonably good job of determining what price to charge for a product. Specifically, most retailers have a rough estimate of the marginal cost of each item sold. For instance, the manager of a clothing store knows how much the store pays the supplier for each pair of jeans and thus has crude information about the marginal cost of selling jeans. (This information is "crude" because the cost to the firm of buying jeans will slightly understate the true marginal cost of selling jeans since it does not include the cost of the sales force, etc.)

The clothing store manager can also gain at least some crude information about the elasticity of demand for jeans at its store. For example, the manager may experiment with some price discounts and observe how quantity demand responds (much in the spirit of the artisans discussed in Inside Business 11–1). Suppose the manager found that 5 percent price discounts increased quantity demanded by 20.5 percent on average. While likely a noisy estimate, this would suggest to the manager that elasticity of demand for jeans at his or her store is somewhere around –4.1 (since the own-price elasticity formula you learned in Chapter 3 indicates the own-price elasticity of demand is $20.5/5 = 4.1$).

Thus, even small firms can obtain some information about demand and costs. All that remains is to show how this information can be used to make pricing decisions. The key is to recall the relation between the elasticity of demand for a firm's product and marginal revenue, which we derived in Chapter 8. This relation is summarized in the following formula.

Formula: Marginal Revenue for a Firm with Market Power. The marginal revenue for a firm with market power is given by

$$MR = P\left[\frac{1 + E_F}{E_F}\right]$$

INSIDE BUSINESS 11–1

Pricing Markups as Rules of Thumb

Many malls and flea markets sponsor shows to which home producers and do-it-yourselfers bring their products for fun and profit. Most of these small businesses are run by craftspeople with little or no knowledge of economics, yet they often reap large profits. One might ask how these artisans find a price that maximizes their profits—or do they?

If you ask them, you will find that most artisans who frequent these shows use a rule-of-thumb markup strategy. They take the price of the materials, and add an hourly wage rate for themselves, then charge from 1.5 to 5 times their marginal cost. How do they determine the price to charge? Through trial and error and word of mouth from artisan to artisan.

Who has higher markups, and who has lower markups? Those products that are extremely unique and show a high degree of crafting skill have the high markups, whereas the products that almost anyone with some free time could make have the low markups. This is exactly what economic theory would predict. The more unique products will have fewer substitutes and, therefore, will have a more inelastic demand than those that are easily copied. This fact, in turn, implies a higher profit-maximizing markup.

where E_F is the own-price elasticity of demand for the firm's product and P is the price charged.

Because the profit-maximizing level of output is where marginal revenue equals marginal cost, this formula implies that

$$P\left[\frac{1+E_F}{E_F}\right] = MC$$

at the profit-maximizing level of output. If we solve this equation for P, we obtain the profit-maximizing price for a firm with market power:

$$P = \left[\frac{E_F}{1+E_F}\right] MC$$

In other words, the price that maximizes profits is a number K times marginal cost:

$$P = K \times MC$$

where $K = E_F/(1 + E_F)$. The number K can be viewed as the profit-maximizing markup factor. For the case of the clothing store, the manager's best estimate of the elasticity of demand is -4.1, so $K = -4.1/(1 - 4.1) = 1.32$. In this instance, the profit-maximizing price is 1.32 times marginal cost:

$$P = 1.32\ MC$$

PRINCIPLE

Profit-Maximizing Markup for Monopoly and Monopolistic Competition

The price that maximizes profit is given by

$$P = \left[\frac{E_F}{1+E_F}\right] MC$$

where E_F is the own-price elasticity of demand for the firm's product and MC is the firm's marginal cost. The term in brackets is the optimal markup factor.

A manager should note two important things about this pricing rule. First, the more elastic the demand for the firm's product, the lower the profit-maximizing markup. Since demand is more elastic when there are many available substitutes for a product, managers that sell such products should have a relatively low markup. In the extreme case when the elasticity of demand is perfectly elastic ($E_F = -\infty$), this markup rule reveals that price should be set equal to marginal cost. This should come as no surprise since we learned in Chapter 8 that a perfectly competitive firm that faces a perfectly elastic demand curve charges a price equal to marginal cost.

The second thing to notice is that the higher the marginal cost, the higher the profit-maximizing price. Firms with higher marginal costs will charge higher prices than firms with lower marginal costs, other things being the same.

One caveat that you should keep in mind when applying the markup formula is that the elasticity of demand may change when you alter the price of a good or service. For instance, in Chapter 3 we learned that when the demand function is linear, demand is more elastic at higher prices than at lower prices. In this case, a slight increase in price will lead to a slight increase in the elasticity of demand, which in turn makes the optimal markup slightly lower than that calculated based on the original estimate of the elasticity of demand. For this reason, if you have an estimate of the demand function, you may more accurately determine the profit-maximizing price by computing marginal revenue directly from the demand function, equating it with marginal cost, and then determining the profit-maximizing price.

In managerial practice, however, many pricing decisions must be made without estimates of demand functions. If the only information available is a numerical estimate of the elasticity of demand, the profit-maximizing markup formula may be used to approximate the optimal markup and price. Under certain conditions, this approach exactly yields the optimal markup. More specifically, we learned in Chapter 3 that the elasticity of demand is constant for a log-linear demand function. Thus, when demand is log-linear, you needn't worry about this caveat because the elasticity does not change when the price changes. In this case, all you need to determine the profit-maximizing markup is a numerical estimate of the elasticity of demand.

DEMONSTRATION PROBLEM 11–2

The manager of a convenience store competes in a monopolistically competitive market and buys cola from a supplier at a price of $1.25 per liter. After some experimentation with her pricing and conversations with managers in different markets, she perceives that the elasticity of demand for cola sold by her store is −4. What price should the manager charge for a liter of cola to maximize profits?

ANSWER:

The marginal cost of cola to the firm is $1.25, or 5/4, per liter and $K = 4/3$. Using the pricing rule for a monopolistically competitive firm, the profit-maximizing price is

$$P = \left[\frac{4}{3}\right]\left[\frac{5}{4}\right] = \frac{5}{3}$$

or about $1.67 per liter.

A Simple Pricing Rule for Cournot Oligopoly

Recall that in Cournot oligopoly, there are few firms in the market servicing many consumers. The firms produce either differentiated or homogeneous products, and each firm believes rivals will hold their output constant if it changes its own output.

In Chapter 9 we saw that to maximize profits, a manager of a firm in Cournot oligopoly produces where marginal revenue equals marginal cost. We also saw how to calculate the profit-maximizing price and quantity given information about demand and cost curves. Recall that this procedure requires full information about the demand and costs of all firms in the industry and is complicated by the fact that the marginal revenue of a Cournot oligopolist depends on the outputs produced by all firms in the market. Ultimately, the solution is based on the intersection of reaction functions.

Fortunately, we can also provide a simple pricing rule that managers can use in Cournot oligopoly. Suppose an industry consists of N Cournot oligopolists, each having identical cost structures and producing similar products. In this instance, the profit-maximizing price in Cournot equilibrium is given by a simple formula.

PRINCIPLE

Profit-Maximizing Markup for Cournot Oligopoly

If there are N identical firms in a Cournot oligopoly, the profit-maximizing price for a firm in this market is

$$P = \left[\frac{NE_M}{1 + NE_M}\right] MC$$

where N is the number of firms in the industry, E_M is the market elasticity of demand, and MC is marginal cost.

A CALCULUS ALTERNATIVE

Instead of having to memorize this formula, we can simply substitute the relation between a Cournot oligopolist's own-price elasticity of demand and that of the market into the formula for the markup rule for monopoly and monopolistic competition. In particular, for a homogeneous-product Cournot oligopoly with N firms, we will show that the elasticity of demand for an individual firm's product is N times that of the market elasticity of demand:

$$E_F = NE_M$$

When we substitute this for E_F in the pricing formula for monopoly and monopolistic competition, the result is the pricing formula for Cournot oligopoly.

To see that $E_F = NE_M$, we need a little calculus. Specifically, if

$$Q = \sum_{i=1}^{N} Q_i$$

is total industry output and industry demand is $Q = f(P)$, the own-price elasticity of market demand is

$$E_M = \frac{dQ}{dP}\frac{P}{Q} = \frac{df(P)}{dP}\frac{P}{Q}$$

The demand facing an individual firm (say, firm 1) is

$$Q_1 = f(P) - Q_2 - Q_3 - \cdots - Q_N$$

Thus, since the firm views the output of other firms as fixed, the elasticity of demand for an individual firm is

$$E_F = \frac{\partial Q_1}{\partial P}\frac{P}{Q_1} = \frac{df(P)}{dP}\frac{P}{Q_1}$$

But with identical firms, $Q_1 = Q/N$, so

$$E_F = \frac{df(P)}{dP}\frac{PN}{Q} = NE_M$$

which is what we needed to establish.

The pricing rule given for a firm in Cournot oligopoly has a very simple justification. When firms in a Cournot oligopoly sell identical products, the elasticity of demand for an individual firm's product is N times the market elasticity of demand:

$$E_F = NE_M$$

If $N = 1$ (monopoly), there is only one firm in the industry, and the elasticity of demand for that firm's product is the same as the market elasticity of demand ($E_F = E_M$). When $N = 2$ (Cournot duopoly), there are two firms in the market, and each firm's elasticity of demand is twice as elastic as that for the market ($E_F = 2E_M$). Thus, the markup formula for Cournot oligopoly is really identical to that presented in the previous section, except that we are using the relation between elasticity of demand for an individual firm's product and that of the market.

Three aspects of this pricing rule for Cournot oligopoly are worth noting. First, the more elastic the market demand, the closer the profit-maximizing price is to marginal cost. In the extreme case where the absolute value of the market elasticity of demand is infinite, the profit-maximizing price is marginal cost, regardless of how many firms are in the industry. Second, notice that as the number of firms increases, the profit-maximizing price gets closer to marginal cost. Notice that in the limiting case where there are infinitely many firms ($N = \infty$), the profit-maximizing price is exactly equal to marginal cost. This is consistent with our analysis of perfect competition: When many firms produce a homogeneous product, price equals marginal cost. Thus, perfect competition can be viewed as the limiting case of Cournot oligopoly, as the number of firms approaches infinity. Finally, notice that the higher the marginal cost, the higher the profit-maximizing price in Cournot oligopoly.

DEMONSTRATION PROBLEM 11–3

Suppose three firms compete in a homogeneous-product Cournot industry. The market elasticity of demand for the product is −2, and each firm's marginal cost of production is $50. What is the profit-maximizing equilibrium price?

ANSWER:

Simply set $N = 3$, $E_M = -2$, and $MC = \$50$ in the markup formula for Cournot oligopoly to obtain

$$P = \left[\frac{(3)(-2)}{1 + (3)(-2)}\right]\$50 = \$60$$

STRATEGIES THAT YIELD EVEN GREATER PROFITS

The analysis in the previous section demonstrated how a manager can implement the familiar $MR = MC$ rule for setting the profit-maximizing price. Given estimates of demand and cost functions, such a price can be computed directly. Alternatively, given publicly available estimates of demand elasticities, a manager can implement the rule by using the appropriate markup formula.

In some markets, managers can enhance profits above those they would earn by simply charging a single per-unit price to all consumers. As we will see in this section, several pricing strategies can be used to yield profits above those earned by simply charging a single price where marginal revenue equals marginal cost.

Extracting Surplus from Consumers

The first four strategies we will discuss—price discrimination, two-part pricing, block pricing, and commodity bundling—are strategies appropriate for firms with various cost structures and degrees of market interdependence. Thus, these strategies can enhance profits of firms in industries with monopolistic, monopolistically competitive, or oligopolistic structures. The pricing strategies discussed in this section enhance profits by enabling a firm to extract additional surplus from consumers.

Price Discrimination

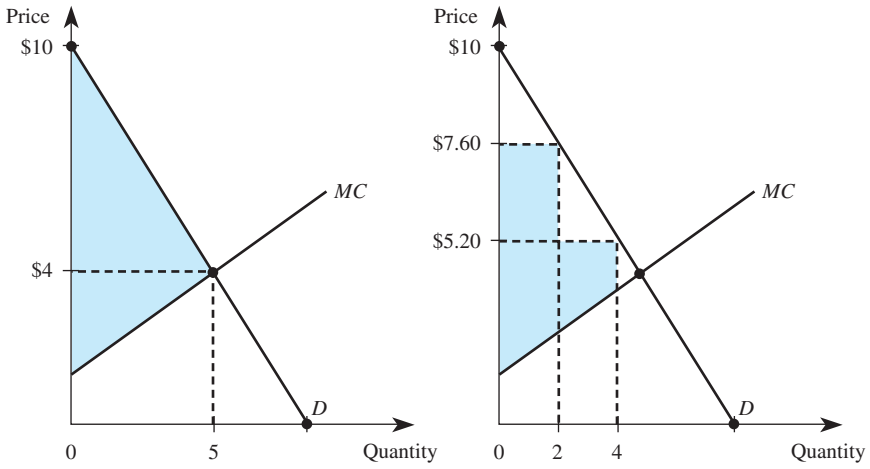
price discrimination
The practice of charging different prices to consumers for the same good or service.

Up until this point, our analysis of pricing decisions presumes the firm must charge the same price for each unit that consumers purchase in the market. Sometimes, however, firms can earn higher profits by charging different prices for the same product or service, a strategy referred to as **price discrimination**. The three basic types of price discrimination—first-, second-, and third-degree price discrimination—are examined next. As we will see, each type requires that the manager have different types of information about consumers.

Ideally, a firm would like to engage in *first-degree price discrimination*—that is, charge each consumer the maximum price he or she would be willing to pay for each unit of the good purchased. By adopting this strategy, a firm extracts all surplus from consumers and thus earns the highest possible profits. Unfortunately for managers, first-degree price discrimination (also called perfect price discrimination) is extremely difficult to implement because it requires the firm to know precisely the maximum price each consumer is willing and able to pay for alternative quantities of the firm's product.

Nonetheless, some service-related businesses, including car dealers, mechanics, doctors, and lawyers, successfully practice a form of first-degree price discrimination. For instance, most car dealers post sticker prices on cars that are well above the dealer's actual marginal cost but offer "discounts" to customers on a case-by-case basis. The best salespersons are able to size up customers to determine the minimum discount necessary to get them to drive away with the car. In this way they are able to charge different prices to different consumers depending on each consumer's willingness and ability to pay. This practice permits them to sell more cars and to earn higher profits than they would if they charged the same price to all consumers. Similarly, most professionals also charge rates for their services that vary, depending on their assessment of customers' willingness and ability to pay.

Panel (a) of Figure 11–1 shows how first-degree price discrimination works. Each point on the market demand curve reflects the maximum price that consumers would be willing to pay for each incremental unit of the output. Consumers start out with 0 units of the good, and the firm can sell the first incremental unit for $10. Since the demand curve slopes downward,



(a) First-degree price discrimination (b) Second-degree price discrimination

Figure 11–1
First- and Second-Degree Price Discrimination

the maximum price the firm can charge for each additional unit declines, ultimately to $4 at an output of 5 units. The difference between each point on the demand curve and the firm's marginal cost represents the profits earned on each incremental unit sold. Thus, the shaded area between the demand curve and the firm's marginal cost curve reflects the total contribution to the firm's profit when it charges each consumer the maximum price he or she will pay for small increments of output between 0 and 5 units. This strategy allows the firm to earn the maximum possible profits. Notice that consumers receive no consumer surplus on the 5 units they purchase: The firm extracts all surplus under first-degree price discrimination. As noted earlier, however, this favorable outcome (from the firm's perspective) can occur only if the manager has perfect information about the price that each consumer is willing and able to pay for each incremental unit of output.

In situations where the firm does not know the maximum price that each consumer will pay for a good, or when it is not practical to post a continuous schedule of prices for each incremental unit purchased, a firm might be able to employ second-degree price discrimination to extract part of the surplus from consumers. *Second-degree price discrimination* is the practice of posting a discrete schedule of declining prices for different ranges of quantities. This practice is very common in the electric utility industry, where firms typically charge a higher rate on the first hundred kilowatt-hours of electricity used than on subsequent units. The primary advantage of this strategy is that the firm can extract some consumer surplus from consumers without needing to know beforehand the identity of the consumers who will choose to purchase small amounts (and thus are willing and able to pay a higher price per unit). Given the posted schedule of prices, consumers sort themselves according to their willingness to pay for alternative quantities of the good. Thus, the firm charges different prices to different consumers, but does not need to know specific characteristics of individual consumers.

To illustrate how second-degree price discrimination works, suppose the Acme Beverage Company charges consumers $7.60 per case for the first two cases purchased and $5.20 for each additional case. The shaded region in panel (b) of Figure 11–1 shows Acme's contributions to profits with this strategy. The first two cases are sold at a price of $7.60 each, and the shaded region between this price and the marginal cost curve reflects the firm's contribution to profits on sales of these two cases. The second two cases are

priced at $5.20 each, so the shaded region between that price and the marginal cost curve between 2 and 4 units of output reflects Acme's profit contributions from selling the second two cases. Notice that consumers end up with some consumer surplus, which means that second-degree price discrimination yields lower profits for the firm than it would have earned if it were able to perfectly price discriminate. Nonetheless, profits are still higher than they would have been if the firm had used the simple strategy of charging the same price for all units sold. In effect, consumers purchasing small quantities (or, alternatively, those having higher marginal valuations) pay higher prices than those who purchase in bulk.

The final type of price discrimination is commonly practiced by firms that recognize that the demand for their product differs systematically across consumers in different demographic groups. In these instances, firms can profit by charging different groups of consumers different prices for the same product, a strategy referred to as *third-degree price discrimination*. For example, it is common for stores to offer "student discounts" and for hotels and restaurants to offer "senior citizen discounts." These practices effectively mean that students and senior citizens pay less for some goods than do other consumers. One might think that these pricing strategies are instituted to benefit students and senior citizens, but there is a more compelling reason: to increase the firm's profits.

To see why third-degree price discrimination enhances profits, suppose a firm with market power can charge two different prices to two groups of consumers and the marginal revenues of selling to groups 1 and 2 are MR_1 and MR_2, respectively. The basic profit-maximizing rule is to produce output such that marginal revenue is equal to marginal cost. This principle is still valid, but the presence of two marginal revenue functions introduces some ambiguity.

It turns out that to maximize profits, the firm should equate the marginal revenue from selling output to each group to marginal cost: $MR_1 = MC$ and $MR_2 = MC$. To see why, suppose $MR_1 > MC$. If the firm produced one more unit and sold it to group 1, it would increase revenue by more than costs would increase. As additional output is sold to group 1, marginal revenue declines until it ultimately equals marginal cost.

Since $MR_1 = MC$ and $MR_2 = MC$, it follows that the firm will allocate output between the two groups such that $MR_1 = MR_2$. To see why, suppose the marginal revenue for group 1 is 10 and the marginal revenue for group 2 is 5. If one less unit were sold to group 2, revenue from that group would fall by 5. If the extra unit of output were sold to group 1, revenue would increase by 10. Thus, it pays for the firm to allocate output to the group with the greater marginal revenue. As additional output is allocated to the group, its marginal revenue falls until, in equilibrium, the marginal revenues for the two groups are exactly equal.

To understand the basis for third-degree price discrimination, suppose that two groups of consumers have elasticities of demand of E_1 and E_2, and the firm can charge group 1 a price of P_1 and group 2 a price of P_2. Using the formula for the marginal revenue of a firm with market power, it follows that the marginal revenue of selling the product to group 1 at a price of P_1 is

$$MR_1 = P_1\left[\frac{1 + E_1}{E_1}\right]$$

while the marginal revenue of selling to group 2 at a price of P_2 is

$$MR_2 = P_2\left[\frac{1 + E_2}{E_2}\right]$$

As mentioned, a profit-maximizing firm should equate the marginal revenue of each group to marginal cost, which implies that $MR_1 = MR_2$. Using the formula for marginal revenue, this condition may be rewritten as

$$P_1\left[\frac{1+E_1}{E_1}\right] = P_2\left[\frac{1+E_2}{E_2}\right]$$

If $E_1 = E_2$, the terms in brackets are equal, and thus the firm will maximize profits by charging each group the same price. If the demand by group 1 is more elastic than that by group 2, $E_1 < E_2 < 0$. In this instance, the firm should charge a lower price to group 1 since it has a more elastic demand than group 2.

Thus, in order for third-degree price discrimination to enhance profits, differences must exist in the elasticity of demand of various consumers. In the examples cited earlier, there is reason to believe that senior citizens have a more elastic demand for a hotel room or a restaurant meal than other consumers. Most retired individuals are on fixed incomes and thus are much more sensitive to price than people who still work. The fact that they are charged lower prices for a hotel room is a simple implication of third-degree price discrimination, namely, charging a lower price to people with more elastic demands.

Another condition that must exist for third-degree price discrimination to be effective is that the firm must have some means of identifying the elasticity of demand by different groups of consumers; otherwise, the firm has no way of knowing to which group of consumers it should charge the higher price. In practice, this is not difficult to do. Hotels require individuals seeking a senior citizens' discount to present evidence of their age, such as a driver's license. This effectively identifies an individual as likely to have a more elastic demand for a hotel room.

Finally, note that no type of price discrimination will work if the consumers purchasing at lower prices can resell their purchases to individuals being charged higher prices. In this instance, consumers who purchase the good at a low price could buy extra quantities and resell them to those who face the higher prices. The firm would sell nothing to the group being charged the higher price because those consumers would save money by buying from consumers who purchased at the low price. In essence, the possibility of resale makes the goods purchased by the consumers charged the low price a perfect substitute for the firm's product. Those consumers can undercut the price the firm is charging the other group, thus reducing the firm's profits.

Formula: Third-Degree Price Discrimination Rule. To maximize profits, a firm with market power produces the output at which the marginal revenue for each group equals marginal cost:

$$\underbrace{P_1\left[\frac{1+E_1}{E_1}\right]}_{MR_1} = MC$$

$$\underbrace{P_2\left[\frac{1+E_2}{E_2}\right]}_{MR_2} = MC$$

DEMONSTRATION PROBLEM 11–4

You are the manager of a pizzeria that produces at a marginal cost of $6 per pizza. The pizzeria is a local monopoly near campus (there are no other restaurants or food stores within 500 miles). During the day, only students eat at your restaurant. In the evening, while students are studying, faculty members eat there. If students have an elasticity of demand for pizzas of −4 and the faculty has an elasticity of demand of −2, what should your pricing policy be to maximize profits?

ANSWER:

Assuming faculty would be unwilling to purchase cold pizzas from students, the conditions for effective price discrimination hold. It will be profitable to charge one price—say, P_L—on the "lunch menu" (effectively a student price) and another price, such as P_D, on the "dinner menu" (effectively a faculty price). To determine precisely what price to put on each menu, note that the people buying pizza off the lunch menu have an elasticity of demand of −4, while those buying off the dinner menu have an elasticity of demand of −2. The conditions for profit maximization require that the marginal revenue of selling a pizza to each group equal marginal cost. Using the third-degree price discrimination rule, this means that

$$P_L\left[\frac{1+E_L}{E_L}\right] = MC$$

and

$$P_D\left[\frac{1+E_D}{E_D}\right] = MC$$

Setting $E_D = -2$, $E_L = -4$, and $MC = 6$ yields

$$P_L\left[\frac{1-4}{-4}\right] = 6$$

$$P_D\left[\frac{1-2}{-2}\right] = 6$$

which simplify to

$$P_L\left[\frac{3}{4}\right] = 6$$

$$P_D\left[\frac{1}{2}\right] = 6$$

Solving these two equations yields $P_L = \$8$ and $P_D = \$12$. Thus, to maximize profits, you should price a pizza on the lunch menu at $8 and a pizza on the dinner menu at $12. Since students have a more elastic demand for pizza than do faculty members, they should be charged a lower price to maximize profits.

Two-Part Pricing

two-part pricing
Pricing strategy in which consumers are charged a fixed fee for the right to purchase a product, plus a per-unit charge for each unit purchased.

Another strategy that firms with market power can use to enhance profits is **two-part pricing**. With two-part pricing, a firm charges a fixed fee for the right to purchase its goods, plus a per-unit charge for each unit purchased. This pricing strategy is commonly used by athletic clubs to enhance profits. Golf courses and health clubs, for instance, typically charge a fixed "initiation fee" plus a charge (either per month or per visit) to use the facilities. In this section, we will see how such a pricing strategy can enhance the profits of a firm.

INSIDE BUSINESS 11–2

Is Price Discrimination Bad for Consumers?

The practice of price discrimination may seem unfair from consumers' perspectives. Why should one consumer pay a different price than another for the same product? Further, the concept of "discrimination" can conjure notions of *exclusion* from other contexts such as racial or gender discrimination. However, in many circumstances, price discrimination can actually serve as a means of *inclusion*, allowing groups of consumers to enjoy a product that would not be accessible if producers could only charge one price to everyone.

For example, many amusement parks, such as Kings Island and Cedar Point in Ohio, charge one price for regular admission and a different, lower price for senior citizens. This pricing scheme is a simple example of third-degree price discrimination, where different demographic groups face different prices for the same product. Without the ability to price discriminate, it is likely the parks would charge everyone the (higher) regular admission fee since senior citizens comprise only a small fraction of the parks' customer base. This higher price would drive many senior citizens out of the market, given they are often a more price-sensitive group. However, by charging seniors a lower price, the parks induce many more seniors to participate in this market, and make greater profits in the process.

Figure 11–2(a) provides a diagram of the demand, marginal revenue, and marginal cost for a firm with market power. Here the demand function is $Q = 10 - P$ and the cost function is $C(Q) = 2Q$. If the firm adopted a pricing strategy of simply charging a single price to all consumers, the profit-maximizing level of output would be $Q = 4$ and the profit-maximizing price would be $P = 6$. This price–quantity combination corresponds to the point where marginal revenue equals marginal cost. Notice that the firm's profits are given by the shaded rectangle, which is

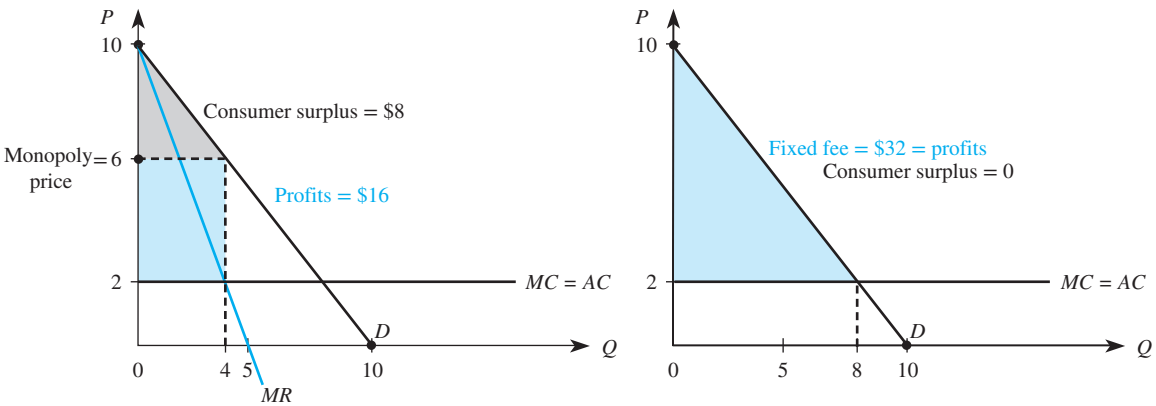
$$(\$6 - \$2)4 = \$16$$

Notice that the consumer surplus received by all consumers in the market—the value received but not paid for—corresponds to the upper triangle in Figure 11–2(a), which is

$$\frac{1}{2}[(\$10 - \$6)4] = \$8$$

Figure 11–2

Comparisons of Standard Monopoly Pricing and Two-Part Pricing



(a) Standard monopoly pricing

(b) Two-part pricing

In other words, consumers receive a total of $8 in value from the four units purchased that is not extracted through the price they paid.

Like first-degree price discrimination, two-part pricing allows a firm to extract all consumer surplus from consumers. In particular, suppose the demand function in Figure 11–2(a) is that of a single individual and the firm uses the following pricing scheme: a fixed fee of $32 that gives the consumer the right to buy the product at a per-unit charge of $2. This situation is depicted in Figure 11–2(b) for the same demand and cost functions as in Figure 11–2(a). With a per-unit charge of $2, the consumer will purchase eight units and receive a consumer surplus of

$$\frac{1}{2}[(\$10 - \$2)8] = \$32$$

By charging a fixed fee of $32, the firm extracts all of this consumer's surplus. The firm sells each unit at its marginal cost of $2, and thus makes no profit on each unit sold at this price. But the firm also receives the fixed payment of $32, which is pure profit. The $32 in profits earned using the two-part pricing scheme is larger than the $16 the firm would earn by using a simple pricing strategy.

PRINCIPLE

Two-Part Pricing

A firm can enhance profits by engaging in two-part pricing: charge a per-unit price that equals marginal cost, plus a fixed fee equal to the consumer surplus each consumer receives at this per-unit price.

We mentioned that athletic clubs often engage in two-part pricing. They charge an initiation fee, plus a per-unit fee for each visit to the facility. Notice that if the marginal cost is low, the optimal per-unit fee will be low as well. In the extreme case where marginal cost is zero, an athletic facility's profit-maximizing two-part pricing strategy will be to charge $0 for each visit but a fixed initiation fee equal to a consumer's surplus. With two-part pricing, all profits are derived from the fixed fee. Setting the per-unit fee equal to marginal cost ensures that the surplus is as large as possible, thus allowing the largest fixed fee consistent with maximizing profits.

There are numerous other examples of two-part pricing strategies. Buying clubs are an excellent example. By paying a membership fee in a buying club, members get to buy products at "cost." Notice that if the membership fee is set equal to each consumer's surplus, the owner of a buying club actually makes higher profits than would be earned by simply setting the monopoly price.

DEMONSTRATION PROBLEM 11–5

Suppose the total monthly demand for golf services is $Q = 20 - P$. The marginal cost to the firm of each round is $1. If this demand function is based on the individual demands of 10 golfers, what is the optimal two-part pricing strategy for this golf services firm? How much profit will the firm earn?

ANSWER:

The optimal per-unit charge is marginal cost. At this price, $20 - 1 = 19$ rounds of golf will be played each month. The total consumer surplus received by all 10 golfers at this price is thus

$$\frac{1}{2}[(20 - 1)19] = \$180.50$$

Because this is the total consumer surplus enjoyed by all 10 consumers, the optimal fixed fee is the consumer surplus enjoyed by an individual golfer ($180.50/10 = $18.05 per month). Thus, the optimal two-part pricing strategy is for the firm to charge a monthly fee to each golfer of $18.05, plus greens fees of $1 per round. The total profits of the firm thus are $180.50 per month, minus the firm's fixed costs.

Two-part pricing allows a firm to earn higher profits than it would earn by simply charging a price for each unit sold. By charging a fixed fee, the firm is able to extract consumer surplus, thus enhancing its profits. Unlike price discrimination, two-part pricing does not require that consumers have different elasticities of demand for the firm's product. By charging a per-unit fee for each unit purchased, consumers can vary the amounts they purchase according to their individual demands for the product.

Block Pricing

block pricing
Pricing strategy in which identical products are packaged together in order to enhance profits by forcing customers to make an all-or-none decision to purchase.

Another way a firm with market power can enhance profits is to engage in **block pricing**. If you have purchased toilet paper in packages of four rolls or cans of soda in a six-pack, you have had firsthand experience with block pricing.

Let us see how block pricing can enhance a firm's profits. Suppose an individual consumer's demand function is $Q = 10 - P$ and the firm's costs are $C(Q) = 2Q$. Figure 11–3 graphs the relevant curves. We see that if a firm charges a price of $2 per unit, it will sell eight units to the consumer. Notice, however, that the consumer receives a surplus of the upper triangle, which is

$$\frac{1}{2}[(\$10 - \$2)8] = \$32$$

This consumer's surplus reflects the value the consumer receives over and above the cost of buying eight units. In fact, in this case, the consumer pays $\$2 \times 8 = \$16$ to the firm for the eight units but receives additional surplus of $32. The total value to the consumer of the eight units is $\$16 + \$32 = \$48$.

Block pricing provides a means by which the firm can get the consumer to pay the full value of the eight units. It works very simply. Suppose the firm packaged eight units of its product and charged a price for the package. In this case, the consumer has to make an

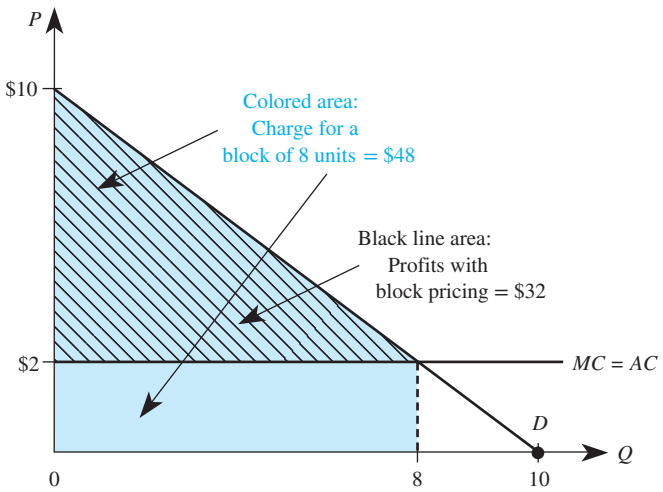


Figure 11–3
Block Pricing

all-or-none decision between buying eight units and buying nothing. We just saw that the total value to the consumer of eight units is $48. Therefore, as long as the price of the package of eight units is not greater than $48, this consumer will find it in her or his interest to buy the package.

Thus, the profit-maximizing price for the firm to charge for the package of eight units is $48. By charging this price for a package of eight instead of pricing each unit separately and letting the consumer choose how many units to buy, the firm earns $32 in profits—the value of the would-be consumer's surplus when the price is $2.

PRINCIPLE

Block Pricing

By packaging units of a product and selling them as one package, the firm earns more than by posting a simple per-unit price. The profit-maximizing price on a package is the total value the consumer receives for the package.

DEMONSTRATION PROBLEM 11–6

Suppose a consumer's (inverse) demand function for gum produced by a firm with market power is given by $P = 0.2 - 0.04Q$ and the marginal cost is zero. What price should the firm charge for a package containing five pieces of gum?

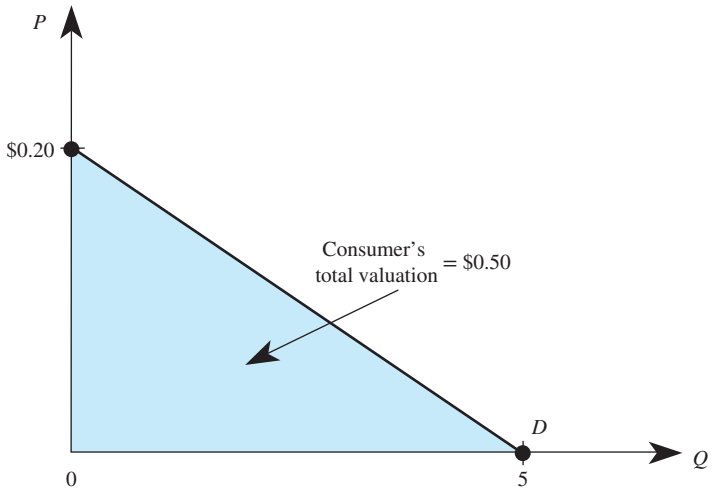
ANSWER:

When $Q = 5$, $P = 0$; when $Q = 0$, $P = 0.2$. This linear demand is graphed in Figure 11–4. Thus, the total value to the consumer of five pieces of gum is

$$\frac{1}{2}[(\$0.2 - \$0)5] = \$0.50$$

which corresponds to the shaded area in Figure 11–4. The firm extracts all this surplus by charging a price of $0.50 for a package of five pieces of gum.

Figure 11–4
Optimal Block Pricing with Zero Marginal Cost



Block pricing enhances profits by forcing consumers to make an all-or-none decision to purchase units of a good. Notice that block pricing can enhance profits even in situations where consumers have identical demands for a firm's product.

Commodity Bundling

commodity bundling
The practice of bundling several different products together and selling them at a single "bundle price."

Another strategy managers can use to enhance profits is **commodity bundling**. Commodity bundling refers to the practice of bundling two or more different products together and selling them at a single "bundle price." For instance, travel companies often sell "package deals" that include airfare, hotel, and meals at a bundled price instead of pricing each component of a vacation separately. Computer firms bundle computers, monitors, and software and sell them at a bundled price. Many car dealers bundle options such as blind spot warning, keyless entry, and heated seats and sell them at a "special package price." Let us see how these practices can enhance profits.

Suppose the manager of a computer firm knows there are two consumers who value its computers and monitors differently. Table 11–1 shows the maximum amount the two consumers would pay for a computer and a monitor. The first consumer is willing to pay $2,000 for a computer and $200 for a monitor. The second consumer is willing to pay $1,500 for a computer and $300 for a monitor. However, the manager does not know the identity of each consumer; thus, she cannot price discriminate by charging each consumer a different price.

Suppose the manager priced each component separately: one price for a computer, P_C, and another price for a monitor, P_M. (To simplify profit computations, suppose the cost to the firm of computers and monitors is zero.) If the firm charged $2,000 for a computer, it would sell a computer only to consumer 1 and earn $2,000 because consumer 2 is willing to pay only $1,500 for a computer. If the firm charged $1,500 for a computer, both consumers would buy a computer, netting the firm $3,000. Clearly the profit-maximizing price to charge for a computer is $1,500.

Similarly, if the firm priced monitors at $300, only consumer 2 would purchase a monitor because consumer 1 would pay only $200 for a monitor. By pricing monitors at $200, it would sell two monitors and earn $400. The profit-maximizing price to charge for a monitor thus is $200.

On the surface, it appears that the most the firm can earn is $3,400 by pricing computers at $1,500 and monitors at $200. In this case, the firm sells two computers and two monitors. However, the firm can earn higher profits by bundling computers and monitors and selling the bundle at a price of $1,800. To see why, notice that the total value to the first consumer of a computer and a monitor is $2,000 + $200 = $2,200, and the total value to the second consumer of a computer and a monitor is $1,500 + $300 = $1,800. By bundling a computer and a monitor and selling the bundle for $1,800, the firm will sell a bundle to both consumers and earn $3,600—a full $200 more than it would earn if it did not engage in commodity bundling.

Table 11–1

Commodity Bundling

Consumer	Valuation of Computer	Valuation of Monitor
1	$2,000	$200
2	1,500	300

INSIDE BUSINESS 11–3

Bundling to Reduce Churn in Telecommunications

In some markets, bundling may serve as a way for firms to essentially "lock in" consumers to purchasing ongoing services they may not purchase outside of a bundle. This happens when consumers, after purchasing a bundle, are averse toward breaking it up.

For many years, telecommunications firms such as cable companies have offered bundled discounts for television, Internet, and landline telephone services. Such bundle offerings may be driven by cost savings for the firm or profit-enhancement leveraging differences in what consumers are willing to pay for the services. However, they also may help lock in consumers to continually purchasing all three services. Researchers Jeff Prince and Shane Greenstein examined whether "triple play" bundles (television, Internet, phone) offered by cable companies were effective in retaining sales, and found that they were for all three services.

SOURCE: J. Prince and S. Greenstein, "Does Service Bundling Reduce Churn?" *Journal of Economics and Management Strategy* 23, no. 4 (2014).

This example illustrates that commodity bundling can enhance profits when consumers differ with respect to the amounts they are willing to pay for multiple products sold by a firm. It is important to emphasize that commodity bundling can enhance profits even when the manager cannot distinguish among the amounts different consumers are willing to pay for the firm's products. If the manager did know precisely how much each consumer was willing to pay for each product, the firm could earn even higher profits by engaging in price discrimination: charging higher prices to those consumers willing to pay more for its products.

For a video walkthrough of this problem, visit www.mhhe.com/baye10e

DEMONSTRATION PROBLEM 11–7

Suppose three purchasers of a new car have the following valuations for options:

Consumer	Air Conditioner	Power Brakes
1	$1,000	$500
2	800	300
3	100	800

The firm's costs are zero.

1. If the manager knows the valuations and identity of each consumer, what is the optimal pricing strategy?
2. Suppose the manager does not know the identities of the buyers. How much will the firm make if the manager sells brakes and air conditioners for $800 each but offers a special options package (power brakes and an air conditioner) for $1,100?

ANSWER:

1. If the manager knows the buyers' identities, he will maximize profits through price discrimination since resale for these products is unlikely; charge consumer 1 $1,500 for an air conditioner and power brakes; charge consumer 2 $1,100 for an air conditioner and power brakes; and charge consumer 3 $900 for an air conditioner and power brakes. The firm's profits will be $3,500. It makes no difference whether the manager charges the consumers a

bundled price equal to their total valuation of an air conditioner and power brakes or charges a separate price for each component that equals the consumers' valuation.

2. The total value of a bundle containing an air conditioner and power brakes is $1,500 for consumer 1, $1,100 for consumer 2, and $900 for consumer 3. Thus, consumers 1 and 2 will buy the option package because a bundle with an air conditioner and power brakes is worth at least $1,100 to them. The firm earns $2,200 on these consumers. Consumer 3 will not buy the bundle because its total cost is greater than the consumer's valuation ($900). However, consumer 3 will buy power brakes at the price of $800. Thus, the firm earns $3,000 with this pricing strategy—$2,200 comes from consumers 1 and 2, who each purchases the special options package for $1,100, and $800 comes from consumer 3, who chooses to buy only power brakes.

Pricing Strategies for Special Cost and Demand Structures

The pricing strategies we will discuss in this section—peak-load pricing and cross-subsidization—enhance profits for firms that have special cost and demand structures.

Peak-Load Pricing

Many markets have periods in which demand is high and periods in which demand is low. Toll roads tend to have more traffic during rush hour than at other times of the day; utility companies tend to have higher demand during the day than during the late-night hours; and airlines tend to have heavier traffic during the week than during weekends. When the demand during peak times is so high that the capacity of the firm cannot serve all customers at the same price, the profitable thing for the firm to do is engage in **peak-load pricing**.

peak-load pricing
Pricing strategy in which higher prices are charged during peak hours than during off-peak hours.

Figure 11–5 illustrates a classic case of such a situation. Notice that marginal cost is constant up to Q_H, where it becomes vertical. At this point, the firm is operating at full capacity and cannot provide additional units at any price.

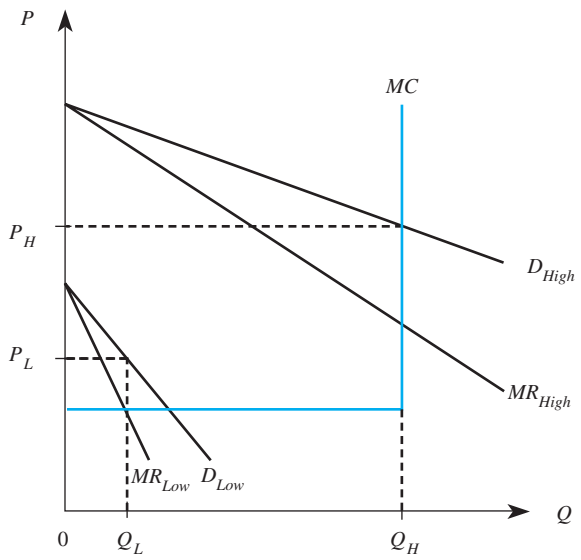


Figure 11–5
Peak-Load Pricing

The two demand curves in Figure 11–5 correspond to peak and off-peak demand for the product: D_{Low} is the off-peak demand, which is lower than D_{High}, the peak demand. In general, where there are two types of demand, a firm will maximize profits by charging different prices to the different groups of demanders. In the case of peak-load pricing, the "groups" refer to those who purchase at different times during the day.

In Figure 11–5, for instance, demand during low-peak times is such that marginal revenue equals marginal cost at point Q_L. Thus, the profit-maximizing price during low-peak times is P_L. In contrast, during high-peak times, marginal revenue equals marginal cost at point Q_H, which corresponds to the firm's full capacity. The profit-maximizing price during high-peak times is P_H. Thus, as is the case in price discrimination, the firm charges two different prices: a low price during low-peak demand and a high price during high-peak demand.

Notice in Figure 11–5 that if the firm charged a high price of P_H at all times of the day, no one would purchase during low-peak periods. By lowering the price during low-peak times but charging a high price during high-peak times, the firm increases its profits by selling to some consumers during low-peak times. Similarly, if the firm charged a low price during all times of the day, it would lose money during high-peak times, when consumers are willing to pay a higher price for services.

PRINCIPLE

Peak-Load Pricing

When demand is higher at some times of the day than at other times, a firm may enhance profits by peak-load pricing: charging a higher price during peak times than is charged during off-peak times.

DEMONSTRATION PROBLEM 11–8

Airports typically charge a higher price for parking during holidays than they do during other times of the year. Why?

ANSWER:

It pays for airports to engage in peak-load pricing. Since the demand for parking is much higher during holidays, when travelers spend extended periods with families, parking lots tend to fill up during that time. If airports charged a high price year round, they would have empty spaces most of the time. If they charged low prices year round, they would lose out on the additional amount consumers are willing to pay during holidays. Thus, with peak-load pricing, airports earn higher profits.

Cross-Subsidies

cross-subsidy
Pricing strategy in which profits gained from the sale of one product are used to subsidize sales of a related product.

The next pricing strategy we will discuss—cross-subsidies—is relevant in situations where a firm has cost complementarities and the demand by consumers for a group of products is interdependent. A firm that engages in a strategy of **cross-subsidies** uses profits made with one product to subsidize sales of another product.

For example, Adobe charges dramatically different prices for two of its products. One product—its *Adobe Reader*—may be obtained "for free" by anyone willing to download the software from Adobe's Internet site. This software permits users to view documents created in portable document format (pdf). In contrast, individuals wishing to create pdf documents must *pay* for a software product called *Adobe Acrobat.*

Adobe engages in this cross-subsidization because complementaries in demand and costs make doing so profitable. More specifically, Adobe enjoys economies of scope and cost

complementarities in making these two products jointly (it is cheaper to design and distribute both types of software within one firm). Furthermore these two products are complementary: The greater the number of people who use *Adobe Reader* to view documents, the greater the amount they will be willing to pay to use *Adobe Acrobat* for document creation. In short, Adobe finds it profitable to price *Adobe Reader* at or below cost because doing so stimulates demand for its complementary software product, thus permitting it to charge a significantly higher price for *Adobe Acrobat* than it would otherwise be able to charge. As we will see in Module Group A, a number of similar pricing strategies (such as penetration pricing) can be used to enhance profits in strategic environments (including online auctions) where network effects are present.

Cross-Subsidization

Whenever the demands for two products produced by a firm are interrelated through costs or demand, the firm may enhance profits by cross-subsidization: selling one product at or below cost and the other product above cost.

PRINCIPLE

Transfer Pricing

Thus far, our analysis of pricing decisions has presumed that a single manager is in charge of pricing and output decisions. However, most large firms have upstream and downstream managers who must make price and output decisions for their own divisions. For example, automakers like Toyota have upstream managers who control the production of inputs (like car engines) produced in *upstream divisions.* These inputs are "transferred" to *downstream divisions*, where downstream managers operate plants that use the inputs to produce the final output (automobiles). An important issue in this setting is optimal **transfer pricing**—the internal price at which an upstream division should sell inputs to the firm's downstream division to maximize the overall profits of the firm.

transfer pricing
Pricing strategy in which a firm optimally sets the internal price at which an upstream division sells an input to a downstream division.

Transfer pricing is important because most division managers are provided an incentive to maximize their own division's profits. As we will see, if the owners of a firm do not set optimal transfer prices, but instead let division managers set the prices of internally manufactured inputs so as to maximize their division's profits, the result might be lower overall profits for the firm.

To illustrate, suppose that there is no outside market for the input produced by the upstream division and that divisional managers are instructed to maximize the profits of their divisions. In this case, the upstream division manager has market power and maximizes the profits of the upstream division by producing where the marginal revenue derived from selling to the downstream division equals the upstream division's marginal cost of producing the input. Because of the monopoly power enjoyed by the upstream division, the input is sold to the downstream division at a price that exceeds the firm's actual marginal cost. Given this input price, the downstream manager would then maximize divisional profits by producing where the marginal revenue it earns in the final product market (MR_d) equals its marginal cost. This implies that it, too, prices above marginal cost. Moreover, because the price the downstream division pays the upstream division for the input is higher than the true marginal cost of the input, the downstream division ends up charging a price for the final product that is actually higher than the price that maximizes overall firm profits. In short, when both divisions mark up prices in excess of marginal cost, *double marginalization* occurs and the result is less-than-optimal overall firm profits.

To circumvent the problem of double marginalization, transfer prices must be set that maximize the overall value of the firm rather than the profits of the upstream division. To see how this can be accomplished, suppose the downstream division requires one unit of the input (one engine, say) to produce one unit of the final output (one car). Assume that the downstream division has a marginal cost of assembling the final output, denoted MC_d, that is in addition to the cost of acquiring the input from the upstream division. In this case the overall profits of the firm are maximized when the upstream division produces engines such that its marginal cost, MC_u, equals the net marginal revenue to the downstream division (NMR_d):

$$NMR_d = MR_d - MC_d = MC_u$$

To see why, notice that it costs the firm MC_u to produce another unit of the input. This input can be converted into another unit of output and sold to generate additional revenues of MR_d in the final product market only after the downstream division expends an additional MC_d to convert the input into the final output. Thus, the actual marginal benefit to the firm of producing another unit of the input is NMR_d. Setting this equal to the marginal cost of producing the input maximizes overall firm profits.

Now that we know the necessary conditions for maximizing overall firm profits, we show how a firm can institute an incentive system that induces the divisional managers to indeed maximize overall firm profits. Suppose higher authorities within the firm determine that the level of final output that maximizes overall firm profits is Q^*. They set the transfer price, P_T, equal to the upstream division's marginal cost of producing the amount of input required by the downstream division to produce Q^* units of final output. According to this internal pricing scheme, the downstream manager can now purchase as many units of the input as it desires from the upstream division at a fixed price of P_T per unit. The upstream and downstream managers are instructed to maximize divisional profits, taking as given the transfer price set by higher authorities within the firm.

Because the upstream division now must sell the input internally at a fixed price of P_T per unit, it behaves like a perfectly competitive firm and maximizes profits by producing where price equals marginal cost: $P_T = MC_u$. Since one unit of input is required for each unit of output, the downstream division's marginal cost of producing final output is now $MC = MC_d + P_T$. The downstream divisional manager maximizes divisional profits by producing where marginal revenue equals marginal cost: $MR_d = MC_d + P_T$. Since $P_T = MC_u$, we may rewrite this as $MR_d - MC_d = MC_u$, which is exactly our condition for maximizing overall firm profits. Thus, we see that by setting the transfer price at the upstream division's marginal cost of producing the firm's profit-maximizing quantity of the input, the problem of double marginalization is avoided even though divisional managers operate independently to maximize their division's profits.

A concrete example will help illustrate how a firm can implement optimal transfer pricing. Suppose that the (inverse) demand for Aviation General's single-engine planes is given by $P = 15{,}000 - Q$. Its upstream division produces engines at a cost of $C_u(Q_e) = 2.5Q_e^2$, and the downstream division's cost of assembling planes is $C_d(Q) = 1{,}000Q$. Let us derive the optimal transfer price when there is no external market for engines.

The optimal transfer price is set where the firm's net marginal revenue from engine production equals the upstream division's marginal cost of producing the engines. Downstream marginal revenue and marginal cost are $MR_d = 15{,}000 - 2Q$ and $MC_d = 1{,}000$, respectively, while the upstream division's marginal cost of producing engines is $MC_u = 5Q_e$. Since it takes one engine to produce one plane ($Q = Q_e$), equating NMR_d and MC_u implies

$$NMR_d = 15{,}000 - 2Q_e - 1{,}000 = 5Q_e$$

Solving for Q_e, we see that to maximize overall firm profits, the upstream division should produce 2,000 engines. Since $Q_e = Q$, the downstream division should produce 2,000 planes to maximize overall firm profits. The optimal transfer price is the upstream division's marginal cost evaluated at 2,000 engines, or $P_T = \$10{,}000$. Thus, the firm maximizes its overall profits when its accountants set the (internal) transfer price of engines at $10,000 per unit, and divisional managers are provided an incentive to maximize divisional profits given this price.

Pricing Strategies in Markets with Intense Price Competition

The final pricing strategies we will examine—price matching, inducing brand loyalty, and randomized pricing—are valuable for firms competing in Bertrand oligopoly. Recall that firms in Bertrand oligopoly compete in price and sell similar products. As we learned in Chapters 9 and 10, in these instances price wars will likely result, leading to prices that are close to marginal cost and profits that are near zero. While the pricing strategies discussed in this section can be used in situations other than Bertrand oligopoly, they are particularly useful for mitigating the price wars that frequently occur in such a market.

Price Matching

In Chapters 9 and 10, we showed that when two or more firms compete in a homogeneous-product Bertrand oligopoly, the Nash equilibrium is for each firm to charge marginal cost and earn zero profits. However, in Chapter 10 we showed that if the game is infinitely repeated, firms can maintain collusive outcomes by adopting trigger strategies, which punish rivals that deviate from the high price. In an infinitely repeated game, punishments are threatened in the future if a firm cheats on a collusive agreement, and this can lead to a situation where firms end up charging high prices. However, recall that this strategy can work only if the interest rate is low and firms can effectively monitor the behavior of other firms in the market.

In cases where trigger strategies do not work (because the game is not infinitely repeated or the firms cannot monitor other firms' behavior), there is another way firms can attain higher profits: by advertising a price-matching strategy. A firm that uses a **price-matching strategy** advertises a price and a promise to "match" any lower price offered by a competitor.

price matching
A strategy in which a firm advertises a price and a promise to match any lower price offered by a competitor.

To illustrate how such a strategy can enhance profits, suppose the firms in a market play a one-shot Bertrand pricing game. However, in addition to advertising a price, the firms advertise a commitment to match any lower price found in the market. Such an advertisement would look something like the following:

> Our price is P. If you find a better price in the market, we will match that price. We will not be undersold!

This sounds like a good deal for consumers; indeed, simply announcing this strategy may induce some consumers to buy from the firm to be "assured" of a great deal.

It turns out, however, that if all firms in the market announce such a policy, they can set the price (P) to the high monopoly price and earn large profits instead of the zero profits they would earn in the usual one-shot Bertrand oligopoly. How does this work?

Suppose all firms advertised the high monopoly price but promised to match any lower price found by consumers. Because all firms are charging the same high price, consumers can't find a better price in the market. The result is that firms share the market, charge the monopoly price, and earn high profits. Furthermore, notice that no firm has an incentive to charge a lower price in an attempt to steal customers from rivals. If a firm lowered its price, the rivals would match that price and gain back their share of the market. By lowering its

INSIDE BUSINESS 11–4

The Prevalence of Price-Matching Policies and Other Low-Price Guarantees

Competition in the market for online travel services has heightened to the point that some companies run advertisements like this one by Orbitz:

> In the unlikely event that you find a lower rate on a standalone flight, car or cruise on Orbitz.com or on another U.S.-based website within 24 hours of booking with Orbitz.com, we will credit or refund you the difference in price.[1]

This advertisement is an example of what economists call a *low-price guarantee (LPG)*.

As noted in the text, LPGs permit firms to charge higher prices because the guarantees weaken the incentive for rivals to undercut any given store's price. If you run a simple Google search on "low price guarantee," you will find dozens of firms making such claims. It is interesting to note that some particularly prominent LPGs are made by some of Orbitz's competitors, including Hotwire and Priceline. Such advertisements predate, and extend well beyond, online advertising. For instance, several years ago Maria Arbatskaya, Morten Hviid, and Greg Shaffer examined the frequency with which tire retailers use LPGs in their newspaper advertisements. Based on samples of over 500 tire advertisements across the country, over half contained LPGs.

[1]An excerpt from Orbitz.com at https://www.orbitz.com/p/info-other/guarantees (viewed January 13, 2020).

SOURCE: Maria Arbatskaya, Morten Hviid, and Greg Shaffer, "The Effects of Low-Price Guarantees on Tire Prices," *Advances in Applied Microeconomics* 8 (1999), pp. 123–38.

price, a firm effectively triggers a price war, which results in no greater share of the market and lower profits. Thus, if all firms adopt price-matching strategies, the result is that each firm charges the monopoly price and shares the market to earn high profits.

An important aspect of price-matching policies is that the firms need not monitor the prices charged by rivals. This is in contrast to trigger strategies, in which firms must monitor rivals' prices to know whether to punish a rival that has charged a low price. With a price-matching strategy, it is up to a consumer to show the firm that some rival is offering a better deal. At that point, the firm can match the price for that consumer. The consumers who have not found a better deal continue to pay the higher price. Thus, even if some other firm happened to charge a low price, a firm using a price-matching strategy would get to price discriminate between those consumers who found such a price and those who did not.

Before you choose to adopt a price-matching strategy, there are two things to consider. First, you must devise a mechanism that precludes consumers from claiming to have found a lower price when in fact they have not. Otherwise, consumers will have an incentive to tell you that another firm is "giving goods away" and ask you to match the lower price. One way firms avoid such deception is by promising to match prices that are advertised in some widely circulated newspaper. In this case, the consumer must bring in the advertisement before the price will be matched.

Second, you can get into trouble with a price-matching strategy if a competitor has lower costs than your firm. For instance, if your competitor's marginal cost is $300 for a television set and yours is $400, the profit-maximizing (monopoly) price set by your firm will be higher than that set by the rival. In such an instance, the monopoly price set by your rival may be lower than your cost. In this case, if you have to match your rival's price, you will incur losses on each unit sold.

Inducing Brand Loyalty

Another strategy a firm can use to reduce the tension of Bertrand competition is to adopt strategies that induce *brand loyalty*. Brand-loyal customers will continue to buy a firm's product even if another firm offers a (slightly) better price. By inducing brand loyalty, a firm reduces the number of consumers who will "switch" to another firm if it undercuts its price.

INSIDE BUSINESS 11–5

Kroger Combines Pricing Strategies

Some companies use combinations of pricing strategies to maximize profits. Kroger is the largest grocery store chain in the United States, with over $100 billion in revenues and well over 2,000 supermarkets. Over half of its supermarkets are supermarket fuel centers, which have a Kroger-operated gas station co-located with the supermarket. At these supermarket fuel centers, Kroger typically engages in pricing that both induces brand loyalty and cross-subsidizes its products. Specifically, Kroger offers a fuel points program, where customers receive discounts on fuel for every dollar they spend at the supermarket. This program results in customers often paying gas prices that are notably lower than those charged at independent gas stations, but these losses are cross-subsidized by grocery sales. Further, the accumulation of fuel points works much like a frequent-flyer program or "frequent-filler" program, which induces brand loyalty. As Kroger's fuel points program shows, a firm need not be limited to implementing just one type of strategy; some pricing strategies—like cross-subsidization and pricing to induce loyalty—can work in combination to maximize profits.

Firms can use several methods to induce brand loyalty. One of the more common methods is to engage in advertising campaigns that promote a firm's product as being better than those of competitors. If advertisements make consumers believe that other products in the market are not perfect substitutes, firms engaging in price competition can earn higher profits. When a rival undercuts a firm's price, some customers will remain loyal to the firm, allowing it to charge a higher price and make positive profits.

Notice, however, that such an advertising strategy will not work if consumers believe products to be homogeneous. A self-service gasoline station would be hard-pressed to convince consumers that its product is really "different" from the identical brand sold across the street. In these instances, firms can resort to alternative strategies to promote brand loyalty.

Some gasoline stations now have "frequent-filler" programs, modeled after the frequent-flyer programs initiated by the airlines. Frequent-filler programs provide consumers with a cash rebate after a specified number of fill-ups. With this strategy, even though the products are identical, the consumer has an incentive to remain loyal to the same station to maximize the number of times he or she obtains a rebate. For example, suppose a station offers a $5 rebate after 10 fill-ups. If the consumer fills up at 10 different stations, he or she does not get the rebate, but if all 10 fill-ups are at the same station, the consumer gets $5. Thus, a frequent-filler strategy provides the consumer with an incentive to remain loyal to a particular station even though it offers products identical to its rivals.

Randomized Pricing

The final strategy firms can use to enhance profits in markets with intense price competition is to engage in randomized pricing. With a **randomized-pricing strategy**, a firm varies its price from hour to hour or day to day. Such a strategy can benefit a firm for two reasons.

randomized pricing
Pricing strategy in which a firm intentionally varies its price in an attempt to "hide" price information from consumers and rivals.

First, when firms adopt randomized pricing strategies, consumers cannot learn from experience which firm charges the lowest price in the market. On some days, one firm charges the lowest price; on another day, some other firm offers the best deal. By increasing the uncertainty about where the best deal exists, firms reduce consumers' incentive to shop for price information. Because one store offers the best deal today does not mean it will also offer the best deal tomorrow. To continually find the best price in the market, a consumer must constantly shop for a new deal. In effect, there is only a one-shot gain to a consumer of becoming informed; the information is worthless when new prices are set. This reduces

INSIDE BUSINESS 11–6

Randomized Pricing in the Airline Industry

Airlines compete in a Bertrand market in which rivals continually attempt to learn rivals' prices so that they can undercut them. Despite some brand loyalty created by frequent-flyer programs, a large number of airline customers search online to identify the carrier charging the lowest price on a given route. To get these price-conscious customers, an airline must succeed in charging the lowest price in the market.

Given the structure of the airline market, airlines have sometimes found it profitable to "randomize" their prices so that rivals and consumers cannot learn from experience exactly what the price of a particular route is. By frequently changing its prices, an airline prevents rivals from learning the price they have to undercut to steal customers. With prices that vary randomly over time, an airline may be charging the highest price or lowest price in the market at a given instant. When it charges the lowest price, it sells tickets to both its price-conscious and loyal customers. When it charges high prices, it sells tickets only to its loyal customers, as the price-conscious flyers buy tickets from another airline.

SOURCES: Jihui Chen, "Differences in Average Prices on the Internet: Evidence from the Online Market for Air Travel," *Economic Inquiry* 44, no. 4 (2007), pp. 656–70; Michael R. Baye and Casper G. de Vries, "Mixed Strategy Trade Equilibrium," *Canadian Journal of Economics* 25 (May 1992), pp. 281–93.

consumers' incentive to invest in information about prices. As consumers have less information about the prices offered by competitors, firms are less vulnerable to rivals stealing customers by setting lower prices.

The second advantage of randomized prices is that they reduce the ability of rival firms to undercut a firm's price. Recall that in Bertrand oligopoly, a firm wishes to slightly undercut the rival's price. If another firm offers a slightly better deal, informed consumers will switch to that firm. Randomized pricing not only reduces the information available to consumers, but it precludes rivals from knowing precisely what price to charge to undercut a given firm's price. Randomized-pricing strategies tend to reduce rivals' incentive to engage in price wars and thus can enhance profits.

We should point out that it is not always profitable to engage in randomized-pricing strategies. In many instances, other strategies, such as price-matching strategies, can be a more effective means of enhancing profits. Moreover, in some instances it may not be feasible to change prices as frequently as randomized-pricing strategies require. The cost of hiring personnel to continually change price tags can be prohibitive. Randomized pricing can work, however, when prices are entered in a computer and not directly on the products. It can also work when firms advertise "sales" in a weekly newspaper. In these instances, the prices advertised in the sales circular can be varied from week to week so the competition will not know what price to advertise to undercut the firm's price.

ANSWERING THE headLINE

Why does Disney World charge a cover fee for entering the park and then let everyone who enters ride for free? The answer lies in the ability to extract consumer surplus by engaging in two-part pricing. In particular, the marginal cost of an individual ride at an amusement park is close to zero, as in Figure 11–6. If the average consumer has a demand curve like the one in Figure 11–6, setting the monopoly price would result in a price of $12.00 per ride. Since each customer would go on five rides, the amusement park would earn $60.00 per customer. (This ignores fixed costs, which must be paid

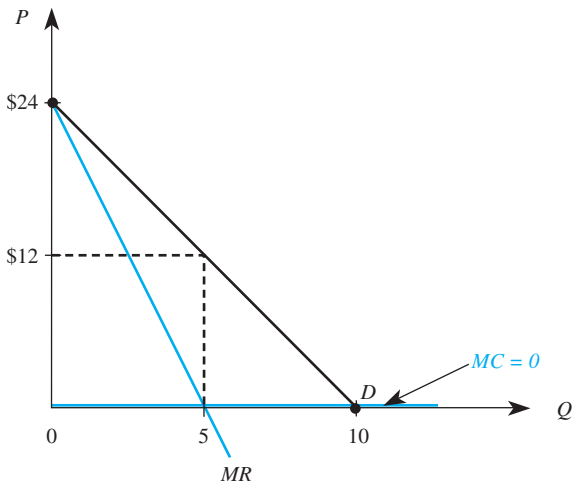


Figure 11–6
The Disney Dilemma

regardless of the pricing strategy.) But this would leave the average consumer with $30.00 in consumer surplus. By charging an entry fee of $120 but pricing each ride at $0, each consumer rides an average of 10 rides and the park extracts all consumer surplus and earns higher profits.

SUMMARY

This chapter presented pricing strategies used by firms with some market power. Unlike firms in a perfectly competitive market, when there are a small number of firms and products are slightly differentiated, a manager can use pricing strategies that will foster positive economic profits. These strategies range from simple markup rules to more complex two-part pricing strategies that enable a firm to extract all consumer surplus.

This chapter showed how markup rules come into existence. If a firm is monopolistic or monopolistically competitive, the elasticity from the firm's demand function can be used to find the markup factor that will maximize the firm's profits. If a manager operates in a Cournot oligopoly, the firm's own-price elasticity is simply the number of firms in the market times the market elasticity. Knowing this, a manager in this kind of market can easily calculate the appropriate markup rule for his or her pricing strategies.

In some markets, the manager can actually do better than the single monopoly price. This can be accomplished through price discrimination or two-part pricing. Other pricing strategies that enhance profits include peak-load pricing, block pricing, commodity bundling, cross-subsidization, and optimal transfer pricing. The chapter concluded with descriptions of strategies that can help managers in a Bertrand oligopoly avoid the tendency toward zero economic profits.

KEY TERMS AND CONCEPTS

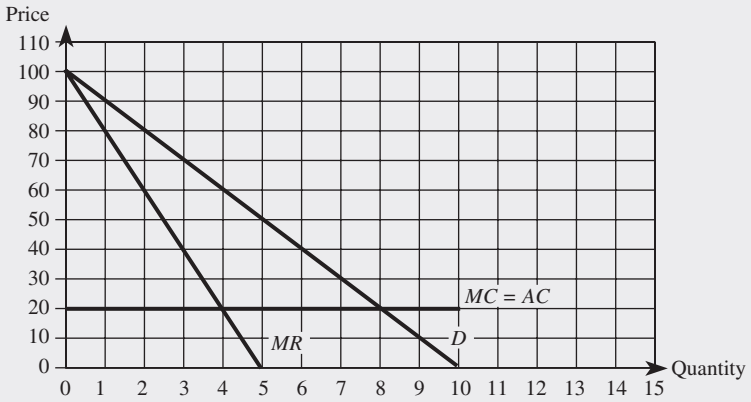
block pricing
brand loyalty
commodity bundling
cross-subsidies
double marginalization
downstream division
first-degree price discrimination
peak-load pricing
price discrimination
price matching
randomized pricing
second-degree price discrimination
third-degree price discrimination
transfer pricing
two-part pricing
upstream division

CONCEPTUAL AND COMPUTATIONAL QUESTIONS

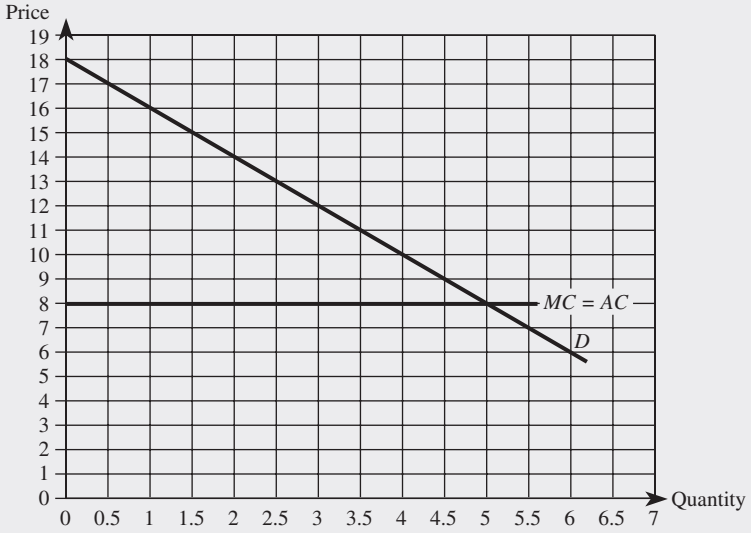
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1. Based on the best available econometric estimates, the market elasticity of demand for your firm's product is –3. The marginal cost of producing the product is constant at $100, while average total cost at current production levels is $175. Determine your optimal per unit price if: *(LO1)*
   a. You are a monopolist.
   b. You compete against one other firm in a Cournot oligopoly.
   c. You compete against 19 other firms in a Cournot oligopoly.
2. Based on the following graph (which summarizes the demand, marginal revenue, and relevant costs for your product), determine your firm's optimal price, output, and the resulting profits for each of the following scenarios: *(LO2)*
   a. You charge the same unit price to all consumers.
   b. You engage in first-degree price discrimination.
   c. You engage in two-part pricing.
   d. You engage in block pricing.



3. You are the manager of a firm that charges customers $16 per unit for the first unit purchased and $12 per unit for each additional unit purchased in excess of one unit. The accompanying graph summarizes your relevant demand and costs. *(LO2)*
   a. What is the economic term for your firm's pricing strategy?
   b. Determine the profits you earn from this strategy.
   c. How much additional profit would you earn if you were able to perfectly price discriminate?



4. You are the manager of a monopoly that sells a product to two groups of consumers in different parts of the country. Analysts at your firm have determined that group 1's elasticity of demand is -3, while group 2's is -5. Your marginal cost of producing the product is \$40. *(LO1, LO2)*
   a. Determine your optimal markups and prices under third-degree price discrimination.
   b. Identify the conditions under which third-degree price discrimination enhances profits.
5. You are the manager of a monopoly. Your analytics department estimates that a typical consumer's inverse demand function for your firm's product is $P = 200 - 20Q$, and your cost function is $C(Q) = 80Q$. *(LO2)*
   a. Determine the optimal two-part pricing strategy.
   b. How much additional profit do you earn using a two-part pricing strategy compared with charging this consumer a per-unit price?
6. A monopoly is considering selling several units of a homogeneous product as a single package. Analysts at your firm have determined that a typical consumer's demand for the product is $Q^d = 80 - 0.5P$, and the marginal cost of production is \$100. *(LO2)*
   a. Determine the optimal number of units to put in a package.
   b. How much should the firm charge for this package?
7. You are the manager of a firm that produces products *X* and *Y* at zero cost. You know that different types of consumers value your two products differently, but you are unable to identify these consumers individually at the time of the sale. In particular, you know there are three types of consumers (1,000 of each type) with the following valuations for the two products: *(LO2)*

Consumer Type	Product *X*	Product *Y*
1	\$90	\$ 60
2	70	140
3	40	160

   a. What are your firm's profits if you charge \$40 for product *X* and \$60 for product *Y?*
   b. What are your profits if you charge \$90 for product *X* and \$160 for product *Y?*
   c. What are your profits if you charge \$150 for a bundle containing one unit of product *X* and one unit of product *Y?*
   d. What are your firm's profits if you charge \$210 for a bundle containing one unit of *X* and one unit of *Y,* but also sell the products individually at a price of \$90 for product *X* and \$160 for product *Y?*
8. A large firm has two divisions: an upstream division that is a monopoly supplier of an input whose only market is the downstream division that produces the final output. To produce one unit of the final output, the downstream division requires one unit of the input. If the inverse demand for the final output is $P = 1{,}000 - 80Q$, would the company's value be maximized by paying upstream and downstream divisional managers a percentage of their divisional profits? Explain. *(LO3)*
9. According to some translations, Nobel Laureate Albert Einstein once said, "God does not play dice with the universe." Does this mean that a profit-maximizing firm would never use something like dice or a roulette wheel to help shape its pricing decisions? Explain. *(LO4)*
10. Does the presence of online auction sites, such as eBay, make it easier or harder for traditional retailers and wholesalers to engage in profitable price discrimination? Explain. *(LO2)*

PROBLEMS AND APPLICATIONS

connect

11. You are the owner of a local Honda dealership. Unlike other dealerships in the area, you take pride in your "no-haggle" sales policy. Last year, your dealership earned record profits of $1.3 million. In your market, you compete against two other dealers, and the market-level price elasticity of demand for midsized Honda automobiles is −1.5. In each of the last five years, your dealership has sold more midsized automobiles than any other Honda dealership in the nation. This entitled your dealership to an additional 20 percent off the manufacturer's suggested retail price (MSRP) in each year. Taking this into account, your marginal cost of a midsized automobile is $12,000. What price should you charge for a midsized automobile if you expect to maintain your record profits? *(LO1)*

12. You are a pricing analyst for QuantCrunch Corporation, a company that recently spent $15,000 to develop a statistical software package. To date, you only have one client. A recent internal study revealed that this client's demand for your software is $Q^d = 300 - 0.2P$ and that it would cost you $1,000 per unit to install and maintain software at this client's site. The CEO of your company recently asked you to construct a report that compares (1) the profit that results from charging this client a single per-unit price with (2) the profit that results from charging $1,450 for the first 10 units and $1,225 for each additional unit of software purchased. Construct this report, including in it a recommendation that would result in even higher profits. *(LO2)*

13. You are the manager of a local sporting goods store and recently purchased a shipment of 60 sets of skis and ski bindings at a total cost of $25,000 (your wholesale supplier would not let you purchase the skis and bindings separately, nor would it let you purchase fewer than 60 sets). The community in which your store is located consists of many different types of skiers, ranging from advanced to beginners. From experience, you know that different skiers value skis and bindings differently. However, you cannot profitably price discriminate because you cannot prevent resale. There are about 20 advanced skiers who value skis at $400 and ski bindings at $275; 20 intermediate skiers who value skis at $300 and ski bindings at $400; and 20 beginning skiers who value skis at $200 and ski bindings at $350. Determine your optimal pricing strategy. *(LO2)*

14. According to International Data Corporation (IDC), the number of worldwide smartphone owners will soon exceed 3 billion. That number is expected to grow at nearly 10 percent per year for the next five years. While the actual cost of a smartphone is about $300, wireless carriers in some countries offer their customers a "free" smartphone with a two-year wireless service agreement. Is this pricing strategy rational? Explain. *(LO3)*

15. The American Baker's Association reports that annual sales of bakery goods last year rose 15 percent, driven by a 50 percent increase in the demand for bran muffins. Most of the increase was attributed to a report that diets rich in bran help prevent certain types of cancer. You are the manager of a bakery that produces and packages gourmet bran muffins, and you currently sell bran muffins in packages of three. However, as a result of this new report, a typical consumer's inverse demand for your bran muffins is now $P = 8 - 1.5Q$. If your cost of producing bran muffins is $C(Q) = 0.5Q$, determine the optimal number of bran muffins to sell in a single package and the optimal package price. *(LO2)*

16. You own a franchise of rental car agencies in Florida. You recently read a report indicating that about 80 percent of all tourists visit Florida during the winter months in any given year and that 60 percent of all tourists traveling to Florida by air rent automobiles. Travelers not planning ahead often have great difficulty finding rental cars due to high demand. However, during nonwinter months tourism drops dramatically and travelers have no problem securing rental car reservations. Determine the optimal pricing strategy, and explain why it is the best pricing strategy. *(LO3)*

17. Blue Skies Aviation is a manufacturer of small single-engine airplanes. The company is relatively small and prides itself on being the only manufacturer of customized airplanes. The company's high standard of quality is attributed to its refusal to purchase engines from outside vendors, and it preserves its competitive advantage by refusing to sell engines to competitors. To achieve maximum efficiencies, the company has organized itself into two divisions: a division that manufactures engines and a division that manufactures airplane bodies and assembles airplanes. Consultants have estimated that the demand for Blue Skies' customized planes is $P = 812{,}000 - 3{,}000Q$. The cost of producing engines is $C_e(Q_e) = 5{,}000Q_e^2$ and the cost of assembling airplanes is $C_a(Q) = 12{,}000Q$. What problems would occur if the managers of each division were given incentives to maximize each division's profit separately? What price should the owners of Blue Skies set for engines in order to avoid this problem and maximize overall profits? *(LO3)*
18. As a manager of a chain of movie theaters that are monopolies in their respective markets, you have noticed much higher demand on weekends than during the week. You therefore conducted a study that has revealed two different demand curves at your movie theaters. On weekends, the inverse demand function is $P = 20 - 0.001Q$; on weekdays, it is $P = 15 - 0.002Q$. You acquire legal rights from movie producers to show their films at a cost of $25,000 per movie, plus a $2.50 "royalty" for each moviegoer entering your theaters (the average moviegoer in your market watches a movie only once). Devise a pricing strategy to maximize your firm's profits. *(LO3)*
19. Many home improvement retailers like Home Depot and Lowe's have low-price guarantee policies. At a minimum, these guarantees promise to match a rival's price, and some promise to beat the lowest advertised price by a given percentage. Do these types of pricing strategies result in cutthroat Bertrand competition and zero economic profits? If not, why not? If so, suggest an alternative pricing strategy that will permit these firms to earn positive economic profits. *(LO4)*
20. Heathrow Airport Holdings is a private company that operates Heathrow Airport in London. Suppose the company recently commissioned your consulting team to prepare a report on traffic congestion at Heathrow. Your report indicates that Heathrow is more likely to experience significant congestion between July and September than at other times of the year. Based on your estimates, demand is $Q_1^d = 600 - 0.25P$, where Q_1^d is quantity demanded for runway time slots between July and September. Demand during the remaining nine months of the year is $Q_2^d = 220 - 0.1P$, where Q_2^d is quantity demanded for runway time slots. The additional cost Heathrow Airport Holdings incurs each time one of the 80 different airlines utilizes the runway is £1,100 provided 80 or fewer airplanes use the runway on a given day. When more than 80 airplanes use Heathrow's runways, the additional cost incurred by the company is £6 billion (the cost of building an additional runway and terminal). Heathrow Airport Holdings currently charges airlines a uniform fee of £1,712.50 each time the runway is utilized. As a consultant to Heathrow Airport Holdings, devise a pricing plan that would enhance the company's profitability. *(LO3)*
21. Suppose the European Union (EU) is investigating a proposed merger between two of the largest distillers of premium Scotch liquor. Based on some economists' definition of the relevant market, the two firms proposing to merge enjoyed a combined market share of about two-thirds, while another firm essentially controlled the remaining share of the market. Additionally, suppose that the (wholesale) market elasticity of demand for Scotch liquor is –1.3 and that it costs $16.20 to produce and distribute each liter of Scotch. Based only on these data, provide quantitative estimates of the likely pre- and postmerger prices in the wholesale market for premium Scotch liquor. In light of your estimates, are you surprised that the EU might raise concerns about potential anticompetitive effects of the proposed merger? Explain carefully. *(LO1)*

22. An analyst for FoodMax estimates that the demand for its Brand X potato chips is given by $\ln Q_X^d = 12.14 - 2.8\ln P_X + 3.4P_Y + 0.7\ln A_X$, where Q_X and P_X are the respective quantity and price of a four-ounce bag of Brand X potato chips, P_Y is the price of a six-ounce bag sold by its only competitor, and A_X is FoodMax's level of advertising on Brand X potato chips. Last year, FoodMax sold 7 million bags of Brand X chips and spent $0.42 million on advertising. Its plant lease is $2.1 million (this annual contract includes utilities) and its depreciation charge for capital equipment was $2.8 million; payments to employees (all of whom earn annual salaries) were $0.8 million. The only other costs associated with manufacturing and distributing Brand X chips are the costs of raw potatoes, peanut oil, and bags; last year FoodMax spent $2.8 million on these items, which were purchased in competitive input markets. Based on this information, what is the profit-maximizing price for a bag of Brand X potato chips? *(LO1)*

23. You manage a company that competes in an industry that is comprised of four equal-sized firms that produce similar products. A recent industry report indicates that the market is fairly saturated in that a 10 percent industrywide price increase would lead to an 18 percent decline in units sold by all firms in the industry. Currently, Congress is considering legislation that would impose a tariff on a key input used by the industry. Your best estimate is that if the legislation passes, your marginal cost will increase by $2. Based on this information, what price increase would you recommend if the tariff legislation is passed by Congress? Explain. *(LO1)*

24. Your company just became international, by offering its products in both the United States and Canada. Experts in your analytics department believe that tastes for your product differ in those two countries and have carefully collected data on prices and quantity demanded in both countries. They then present you with the results of two log-linear regressions, one for each country, as follows:

Log-Linear U.S. Demand (*ln Q* regressed on *ln P*):

	Coefficients	Standard Error	*t*-Stat	*P*-value	Lower 95%	Upper 95%
Intercept	52.756	10.811	4.88	1.68E-06	31.487	74.024
ln P	−5.382	1.171	−4.598	6.15E-06	−7.685	−3.079

Log-Linear Canadian Demand (*ln Q* regressed on *ln P*):

	Coefficients	Standard Error	*t*-Stat	*P*-value	Lower 95%	Upper 95%
Intercept	22.871	10.645	2.148	0.032	1.928	43.814
ln P	−2.096	1.153	−1.818	0.070	−4.364	0172

a. Write down the estimated demand curve for each country in log-linear form, and comment on whether each is precisely estimated.
b. Suppose your marginal costs are $20. What is the profit maximizing price you should charge in each country?

connect Excel Exercises

25. As an online video commentator, you are committed to offering your videos without ads. Until now, you've experimented with different per-video prices for your content and collected user-level data on the number of videos viewed in a week at different prices in the file *Q11-25.xls*.
a. Using these data, estimate a linear inverse demand curve for your average user.
b. You are interested in charging a fixed subscription fee for your services, where users would pay a fee up front and then have unlimited access to your videos at zero cost per video. Assuming the demand curve you estimated in a can be reasonably applied to your entire customer base, what is the highest subscription fee you could charge?

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12 The Economics of Information

LEARNING OBJECTIVES

After completing this chapter, you will be able to:

- **LO1** Identify strategies to manage risk and uncertainty, including diversification and optimal search strategies.
- **LO2** Calculate the profit-maximizing output and price in an environment of uncertainty.
- **LO3** Explain why asymmetric information about "hidden actions" or "hidden characteristics" can lead to moral hazard and adverse selection, and identify strategies for mitigating these potential problems.
- **LO4** Explain how differing auction rules and information structures impact the incentives in auctions, and determine the optimal bidding strategies in a variety of auctions with independent or correlated values.

headLINE

Firm Chickens Out in the FCC Spectrum Auction

The U.S. Congress passed legislation requiring the FCC to abandon its "public hearing" format for awarding radio spectrum licenses. As a result of the legislation, the FCC now auctions off spectrum rights; the high bidder in the auction obtains exclusive rights to the spectrum for a period of 10 years. In its first auction, the FCC auctioned off 10 licenses, netting the U.S. Treasury $600 million in revenues from the winning bidders.

To individual bidders, like inaugural participants Bell South and McCaw (now part of AT&T), the auction format involved considerable uncertainty. While the value of a given license was virtually identical to all of the bidders, no single firm knew for sure what their profits would be if they won the auction. Each firm had its own private estimates of the value of a license, but these estimates differed across bidders.

One firm's private estimate of the value of a license was $85 million. This means that the firm estimated that it would earn $85 million over and above all costs (in present value terms) if it were awarded a license. Yet, this firm dropped out of the bidding when the auction price reached $80 million.

Why do you think the firm dropped out of the bidding when the price was below its private estimate of the value of a license?

INTRODUCTION

Throughout most of this book, we have assumed that participants in the market process—both consumers and firms—enjoy the benefits of perfect information. One need not look very hard at the real world to notice that this assumption is more fiction than fact. Nevertheless, our analyses in the preceding chapters can help us understand the market process. In fact, they are the basis for more complicated analysis that incorporates the effects of uncertainty and imperfect information.

More advanced courses in economics build on the foundations set forth in earlier chapters of this book by relaxing the assumption that people enjoy perfect information. While formal theoretical models of decision making in the presence of imperfect information are well beyond the scope and purpose of this book, it is useful to present an overview of some of the more important aspects of decision making under uncertainty. First, we will describe more formally what we mean by *uncertainty* and examine the impact of uncertainty on consumer behavior. Then we will briefly demonstrate means by which the manager can cope with risk. Finally, we will look at several important implications of uncertainty on the market process, including auction markets.

THE MEAN AND THE VARIANCE

The easiest way to summarize information about uncertain outcomes is to use the statistical concepts of the mean and the variance of a random variable. More specifically, suppose there is some uncertainty regarding the value of some variable. The random variable, x, might represent profits, the price of output, or consumer income. Since x is a random variable, we cannot be sure what its actual value is. All we know is that with given probabilities, different values of the random variable will occur. For example, suppose someone promises to pay you (in dollars) whatever number comes up when a fair die is tossed. If x represents the payment to you, it is clear that you cannot be sure how much you will be paid. If you are lucky, you will roll a 6 and be paid \$6. If you are unlucky, you will roll a 1 and receive \$1. The probability that any number between 1 and 6 is rolled is 1/6 because there are six sides on the die. The expected value (or mean) of x is given by

$$E[x] = \frac{1}{6}(\$1) + \frac{1}{6}(\$2) + \frac{1}{6}(\$3) + \frac{1}{6}(\$4) + \frac{1}{6}(\$5) + \frac{1}{6}(\$6) = \$3.50$$

In other words, even though you do not know for certain how much you will be paid when you roll the die, on average you will earn \$3.50.

The **mean** or **expected value** of a random variable, x, is defined as the sum of the probabilities that different outcomes will occur times the resulting payoffs. Formally, if the possible outcomes of the random variable are $x_1, x_2, \ldots, x_n$ and the corresponding probabilities of the outcomes are $q_1, q_2, \ldots, q_n$, the expected value of x is given by

mean (expected value)
The sum of the probabilities that different outcomes will occur multiplied by the resulting payoffs.

$$E[x] = q_1x_1 + q_2x_2 + \cdots + q_nx_n$$

where $q_1 + q_2 + \cdots + q_n = 1$.

The mean of a random variable thus collapses information about the likelihood of different outcomes into a single statistic. This is a very convenient way of economizing on the amount of information needed to make decisions.

The mean provides information about the average value of a random variable but it yields no information about the degree of risk associated with the random variable. To

illustrate the importance of considering risk in making decisions, consider the following two options:

Option 1: Flip a coin. If it comes up heads, you receive $1; if it comes up tails, you pay $1.

Option 2: Flip a coin. If it comes up heads, you receive $10; if it comes up tails, you pay $10.

Even though the stakes are much higher under option 2 than under option 1, each option has an expected value of zero. On average, you will neither make nor lose money with either option. To see this, note that there is a 50–50 chance the coin will land on heads. Thus, the expected value of option 1 is

$$E_{Option\ 1}[x] = \frac{1}{2}(\$1) + \frac{1}{2}(-\$1) = 0$$

and the expected value of option 2 is

$$E_{Option\ 2}[x] = \frac{1}{2}(\$10) + \frac{1}{2}(-\$10) = 0$$

The two options have the same expected value but are inherently different in nature. By summarizing information about the options using the mean, we have lost some information about the risk associated with the two options. Regardless of which option you choose, you will either gain money or lose money by flipping the coin. Under option 1, half the time you will make $1 more than the average and half the time you will make $1 less than the average. Under option 2, the deviation from the mean of the actual gain or loss is much greater: Half the time you will make $10 more than the average and half the time you will lose $10 more than the average. Since these deviations from the mean are much larger under option 2 than under option 1, it is natural to think of option 2 as being more risky than option 1.

While the preceding discussion provides a rationale for calling option 2 more risky than option 1, it is often convenient for the manager to have a number that summarizes the risk associated with random outcomes. The most common measure of *risk* is the variance, which depends in a special way on the deviations of possible outcomes from the mean. The **variance** of a random variable is the sum of the probabilities that different outcomes will occur times the squared deviations from the mean of the random variable. Formally, if the possible outcomes of the random variable are $x_1, x_2, \ldots, x_n$, their corresponding probabilities are $q_1, q_2, \ldots, q_n$, and the expected value of x is given by $E[x]$, then the variance of x is given by

variance
The sum of the probabilities that different outcomes will occur multiplied by the squared deviations from the mean of the resulting payoffs.

$$\sigma^2 = q_1(x_1 - E[x])^2 + q_2(x_2 - E[x])^2 + \cdots + q_n(x_n - E[x])^2$$

The **standard deviation** is simply the square root of the variance:

standard deviation
The square root of the variance.

$$\sigma = \sqrt{\sigma^2} = \sqrt{q_1\big(x_1 - E[x]\big)^2 + q_2\big(x_2 - E[x]\big)^2 + \cdots + q_n\big(x_n - E[x]\big)^2}$$

Because a larger variance implies a larger standard deviation (and vice versa), it may seem that the standard deviation provides no useful information beyond that contained in the variance. However, the standard deviation does have some very practical applications. In particular, the outcomes for any random variable always will fall within two standard deviations of its mean at least 75 percent of the time. For example, if a random variable, x, has mean of 5 and standard deviation of 1, you can be sure x will take on a value between 3 [= 5 – 2(1)] and 7 [= 5 + 2(1)] at least 75 percent of the time.

Let us apply these formulas to our coin-tossing examples to see how the variance can be used to obtain a number that summarizes the risk associated with the options. In each case,

only two possible outcomes occur with equal probabilities, so $q_1 = q_2 = 1/2$. The mean of each option is zero. Thus, the variance of option 1 is

$$\sigma^2_{Option\ 1} = \frac{1}{2}(1-0)^2 + \frac{1}{2}(-1-0)^2 = \frac{1}{2}(1) + \frac{1}{2}(1) = 1$$

The variance of option 2 is

$$\sigma^2_{Option\ 2} = \frac{1}{2}(10-0)^2 + \frac{1}{2}(-10-0)^2 = \frac{1}{2}(100) + \frac{1}{2}(100) = 100$$

Since

$$\sigma^2_{Option\ 1} = 1 < \sigma^2_{Option\ 2} = 100$$

option 2 is more risky than option 1. Since the standard deviation is the square root of the variance, the standard deviation of option 1 is 1 and the standard deviation of option 2 is 10.

DEMONSTRATION PROBLEM 12–1

The manager of XYZ Company is introducing a new product that will yield $1,000 in profits if the economy does not go into a recession. However, if a recession occurs, demand for the normal good will fall so sharply that the company will lose $4,000. If economists project that there is a 10 percent chance the economy will go into a recession, what are the expected profits to XYZ Company of introducing the new product? How risky is the introduction of the new product?

ANSWER:

If there is a 10 percent chance of a recession, there is a 90 percent chance that there will not be a recession. Using the formula for the expected value of a random variable, the expected profits of introducing the new product are found to be

$$E[x] = q_1x_1 + q_2x_2 = .1(-\$4{,}000) + .9(\$1{,}000) = \$500$$

Thus, the expected profits of introducing the new product are $500. Using variance as a measure of risk,

$$\sigma^2 = .1(-4{,}000 - 500)^2 + .9(1{,}000 - 500)^2 = 2{,}250{,}000$$

UNCERTAINTY AND CONSUMER BEHAVIOR

Now that you understand how to calculate the mean and variance of an uncertain outcome, we will see how the presence of *uncertainty* affects economic decisions of both consumers and managers.

Risk Aversion

In Chapter 4 we assumed consumers have preferences for bundles of goods, which were assumed to be known with certainty. We now will extend our analysis to preferences over uncertain outcomes.

Let F and G represent two uncertain prospects. F might represent the prospects associated with buying 100 shares of stock in company F and G the prospects associated with buying 100 shares of stock in company G. When you purchase a stock, you are uncertain what your actual profits or losses will be; all you know is that there is some mean and variance in return associated with each stock. Different people exhibit different preferences for the same

set of prospects. You may prefer F to G, while a friend prefers G to F. It simply is a matter of taste for risky prospects.

risk averse
Preferring a sure amount of $\$M$ to a risky prospect with an expected value of $\$M$.

risk loving
Preferring a risky prospect with an expected value of $\$M$ to a sure amount of $\$M$.

risk neutral
Indifferent between a risky prospect with an expected value of $\$M$ and a sure amount of $\$M$.

Because attitudes toward risk will differ among consumers, we must introduce some additional terminology to differentiate among these attitudes. First, a **risk-averse** person prefers a sure amount of $\$M$ to a risky prospect with an expected value of $\$M$. A **risk-loving** individual prefers a risky prospect with an expected value of $\$M$ to a sure amount of $\$M$. Finally, a **risk-neutral** individual is indifferent between a risky prospect with an expected value of $\$M$ and a sure amount of $\$M$.

It is possible that for some prospects individuals will be risk loving, while for others they will be risk averse. For small gambles, people typically are risk loving, whereas for larger gambles they are risk averse. You may be willing to bet a quarter that you can guess whether a flipped coin will come up heads or tails. The expected value of this gamble is zero. In this instance, you are behaving as a risk lover: You prefer the gamble with an expected payoff of zero to not playing (receiving zero for certain). If the stakes are raised to, say, $25,000, you will most likely choose not to bet. In this instance, you will prefer not betting (zero for certain) to the gamble with an expected value of zero.

Managerial Decisions with Risk-Averse Consumers

For gambles with nontrivial outcomes, most individuals are risk averse. Here we will point out some implications of risk-averse consumers for optimal managerial decisions.

Product Quality. The analysis of risk can be used to analyze situations where consumers are uncertain about product quality. For instance, suppose a consumer regularly purchases a

INSIDE BUSINESS 12–1

Risk Aversion and the Value of Selling the Firm: The St. Petersburg Paradox

Corporations often are sold at a price that seems much lower than the expected value of future profits. Before you conclude the market is not rational, ask yourself how much you would be willing to pay for the right to toss a coin when

- You receive 2 cents if the first heads is on the first flip.
- You receive 4 cents if the first heads is on the second flip.
- You receive 8 cents if the first heads is on the third flip.
- More generally, you receive 2^n cents if the first heads is on the nth toss.

Since coin flips are independent events, the expected value of participating in this coin toss gamble is

$$E[x] = \left(\frac{1}{2}\right)2 + \left(\frac{1}{2}\right)^2 2^2 + \left(\frac{1}{2}\right)^3 2^3 + \left(\frac{1}{2}\right)^4 2^4 + \cdots$$
$$= 1 + 1 + 1 + 1 + \cdots$$
$$= \infty \text{ cents}$$

Thus, the expected value of this gamble is infinity: On average, you will make an infinite amount of money if you play this game. Of course, we know of no person willing to give up the world to play this particular game. We have found that in a class of 200 students, the most people will pay is about $2, which is considerably lower than the infinite expected value of the gamble. This outcome is known as the *St. Petersburg paradox*.

The answer to this paradox is that it is the utility individuals receive from winning a gamble, not the money itself, that is important. The satisfaction you derive from winning your first $1 million is much greater than that derived from winning your second $1 million, and so on. This diminishing marginal utility of income gives rise to risk aversion, meaning that individuals are willing to pay less than the expected value. For the case of this gamble, the difference between the expected value and the amount an individual is willing to pay is substantial. The same can be true when corporations are up for sale.

particular brand of car wax and thus is relatively certain about the underlying quality and characteristics of the product. If the consumer is risk averse, when will she be willing to purchase a car wax newly introduced to the market?

A risk-averse consumer prefers a sure thing to an uncertain prospect of equal expected value. Thus, if the consumer expects the new car wax to work just as well as the one she regularly purchases, then, other things equal, she will not buy the new product. The reason is that there is risk associated with using a new product; the new wax may make a car look much better than the old wax, or it may damage the paint on the car. When the consumer weighs these possibilities and concludes that the new wax is expected to be just as good as the wax she now uses, she decides not to buy the new product. The consumer prefers the sure thing (the current brand) to the risky prospect (the new product).

Firms use two primary tactics to induce risk-averse consumers to try a new product. First, the firm's manager may lower the price of the new product below that of the existing product to compensate the consumer for the risk associated with trying the new product. When firms send out free samples, they essentially use this technique because to the consumer the price of the new product is zero.

Alternatively, the manager can attempt to make the consumer think that the expected quality of the new product is higher than the certain quality of the old product. Typically firms do this using comparison advertising. For example, an advertisement might show 50 cars being waxed with a new wax and 50 cars being waxed with competitors' products; then the cars are repeatedly washed until only the 50 cars waxed with the new product still shine. If consumers are convinced by such an advertisement, they may go ahead and purchase the new product because its higher expected quality offsets the risk associated with trying a new product.

Chain Stores. Risk aversion also explains why it may be in a firm's interest to become part of a chain store instead of remaining independent. For example, suppose a consumer drives through Smalltown, USA, and decides to eat lunch. There are two restaurants in the town: a local diner and a national hamburger chain. While the consumer knows nothing about this particular diner, his experience suggests that local diners typically are either very good or very bad. On the other hand, national hamburger chains have standardized menus and ingredients; the type and quality of product offered are relatively certain, albeit of average quality. Because the consumer is risk averse, he will choose to eat at the national chain unless he expects the product of the local diner to be sufficiently better than the chain restaurant.

There is nothing special about the restaurant example; similar examples apply to retailing outlets, transmission shops, and other types of stores. While there are exceptions, out-of-town visitors typically prefer to make purchases at chain stores. Local customers are in a better position to know for certain the type and quality of products offered at stores in their town and may shop at the local store instead of the national chain. The key thing to notice is that even if the local store offers a better product than the national chain, the national chain can remain in business if the number of out-of-town customers is large enough.

Online Reviews. The easy flow of information on the Internet has simplified the process of submitting, and making publicly available, customer reviews. Websites like Yelp contain millions of online reviews from customers at restaurants, and many other establishments, all over the United States. Among other things, online reviews can help even the playing field between chains and independent stores. Revisiting our lunch example, if the local diner has many online reviews, this information can help alleviate the risk a consumer perceives if he eats at the local diner; there is now more information about the local diner's food quality, making it less uncertain relative to a well-known chain and potentially attracting more

risk-averse customers. Through this mechanism, managers of local firms—particularly those with a large potential number of out-of-town customers—may enhance demand by facilitating online reviews submitted by previous customers.

Insurance. The fact that consumers are risk averse implies that they are willing to pay to avoid risk. This is precisely why individuals choose to buy insurance on their homes and automobiles. By buying insurance, individuals give up a small (relative to potential losses) amount of money to eliminate the risk associated with a catastrophic loss. For example, if a $100,000 house burns down, an uninsured homeowner loses $100,000; if it does not burn down, the homeowner loses nothing. Most homeowners are willing to pay several hundred dollars to avoid this risk. If the house burns down, the insurance company reimburses the homeowner for the loss. Thus, to a consumer, insurance represents a purchase of a "sure thing"—a house that is worth $100,000 regardless of whether or not it burns down.

Some firms give insurance to customers through "money-back guarantees." Other firms sell a form of insurance to customers. For example, many car manufacturers sell extended-warranty plans to customers whereby the company agrees to pay repair costs. This eliminates the risk associated with owning a car, thus making car ownership more attractive to risk-averse consumers.

Consumer Search

Up until now, we have assumed consumers know the prices of goods with certainty. The analysis is more complicated in situations where consumers do not know the prices charged by different firms for the same product.

Suppose consumers do not know the prices charged by different stores for some homogeneous commodity. Suppose further that there are numerous stores charging different prices for the same brand of watch. A consumer would like to purchase the product from the store charging the lowest price, but she does not know the prices being charged by individual stores. Let c denote the cost of obtaining information about the price charged by an individual store. For example, c might represent the cost of making a phone call, the cost of traveling to a store to find out what price it charges for a watch, or the cost of looking up a price in a catalog or on the Internet.

Suppose that three-quarters of the stores in the market charge $100 for a particular brand of watch and one-quarter charge $40. If the consumer locates a store that sells a watch for $40, she clearly should stop searching; no store charges a price below $40.

What should a risk-neutral consumer do if she visits a store that charges $100? For simplicity, suppose the consumer searches with *free recall* and with *replacement*. By free recall we mean that the consumer is free to return to the store at any time to purchase the watch for $100. The fact that a consumer searches with replacement means that the distribution of prices charged by other firms does not change just because the consumer has learned that the one store charges $100 for a watch. Under these assumptions, if the consumer searches again, one-quarter of the time she will find a price of $40 and thus will save $100 − $40 = $60. But three-quarters of the time the consumer will find a price of $100, and the gains from having searched will be zero. Thus, the expected benefit of an additional search is

$$EB = \frac{1}{4}(\$100 - \$40) + \frac{3}{4}(0) = \$15$$

In other words, if the consumer searches for a price lower than $100, one-quarter of the time she will save $60 and three-quarters of the time she will save nothing. The expected benefit of searching for a lower price thus is $15.

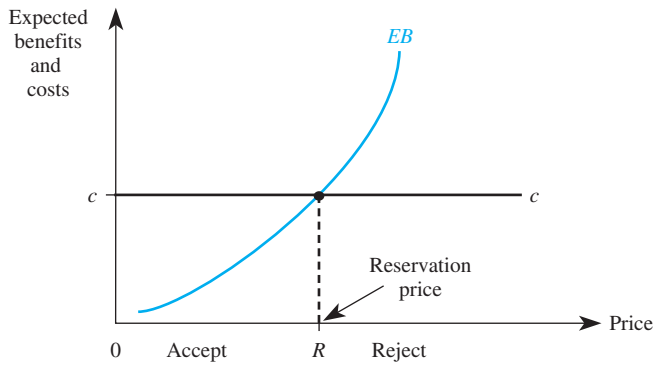


Figure 12–1
The Optimal Search Strategy

The consumer should search for a lower price so long as the expected benefits are greater than the cost of an additional search. For example, if the cost of each search is $5, the consumer will find it in her interest to continue to search for a lower price. But if the cost of searching once more for a lower price is $20, it does not pay to continue searching for a better price.

This example reveals that the expected benefits of searching depend on the lowest price found during previous searches. If the lowest known price is p, the expected benefits (EB) from searching for a price lower than p slopes upward, as in Figure 12–1. Intuitively, as lower prices are found, the savings associated with finding even lower prices diminish.

Figure 12–1 also illustrates the optimal search strategy for a consumer. The cost of each search is the horizontal line labeled c. If the consumer finds a price higher than R, the expected benefits of searching are greater than the cost, and the consumer should reject this price (continue to search for a lower price). On the other hand, if the consumer locates a price below R, it is best to accept this price (stop searching and purchase the product). This is because the expected benefits of searching for an even lower price are less than the cost of

INSIDE BUSINESS 12–2

Obfuscation to Counter Low Internet Search Costs

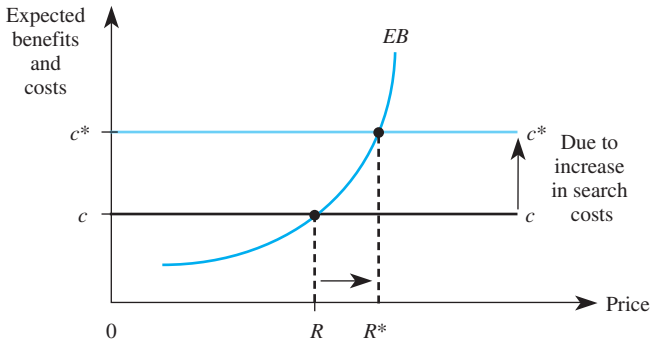
Price comparison websites allow shoppers to learn about prices charged by many different online retailers for a given product. These websites serve to lower consumer search costs to near zero, placing great pressure on retailers to set low prices. One such site is PriceGrabber.com, which compares prices on a wide range of products.

Is all profit lost for firms competing in this market? Not necessarily. Competing firms may engage in obfuscation in an attempt to ease the downward pressure on prices. Economists Glenn Ellison and Sara Fisher Ellison examined firm behavior at a price comparison site for computer parts, called Pricewatch.com, and found several indications of these types of practices. In particular, they document evidence of firms posting complicated descriptions of their products and producing multiple versions of products. In addition, they document another practice they deem as a type of obfuscation, where (1) firms offer a low-quality product at a low price to attract consumers on the comparison site and then (2) once a consumer has clicked, the firm tries to convince the consumer to pay more for a superior product. All of these practices can serve to complicate the search process—and potentially raise profits.

SOURCE: Glenn Ellison and Sara Fisher Ellison, "Search, Obfuscation, and Price Elasticities on the Internet," *Econometrica* (2009), pp. 427–452.

Figure 12–2

An Increase in Search Costs Raises the Reservation Price



searching. If the consumer located a price of R, she would be indifferent between purchasing at that price and continuing to search for a lower price.

reservation price
The price at which a consumer is indifferent between purchasing at that price and searching for a lower price.

The **reservation price**, R, is the price at which the consumer is indifferent between purchasing at that price and searching for a lower price. Formally, if $EB(p)$ is the expected benefit of searching for a price lower than p and c represents the cost per search, the reservation price satisfies the condition

$$EB(R) = c$$

PRINCIPLE

The Consumer's Search Rule

The optimal search rule is such that the consumer rejects prices above the reservation price *(R)* and accepts prices below the reservation price. Stated differently, the optimal search strategy is to search for a better price when the price charged by a firm is above the reservation price and stop searching when a price below the reservation price is found.

What happens if the cost of searching increases? As Figure 12–2 shows, an increase in search costs shifts up the horizontal line to c^*, resulting in a higher reservation price, R^*. This means the consumer will now find more prices acceptable and will search less intensively. Similarly, if the cost of searching for lower prices falls, the consumer will search more heavily for lower prices.

Our analysis of a consumer's decision to shop for lower prices can be used to aid managers in setting prices. In particular, when consumers have imperfect information about prices and search costs are low, the optimal prices set by a manager will be lower than when search costs are high. Moreover, managers must be careful not to price their products above consumers' reservation price; doing so will induce consumers to seek out lower prices at other firms. If you observe a large number of consumers "browsing" in your store but not making purchases, it may be a sign that your prices are set above their reservation price and that they have decided to continue to search for a lower price.

UNCERTAINTY AND THE FIRM

We have seen that the presence of uncertainty has a direct impact on consumer behavior and that the firm manager must take these effects into account to fully understand the nature of consumer demand. Uncertainty also affects the manager's input and output decisions. In this section, we will examine the implications of uncertainty for production and output decisions.

It is important to point out that all our analysis of the impact of uncertainty on consumer behavior is directly applicable to the firm's manager. We will briefly discuss extensions of the analysis of uncertainty to highlight its direct influence on managerial decisions.

Risk Aversion

Just as consumers have preferences regarding risky prospects, so does the manager of the firm. A manager who is risk neutral is interested in maximizing expected profits; the variance of profits does not affect a risk-neutral manager's decisions. If the manager is risk averse, he or she may prefer a risky project with a lower expected value if it has lower risk than one with a higher expected value. Alternatively, if given a choice between a risky project with an expected return of $1 million and a certain return of $1 million, a risk-averse manager will prefer the sure thing. For the manager to be willing to undertake a risky project, the project must offer a higher expected return than a comparable "safe" project. Just how much higher depends on the manager's particular risk preferences.

Whenever a manager faces a decision to choose among risky projects, it is important to carefully evaluate the risks and expected returns of the projects and then to document this evaluation. The reason is simple. Risky prospects may result in bad outcomes. A manager is less likely to get fired over a bad outcome if she or he provides evidence that, based on the information available at the time the decision was made, the decision was sound. A convenient way to do this is to use mean-variance analysis, as the next demonstration problem illustrates.

DEMONSTRATION PROBLEM 12–2

A risk-averse manager is considering two projects. The first project involves expanding the market for bologna; the second involves expanding the market for caviar. There is a 10 percent chance of a recession and a 90 percent chance of an economic boom. During a boom, the bologna project will lose $10,000, whereas the caviar project will earn $20,000. During a recession, the bologna project will earn $12,000 and the caviar project will lose $8,000. If the alternative is earning $3,000 on a safe asset (say, a Treasury bill), what should the manager do? Why?

ANSWER:

The first thing the manager should do is summarize the available information to document the relevant alternatives:

Project	Boom (90%)	Recession (10%)	Mean	Standard Deviation
Bologna	−$10,000	$12,000	−$ 7,800	6,600
Caviar	20,000	−8,000	17,200	8,400
Joint	10,000	4,000	9,400	1,800
T-bill	3,000	3,000	3,000	0

The "joint" option reflects what would happen if the manager adopted both the bologna and caviar projects. For example, if the manager jointly adopted the caviar and bologna projects, during a boom the firm would lose $10,000 on the bologna project but make $20,000 on the caviar project. Thus, during a boom, the joint project will result in a return of $10,000. Similar calculations reveal the joint project will yield a return of $4,000 during a recession.

Based on the preceding table, what should a prudent manager do? The first thing to note is that the manager should not invest in a Treasury bill. The joint project will generate profits of $4,000

during a recession and $10,000 during a boom. Thus, regardless of what happens to the economy, the manager is assured of making at least $4,000 under the joint project, which is greater than the return of $3,000 on the Treasury bill.

The second thing to notice is that the expected (mean) profits of the bologna project are negative. A risk-averse manager would never choose this project (neither would a risk-neutral manager). Thus, the manager should adopt either the caviar project or the joint project. Precisely which choice the manager makes will depend on his or her preferences for risk.

The returns associated with the joint project in the preceding problem reveal the important notion of *diversification*, which is taught in basic business finance courses. By investing in multiple projects, the manager may be able to reduce risk. This is merely a technical version of the old adage, "Don't put all your eggs in one basket." As the example reveals, there are benefits to diversification, but whether it is optimal to diversify depends on a manager's risk preference and the incentives provided to the manager to avoid risk.

While many managers are risk averse, generally the owners of the firm (the stockholders) want the manager to behave in a risk-neutral manner. A manager who is risk neutral cares only about the expected value of a risky project, not the underlying risk. More specifically, a risk-neutral manager's objective is to take actions that maximize the expected present value of the firm, that is, actions that maximize expected profits. A risk-neutral manager would choose a risky action over a sure thing provided the expected profits of the risky prospect exceeded those of the sure thing.

Why would shareholders want managers to take actions that maximize expected profits even when doing so might involve considerable risk? Shareholders can pool and diversify risks by purchasing shares of many different firms to eliminate the systematic risk associated with the firm's operation. It therefore is inefficient for managers to spend time and money attempting to diversify against risk when doing so will reduce the firm's expected profits. Thus, while the owners of a firm may be risk averse, they prefer managers who make risk-neutral decisions.

A simple example will illustrate why shareholders desire managers to behave in a risk-neutral manner. Suppose a manager must decide which of two projects to undertake. The first project is risky, with a 50–50 chance of yielding profits of $2 million or zero. The second project will yield a certain return of $900,000. The expected profits earned by the risky project are $1 million, which is greater than those of the project yielding a certain return. But the variance of the risky project is greater than that of the certain one; half the time profits will be zero, half the time they will be $2 million. Why would shareholders want the manager to undertake the risky project even though it has greater risk? The answer is that shareholders can purchase shares of many firms in the economy. If the managers of each of these firms choose the risky project, the projects will not pay off for some firms but will pay off for others. If the profits earned by one firm are independent of those earned by other firms, then, on average, the unfavorable outcomes experienced by some firms will be more than offset by the favorable outcomes at other firms. This situation is similar to flipping a coin: Flip a coin once and you cannot be sure it will turn up heads; flip a coin many times and you can rest assured that half the flips will be heads. Similarly, when shareholders own shares of many different firms, each of which takes on risky projects, they can rest assured that half of the firms will earn $2 million.

For these reasons, as a manager you are likely to be given an incentive to maximize the expected profits of your firm. If you are provided with such incentives, you will behave in a risk-neutral manner even if you and the owners of the firm are risk averse.

Producer Search

Just as consumers search for stores charging low prices, producers search for low prices of inputs. When there is uncertainty regarding the prices of inputs, optimizing firms employ optimal search strategies. The search strategy for a risk-neutral manager will be precisely the same as that of a risk-neutral consumer. Rather than repeat the basic theory, it is more useful to illustrate these concepts with an example.

DEMONSTRATION PROBLEM 12–3

A risk-neutral manager is attempting to hire a worker. All workers in the market are of identical quality but differ with respect to the wage at which they are willing to work. Suppose half of the workers in the labor market are willing to work for a salary of $40,000 and half will accept a salary of $38,000. The manager spends three hours interviewing a given worker and values this time at $300. The first worker the manager interviews says he will work only if paid $40,000. Should the firm manager make him an offer or interview another worker?

ANSWER:

This is an optimal search problem with a search cost of $300. If the manager searches for another worker, half of the time she will find one willing to work for $38,000 and thus will save $2,000. But half of the time the manager will find a worker just like the one she chose not to hire, and the effort will have been for nothing. Thus, the expected benefit of interviewing another worker is

$$EB = \frac{1}{2}(\$2{,}000) + \frac{1}{2}(0) = \$1{,}000$$

Since this is greater than the cost of $300, the manager should not hire the worker but instead search for a worker willing to work for $38,000.

Profit Maximization

The basic principles of profit maximization can also be modified to deal with uncertainty. To illustrate how the basic principles of profit maximization are affected by the presence of uncertainty, let us suppose the manager is risk neutral and demand is uncertain. Recall that the goal of a risk-neutral manager is to maximize expected profits.

The risk-neutral manager must determine what output to produce before she is certain of the demand for the product. Because demand is uncertain, revenues are uncertain. This means that to maximize expected profits, the manager should equate expected marginal revenue with marginal cost in setting output:

$$E[MR] = MC$$

The reason is simple. If expected marginal revenue exceeded marginal cost, the manager could increase expected profits by expanding output. The production of another unit of output would, on average, add more to revenue than it would to costs. Similarly, if expected marginal revenue was less than marginal cost, the manager should reduce output. This is because by reducing output, the firm would reduce costs by more than it would reduce expected revenue.

Thus we see that when the manager is risk neutral, profit maximization under uncertain demand is very similar to profit maximization under certainty. All the manager needs to do is adjust the corresponding formula to represent the expected marginal revenue.

For a video walkthrough of this problem, visit www.mhhe.com/baye10e

DEMONSTRATION PROBLEM 12–4

Appleway Industries produces apple juice and sells it in a competitive market. The firm's manager must determine how much juice to produce before he knows what the market (competitive) price will be. Economists estimate that there is a 30 percent chance the market price will be $2 per gallon and a 70 percent chance it will be $1 when the juice hits the market. If the firm's cost function is $C = 200 + 0.0005Q^2$, how much juice should be produced to maximize expected profits? What are the expected profits of Appleway Industries?

ANSWER:

The profits of Appleway Industries are given by

$$\pi = pQ - 200 - 0.0005Q^2$$

Since price is uncertain, the firm's revenues and profits are uncertain. For a competitive firm, $MR = p$; thus, marginal revenue also is uncertain. Marginal cost is given by $MC = 0.001Q$. To maximize expected profits, the manager equates expected price with marginal cost:

$$E[p] = 0.001Q$$

The expected price is given by

$$E[p] = .3(2) + .7(1) = 0.60 + 0.70 = \$1.30$$

Equating this with marginal cost, we obtain

$$1.30 = 0.001Q$$

Solving for Q, we find that the output that maximizes expected profits is $Q = 1{,}300$ gallons. Expected profits for Appleway Industries are

$$\begin{aligned} E[\pi] &= E[p]Q - 200 - 0.0005Q^2 \\ &= 1.30(1{,}300) - 200 - 0.0005(1{,}300)^2 \\ &= 1{,}690 - 200 - 845 = \$645 \end{aligned}$$

Thus, Appleway Industries can expect to make $645 in profits.

While our analysis of profit maximization under uncertainty is far from exhaustive, it points out that much of our previous analysis can be easily extended to deal with uncertainty. In fact, these extensions are important topics in more advanced courses in economics.

UNCERTAINTY AND THE MARKET

The presence of uncertainty can have a profound impact on the ability of markets to efficiently allocate resources. In this section, we examine some problems created in markets when there is uncertainty. We also show how managers and other market participants can overcome some of these problems.

Asymmetric Information

When some people in the market have better information than others, the people with the least information may choose not to participate in a market. To see why this is so, suppose someone

offers to sell you a box full of money. You do not know how much money is in the box, but she does. Should you choose to buy the box?

The answer is no. Since she knows how much money is in the box, she will never sell you the box unless you offer her more for the box than is in it. Suppose she knows the box contains $10. If you offered her $6 for the box, she would have no incentive to engage in the transaction. If you offered her $12, she would gladly sell you the box, and you would lose $2.

asymmetric information
A situation that exists when some people have better information than others.

As the preceding example reveals, **asymmetric information** can result in a situation where people with the least information rationally refuse to participate in the market. If you think of the box in the example as being a company whose stock is traded on the NASDAQ or the New York Stock Exchange, it should be clear why there is so much concern over insider trading—the buying and selling of stocks by persons who have privileged information about a firm. If some people know for certain what a stock will sell for tomorrow (say, due to a takeover) and others do not, asymmetric information exists. The only time insiders will purchase stock is when they know it is selling at a price below what it is worth; the only time insiders will sell stock is when they know it is selling at a premium over what it is worth. If people know that insiders regularly trade in the stock market, people who are not insiders may rationally choose to stay out of the stock market to avoid paying too much for a stock or selling it for too little. In extreme cases, this situation can completely destroy the stock market, as no one is willing to buy or sell shares of firms' stock. For this reason, and as discussed in Module Group B, there are laws that restrict persons with privileged information about a firm from buying shares of that firm's stock.

Asymmetric information between consumers and the firm can affect firm profits. For example, suppose a firm invests in developing a new product that it knows to be superior to existing products in the market. Consumers, on the other hand, are unlikely to know whether the new product is truly superior to existing products or whether the firm is falsely claiming the product to be superior. If the degree of asymmetric information is severe enough, consumers may refuse to buy a new product even if it really is better than existing products. The reason is that they do not know the product is indeed superior.

Asymmetric information affects many other managerial decisions, including hiring workers and issuing credit to customers. In particular, job applicants have much better information about their own capabilities than does the person in charge of hiring new workers. A job applicant who claims to have excellent skills may be lying or telling the truth; the personnel manager has less information than the applicant. This is why firms spend considerable sums designing tests to evaluate job applicants, doing background checks, and the like. The basic reason for these types of expenditures is to provide the firm with better information about the capabilities and tendencies of job applicants. Similarly, a consumer who wishes to make a purchase on credit has much better information about his own ability to pay off the debt than does the creditor. Of course, every consumer seeking to purchase on credit will claim that he or she will pay off the debt. Asymmetric information makes it difficult for the firm to know whether a person actually will pay off the debt. In fact, firms pay sizable sums to credit bureaus to obtain better information about their credit customers. These expenditures reduce asymmetric information and make it more difficult for customers to take advantage of it.

With this overview of some problems that can arise in the presence of asymmetric information, we turn now to two specific manifestations of asymmetric information: adverse selection and moral hazard. These two concepts are often difficult to distinguish, so it is useful first to distinguish between the types of asymmetric information that generally lead to adverse selection and moral hazard.

hidden characteristics
Things one party to a transaction knows about itself but which are unknown by the other party.

hidden action
Action taken by one party in a relationship that cannot be observed by the other party.

adverse selection
Situation where individuals have hidden characteristics and in which a selection process results in a pool of individuals with undesirable characteristics.

Adverse selection generally arises when an individual has **hidden characteristics**—characteristics that she knows but that are unknown by the other party in an economic transaction. In our example of the job applicant, for instance, the worker knows his own ability but the employer does not. The worker's ability thus reflects a hidden characteristic. In contrast, moral hazard generally occurs when one party takes **hidden actions**—actions that it knows another party cannot observe. For example, if the manager of a firm cannot monitor a worker's effort, then the worker's effort represents a hidden action. Just as it is often difficult to distinguish between ability (a characteristic) and effort (an action), it is sometimes difficult to distinguish between adverse selection and moral hazard.

Adverse Selection

Adverse selection refers to a situation where a selection process results in a pool of individuals with economically undesirable characteristics. A simple example highlights the basic issues involved in adverse selection.

Consider an industry in which all firms allow their employees five days of paid sick leave. Suppose one firm decides to increase the number of paid sick leave days from 5 to 10 to attract more workers. If the workers have hidden characteristics—that is, if the firm cannot distinguish between healthy and unhealthy workers—the plan will probably lure many workers away from other firms. But what type of workers is the firm most likely to attract? Workers who know they are frequently ill and thus who value sick leave the most. Workers who know they never get sick will have little incentive to leave their current employers, but those who are frequently sick will. From the firm's point of view, the policy attracts undesirable workers. In economic terms, the policy results in adverse selection.

Adverse selection explains why people with poor driving records find it difficult to buy automobile insurance. Suppose there are two types of people with bad driving records: (1) those who are poor drivers and frequently have accidents and (2) those who are good drivers but, due purely to bad luck, have been involved in numerous accidents in the past. Past accidents by bad drivers are a result of their driving habits and are good indicators of the number of expected future accidents. Past accidents by good drivers, on the other hand, are

INSIDE BUSINESS 12–3

Groucho Marx the Economist?

One of the most famous American comedians of the twentieth century, Groucho Marx, was renowned for his witty one-liners. One of his best-known one-liners goes like this: "Please accept my resignation. I don't care to belong to any club that will have me as a member." On its surface, the statement sounds absurd. However, it is also a very subtle and clever example of adverse selection at work.

To illustrate, first note that the asymmetric information in this case concerns the quality of a club. Groucho does not know the quality level of a given club, but each club knows its own quality level. Further, each club can observe the type of person Groucho is and decide whether to let him join. To see why Groucho may choose to reject every club that offers him membership, consider the following simple scenario. Suppose there are two clubs—a high-quality club and a low-quality club. Groucho cannot tell which is which but only is willing to join the high-quality club. However, knowing the type of person Groucho is, only the low-quality club will offer him membership. The process of deciding whether to admit Groucho has generated adverse selection—by limiting Groucho to the set of clubs willing to admit him, he is left with only the low-quality club. Hence, even though Groucho cannot tell either club's quality by looking at it, he knows only the low-quality club will allow him to join, and so rejects the offer.

not a good indicator of the expected number of future accidents; they merely reflect an unusual string of bad luck.

An insurance company has asymmetric information; it does not know whether a person with a bad driving record is truly a poor driver or whether past accidents were unusual events due to bad luck. Assuming that those who have poor driving records know their own type, we have a situation where one side of the insurance market has hidden characteristics. Suppose an insurance company decides to insure drivers with poor driving records, but at a very high premium to cover the anticipated future claims due to bad driving. The insurance company must charge all drivers with bad records the same insurance rate since it cannot distinguish between those who are good drivers and those who are bad drivers. By charging the same price to both types of drivers, adverse selection results. As the insurance company raises insurance rates to cover the losses of bad drivers, the only people who will be willing to pay the higher price are those drivers who know they are most likely to have accidents. The good drivers, who know that their past accidents were unusual events, will not be willing to pay the high rate. Thus, the insurance company will end up selling policies only to the drivers most likely to wreck their cars. Because insurance works only when there are some drivers who pay premiums and do not wreck their automobiles, insurance companies typically find it in their interest to charge lower prices for insurance and refuse to insure any driver with a bad driving record. Doing otherwise would lead to adverse selection within the pool of drivers with poor records.

Moral Hazard

Sometimes when two parties engage in a contract, one party agrees to insulate the other party from economic loss. If the contract induces the party that is insulated from loss to take a hidden action that harms the other party, we say that **moral hazard** exists.

moral hazard
Situation where one party to a contract takes a hidden action that benefits him or her at the expense of another party.

Consider, for instance, the principal–agent problem we first examined in Chapter 6. In this setting, the owner hires a manager to operate the firm, which earns profits that vary randomly with economic conditions. Unfortunately, profits also depend on the manager's effort, which is unobservable to the owner. Thus, the effort of the manager represents a hidden action. Notice that if the owner agrees to pay the manager a fixed salary of $50,000 (the contract), then the manager is completely insulated from any economic loss that might arise due to random fluctuations in the firm's profits. The manager now has an incentive to spend less time at the office (the hidden action), and the reduced effort of the manager results in lower firm profits (and thus harms the owner). In other words, the fixed salary contract, coupled with the hidden action of the manager, results in moral hazard. As we learned in Chapter 6, the owner can overcome this problem by either monitoring the manager (taking away the hidden action) or making the manager's pay contingent on the firm's profits (taking away the manager's insurance against economic loss).

As you might suspect, the nature of insurance markets makes insurance companies particularly vulnerable to the moral hazard problem. As we discussed earlier in this chapter, the fact that individuals are risk averse provides an incentive for them to purchase insurance against large losses. Most people have insurance on their homes and automobiles and some form of health insurance. Usually the probability of a loss depends on the hidden effort expended by the insured to avoid the loss. Thus, a moral hazard exists: When individuals are fully insured, they have a reduced incentive to put forth effort to avoid a loss.

For example, suppose a company rents cars and fully insures renters against damage to the cars. Obviously, the company cannot observe the effort put forth by renters to avoid damages to rented vehicles. Since renters are fully insured and can take hidden actions that may result in damages to cars, they are indifferent between returning the car with a stolen radio and

returning the car in perfect condition. If a radio is stolen, the replacement cost is paid for out of the company's pocket. Thus, when the car is fully insured, the driver has less incentive to take the time to lock the car or to avoid parking the car in areas where theft is likely. If the car were uninsured, the driver would have to replace stolen items with his or her own money and therefore would be much more careful with the car. Thus, if the company insures renters against damage, drivers will be less careful with cars than if they were not insured against damage. In economic terms, a moral hazard exists.

One way car insurance companies attempt to reduce moral hazard is by requiring a deductible on all insurance claims. If the deductible is $500, the first $500 in losses is paid by the insured. This effectively means that the person buying insurance must pay something in the event of a loss and thus has an incentive to take actions to reduce the likelihood of a loss.

Moral hazard is one factor that has contributed to rising medical costs during the past decade. When individuals have health insurance or belong to a health maintenance organization (HMO), they do not pay for the full marginal cost of medical services. As a consequence, individuals are more likely to visit a doctor when they have a minor illness (say, a cold) than they would if they had to pay the full marginal cost of going to a doctor.

The effect of this is twofold. First, the moral hazard results in an increase in the demand for medical services, leading to a higher equilibrium price of medical services. This is because individuals do not pay the full cost of a visit to a doctor and thus use physicians' services more frequently than they would if they were required to pay the full cost of each visit. Second, insurance companies must increase the rates they charge for medical insurance to cover the higher costs of insurance claims due to more frequent visits. This might lead those who know they are in good health to decide against insurance coverage, which means that the higher medical insurance premiums also lead to adverse selection. In this case, the insurance company is left to insure a pool of less-healthy individuals, which exacerbates the problem. Thus, moral hazard and adverse selection may be partially responsible for the recent increases in the cost of medical insurance, and the recent trend in the United States toward high-deductible insurance policies.

Signaling and Screening

We learned that incentive contracts can be used to mitigate moral hazard problems that stem from hidden actions. We now show how managers and other market participants can use signaling and screening to mitigate some of the problems that arise when one party to a transaction has hidden characteristics.

signaling
An attempt by an informed party to send an observable indicator of his or her hidden characteristics to an uninformed party.

Signaling occurs when an informed party sends a signal (or indicator) of his or her hidden characteristics to an uninformed party in an attempt to provide information about these hidden characteristics. In product markets, firms use a host of devices to signal product quality to consumers: money-back guarantees, free trial periods, and packaging labels that indicate the product has won a "special award" or that the manufacturer has been in business since 1933. In labor markets, job applicants attempt to signal their ability through resumes that tout their "pedigree" (the school at which they earned an undergraduate degree) or the fact that they earned an advanced degree such as an MBA or a PhD.

For a signal to provide useful information to an otherwise uninformed party, the signal must be observable by the uninformed party. Moreover, the signal must be a reliable indicator of the underlying unobservable characteristic and difficult for parties with other characteristics to easily mimic. To be concrete, consider a manager who wishes to hire a worker from an employment pool that consists of two types of individuals: (1) unproductive workers, who produce nothing, and (2) productive workers, who each has a value marginal product of $80,000 per year. Obviously, if the labor market is perfectly competitive and the manager can

observe the productivity of workers before hiring them, unproductive workers will earn a salary of zero and productive workers will earn a salary that equals their value marginal product—$80,000 per year.

The situation is dramatically different when managers cannot observe the productivity of a worker by simply looking at the worker. Suppose that at the time of the hiring decision, workers know whether or not they are productive, but managers do not. From the manager's perspective, there is a 50–50 chance that a given worker is productive or unproductive. Since the expected value marginal product of a worker is .5(0) + .5($80,000) = $40,000, a risk-neutral manager will only be willing to pay a salary of $40,000 to hire a worker with unobservable characteristics. Notice that the unproductive worker earns more than he would have earned if his characteristics were observable to the manager, and the productive worker earns less than he would have earned if the manager knew he was productive. The manager's lack of information, in this case, benefits unproductive workers at the expense of productive ones.

Because productive workers are harmed by the manager's lack of information, it is in their best interest to attempt to provide information to the manager that reveals that they are indeed productive; doing so will boost their salary from $40,000 to $80,000. How can they signal their productivity to the manager? You might think that it would be enough for productive workers to simply tell the manager that they are productive. The problem with this approach is that talk is cheap; if productive workers could boost their earnings by $40,000 by simply declaring, "I'm productive," then unproductive workers could easily mimic this strategy to earn an extra $40,000. For this reason, a rational manager would ignore this idle chatter—everyone has an incentive to claim to be productive, so this message does not reveal anything about the true characteristics of workers.

For signaling to enhance the salaries of productive workers, they must send a signal that cannot be mimicked easily by unproductive workers. For instance, suppose productive workers have innate abilities that make it easy for them to earn a college degree, and unproductive workers have lower innate abilities that preclude them (or, more generally, make it very costly for them) from earning a college degree. In this case, those individuals who know they are productive can earn a college degree to "signal" to managers that they are indeed productive. Unproductive types cannot mimic this signal, so managers can infer that workers with college degrees are the productive types. As a consequence, competitive pressures will result in college graduates earning $80,000. Signaling works because unproductive workers are unable (or, more generally, unwilling to bear the cost required) to mimic this signal; managers thus can infer that applicants with a college degree likely are more productive than those without a degree.

Screening occurs when an uninformed party attempts to sort individuals according to their characteristics. This sorting may be achieved through a **self-selection device**: Individuals who have information about their own characteristics are presented with a set of options, and the options they choose reveal their characteristics to the uninformed party.

screening
An attempt by an uninformed party to sort individuals according to their characteristics.

self-selection device
A mechanism in which informed parties are presented with a set of options, and the options they choose reveal their hidden characteristics to an uninformed party.

A simple example will illustrate how an uninformed manager can use a self-selection device to gain information about the hidden characteristics of workers. Suppose two workers—Henry and Mitchell—have different characteristics: Henry is the better administrator and Mitchell is the better salesperson. Henry and Mitchell know what they do better, but their personnel director does not. Specifically, Henry knows the firm's profits would increase by $60,000 if he were employed as an administrator and that he would be unable to generate any sales if he were employed as a salesperson. Mitchell knows the firm's profits would increase by $15,000 if he were employed as an administrator and that he could generate $1 million in sales if he were employed as a salesperson. The personnel director, Natalie, wants to place each worker in the position that adds the most value to the firm, but she lacks the information needed to make these assignments.

Natalie can overcome her lack of information by offering Henry and Mitchell different employment options and letting them self-select into the job that is best for them as well as for the firm. In particular, suppose Natalie uses a self-selection device whereby she announces the following compensation for administrators and salespeople: Administrators earn a fixed salary of $60,000; salespeople receive a 10 percent sales commission. Confronted with these options, Henry realizes that he would earn $0 as a salesperson and thus will self-select into his best-paying option: the administrative position. Mitchell will opt for the sales position since the $100,000 he earns as a salesperson (10 percent of the $1 million he generates in sales) exceeds the $60,000 he would earn as an administrator. Thus, even though Natalie does not know which of the two individuals would be the better administrator and the better salesperson, the self-selection device sorts workers into the jobs she would have assigned if she had known Henry's and Mitchell's characteristics.

DEMONSTRATION PROBLEM 12–5

One-Jet Airlines has 100 customers and is the only airline servicing two small cities in the Midwest. Half of One-Jet's customers are leisure travelers and half are business travelers. Business travelers are willing to pay $600 for a ticket that does not require a Saturday stayover and $100 for a ticket that requires a Saturday stayover. Leisure travelers are flexible, willing to pay $300 for a ticket regardless of whether it requires a Saturday stayover. One-Jet is unable to determine whether a particular customer is a business or leisure traveler. Consequently, the airline's current pricing policy is to charge $300 for all tickets. As a pricing consultant for One-Jet Airlines, can you devise a self-selection mechanism that will permit One-Jet to increase revenues and continue to serve all its customers? Explain.

ANSWER:

Yes. One-Jet can offer two types of tickets: a $300 "supersaver" ticket that requires a Saturday stayover and a $600 "full-fare" ticket that does not require a Saturday stayover. Given the options, leisure travelers will select the supersaver ticket and business travelers will select the full-fare ticket. This screening device not only sorts travelers by their characteristics but increases One-Jet's revenues from $30,000 (computed as $100 \times \$300$) to $45,000 (computed as $50 \times \$300 + 50 \times \$600$).

AUCTIONS

In an *auction*, potential buyers compete for the right to own a good, service, or, more generally, anything of value. Auctions are used to sell a variety of things, including art, Treasury bills, furniture, real estate, oil leases, corporations, electricity, and numerous consumer goods at auction sites on the Internet. When the auctioneer is a seller, as in an art auction, she or he wishes to obtain the highest possible price for the item. Buyers, on the other hand, seek to obtain the item at the lowest possible price. In some instances, the auctioneer is the person seeking bids from potential suppliers. For instance, a firm that needs new capital equipment may hold an auction in which potential suppliers bid prices that reflect what they would charge for the equipment. In auctions with multiple bidders, competition among bidders leads to more favorable terms for the auctioneer.

Auctions are important for managers to understand because, in many instances, firms participate either as the auctioneer or as a bidder in the auction process. In other words, a firm may wish to sell a good in an auction or buy a good (or input) in an auction. For this

reason, it is important for managers to understand the implications of auctions for managerial decisions.

While the bidders' risk preferences can affect bidding strategies and the expected revenue the auctioneer receives, we will assume throughout this section that bidders are risk neutral. This assumption is satisfied in many auction settings since bidders can mitigate their overall risk by participating in a large number of auctions. Before we explain how much a risk-neutral bidder should bid in an auction, we first describe the rules of some different types of auctions and the nature of the information bidders can have about the item for which they are competing.

Types of Auctions

There are four basic types of auction: English (ascending-bid); first-price, sealed-bid; second-price, sealed-bid; and Dutch (descending-bid) auctions. These auctions differ with respect to (1) the timing of bidder decisions (whether bids are made simultaneously or sequentially) and (2) the amount the winner is required to pay. Keep these two sources of differences in auctions in mind as we discuss each type of auction.

English Auction

The auction you probably are most familiar with is the English auction. In an **English auction**, a single item is to be sold to the highest bidder. The auction begins with an opening bid. Given knowledge of the opening bid, the auctioneer asks if anyone is willing to pay a higher price. The bids continue to rise in a sequential fashion until no other participants wish to increase the bid. The highest bidder—the only bidder left—pays the auctioneer his or her bid and takes possession of the item.

English auction
An ascending sequential-bid auction in which bidders observe the bids of others and decide whether or not to increase the bid. The auction ends when a single bidder remains; this bidder obtains the item and pays the auctioneer the amount of the bid.

Notice that in an English auction, the bidders continually obtain information about one another's bids. Given this information, if they think the item is worth more than the current high bid, they will increase their bids. The auction ends when no other bidder is willing to pay more for the item than the highest bid. For this reason, in an English auction the person who ends up with the item is the one who values the item the most.

To illustrate, suppose three firms are competing for the right to purchase a machine in an English auction at a bankruptcy sale. Firm A values the machine at $1 million, firm B values it at $2 million, and firm C values it at $1.5 million. Which firm will acquire the machine, and at what price?

All three firms will bid up to $1 million for the machine. Once the bid is slightly above this amount, firm A will drop out since it values the machine at $1 million. When the bid reaches $1.5 million, firm C will drop out, which means firm B will acquire the machine for $1.5 million (or perhaps $1.5 million plus $.01). Effectively, the winner of the auction simply has to top the second-highest valuation of the machine.

First-Price, Sealed-Bid Auction

In a **first-price, sealed-bid auction**, the bidders write their bids on pieces of paper without knowledge of bids made by other players. The auctioneer collects the bids and awards the item to the high bidder. The high bidder pays the auctioneer the amount he or she has written on the piece of paper.

first-price, sealed-bid auction
A simultaneous-move auction in which bidders simultaneously submit bids on pieces of paper. The auctioneer awards the item to the high bidder, who pays the amount bid.

Thus, in a first-price, sealed-bid auction, the highest bidder wins the item just as in an English auction. However, unlike in an English auction, the bidders do not know the bids of other players. As we will see, this characteristic can affect bidding behavior and, consequently, the price collected by the auctioneer.

INSIDE BUSINESS 12–4

Second-Price Auctions on eBay

In a second-price auction, the dominant strategy is to bid your true valuation of the item. If you have ever participated in an auction on eBay, chances are you have participated in a second-price auction.

eBay's automatic bidding mechanism permits a bidder to submit his reservation price or "maximum bid." This amount is kept secret by eBay's system. The system automatically updates the bid, using the smallest increment required above the previous high bid. This process continues until the bid required exceeds the reservation price.

This environment is essentially a second-price auction, and the optimal reservation price to submit early in the auction is your true valuation of the item. As eBay explains on its website:

> Automatic bidding is the easiest way to bid on an eBay auction. Simply enter the highest price you're willing to pay for an item, and we do the rest. When you're ready to bid on an auction listing, enter the maximum amount you feel comfortable with. We'll then bid on your behalf—enough to keep you in the lead, but only up to that limit.

SOURCES: https://www.ebay.com/help/buying/bidding/automatic-bidding?id=4014, accessed January 27, 2020; Alvin E. Roth and Axel Ockenfels, "Last-Minute Bidding and the Rules for Ending Second-Price Auctions: Evidence from eBay and Amazon Auctions on the Internet," *American Economic Review* 92, no. 4 (September 2002), pp. 1093–103.

second-price, sealed-bid auction
A simultaneous-move auction in which bidders simultaneously submit bids. The auctioneer awards the item to the high bidder, who pays the amount bid by the second-highest bidder.

Second-Price, Sealed-Bid Auction

A **second-price, sealed-bid auction** is similar to a first-price, sealed-bid auction in that bidders submit bids without knowledge of the bids submitted by others. The person submitting the highest bid wins but has to pay only the amount bid by the second highest bidder. Consider, for instance, the situation where a machine is auctioned off to one of three firms in a second-price, sealed-bid auction. If Firm A bids $1 million, Firm B bids $2 million, and Firm C bids $1.5 million, then the high bidder—Firm B—wins the item, but it pays only the second highest bid, which is $1.5 million.

Dutch auction
A descending sequential-bid auction in which the auctioneer begins with a high asking price and gradually reduces the asking price until one bidder announces a willingness to pay that price for the item.

Dutch Auction

In a **Dutch auction**, the seller begins by asking for a very high price for the item (a price so high that she or he is certain no one will be willing to buy). The auctioneer gradually lowers the price until one buyer indicates a willingness to buy the item at that price. At this point, the auction is over: The bidder buys the item at the last announced price. Dutch auctions are used extensively in the Netherlands to auction flowers such as tulips. Car dealers sometimes use a Dutch auction to sell cars; a price for a particular car is posted each day on a marquee, and the price is lowered each day until someone purchases the car.

The information available to bidders in a Dutch auction is identical to that in a first-price, sealed-bid auction. In particular, no information is available about the bids of other players until the auction is over, that is, when the first bidder speaks up. Consequently, a Dutch auction is strategically equivalent to a first-price, sealed-bid auction. The reason is that in both types of auctions, bidders do not know the bids of other players. Furthermore, in each case the bidder pays what he or she bid for the item. In terms of optimal bidding behavior and the profits earned by the auctioneer, the Dutch auction and first-price, sealed-bid auctions are identical.

Strategic Equivalence of Dutch and First-Price Auctions

The Dutch and first-price, sealed-bid auctions are strategically equivalent; that is, the optimal bids by participants are identical for both types of auctions.

PRINCIPLE

Information Structures

The four basic types of auctions differ with respect to the information bidders have about the bids of other players. In the English auction, players know the current bid and can choose to raise it if they so desire. In the other three types of auctions, players make bids without knowledge of other players' bids; they cannot decide to increase their own bids based on bids made by others.

In analyzing an auction, it is also important to consider the information players have about their valuations of the item being auctioned. One possibility is that each bidder in an auction knows for certain what the item is worth, and furthermore, all players know the valuations of other players in an auction. For example, if a $5 bill were being auctioned off, every bidder would know that the item is worth $5 to each bidder. This is the case of *perfect information*.

Rarely do bidders in an auction enjoy perfect information. Even in situations in which each bidder knows how much he or she values the item, it is unlikely that other bidders are privy to this information. Moreover, individuals may be unsure of an item's true value and must rely on whatever information they have to form an estimate of its worth. These circumstances reflect situations of asymmetric information: Each bidder has information about his or her valuation or value estimate that is unknown by other bidders. These information structures are discussed next.

Independent Private Values

Consider an antique auction in which the bidders are consumers who wish to acquire an antique for personal use. Thus, the bidders' valuations of the item are determined by their individual tastes. While a bidder knows his or her own tastes, he or she does not know the preferences of the other bidders. Thus, there is asymmetric information.

The auction just described is one in which bidders have **independent private values**. The term *private value* refers to the fact that the item's worth to an individual bidder is determined by personal tastes that are known only to that bidder. The fact that these private values are *independent* means that they do not depend on the valuations of others: Even if a player could obtain information about other bidders' valuations, his or her valuation of the object would not change. This information might, however, induce him or her to bid differently in the auction.

independent private values
Auction environment in which each bidder knows his own valuation of the item but does not know other bidders' valuations, and in which each bidder's valuation does not depend on other bidders' valuations of the object.

To be concrete, imagine that the item is an antique desk, which you value at $200 because you know it would make studying managerial economics even more enjoyable (if that's possible). You face another bidder who, unbeknown to you, values the desk at $50. (He only wants the desk for scrap lumber.) Notice the asymmetric information that is present regarding these private values—you each know how much you value the desk but do not know how much the other values it. These valuations are also independent: Even if you knew the other bidder valued the desk at $50, it would not affect your own valuation of the desk. Of course, information about the other bidder's valuation might induce you to bid less aggressively for the antique desk.

Correlated Value Estimates

In many auction settings, bidders are unsure of an item's true valuation. Bidders may have access to different information about an item's actual worth and thus may form different estimates of the item's value. Consider an art auction, where the authenticity of the artist is uncertain. In this case, bidders will likely have different estimates of a painting's value for two reasons. First, individual tastes might lead some individuals to value the painting more than others. Second, bidders might have different estimates of the painting's authenticity. Furthermore, the bidders' estimates of the painting's value are likely to be interdependent. Your estimate of the painting's value would likely be higher if you knew others valued the painting since you value owning a painting that is admired by others. Likewise, your valuation of the painting would likely be higher if you knew others valued the painting because of information they have about the painting's authenticity.

affiliated (or correlated) value estimates
Auction environment in which bidders do not know their own valuation of the item or the valuations of others. Each bidder uses his or her own information to estimate their valuation, and these value estimates are affiliated: The higher a bidder's value estimate, the more likely it is that other bidders also have high value estimates.

This example illustrates an environment in which bidders have **affiliated (or correlated) value estimates**. Each bidder must base his or her decision on an estimate (or guess) of his or her valuation of the item. Furthermore, the bidders' value estimates are correlated, or, more precisely, *affiliated*: The higher one bidder's value estimate, the more likely it is that other bidders also have high value estimates.

A special case of this environment, the **common-value** auction, arises when the true underlying value of the item is the same for all bidders. In this case, individual tastes play no role in shaping the bidders' value estimates. The uncertainty stems purely from the fact that different bidders use different information to form their estimates of the common value of the item.

common value
Auction environment in which the true value of the item is the same for all bidders, but this common value is unknown. Each bidder uses his or her own (private) information to form an estimate of the item's true common value.

A good example of a common-value auction is the government's use of auctions to sell oil, gas, and mineral rights to prospective firms. The true value of these rights (the amount of oil, gas, or ore underneath the earth) is unknown to the bidders, but whatever the amount, the value is the same for all bidders. Each bidder forms an estimate of the true common value by taking seismic readings and performing other tests. Even though the true value is the same for all bidders, each bidder will likely obtain different estimates through its own tests.

Optimal Bidding Strategies for Risk-Neutral Bidders

This section presents the optimal bidding strategies for risk-neutral bidders, that is, strategies that maximize a bidder's expected profits. As we will see, a player's optimal bidding strategy depends not only on the type of auction but on the information available to the bidders when they make their bids.

Strategies for Independent Private Values Auctions

It is easiest to characterize optimal bidding strategies for environments in which the bidders have independent private valuations. In this case, each bidder already knows how much he or she values the item before the auction starts, so bidders learn nothing useful about their own valuations during the auction process.

Consider first an English auction, in which the auctioneer starts with a low price and gradually raises it until only one bidder remains. A bidder who remains in the auction after the price exceeds his valuation risks having to pay more for the item than it is worth to him. A bidder who drops out of the auction before the price reaches her valuation misses an opportunity to obtain the item at a price below her value. Thus, the optimal bidding strategy in an English auction is for each bidder to remain active until the price exceeds his or her own valuation of the object. Thus, the bidder with the highest valuation will win the object and pay an amount to the auctioneer that equals the second-highest valuation (the price at which the last competitor drops out).

The Optimal Bidding Strategy for an English Auction

A player's optimal bidding strategy in an English auction with independent, private valuations is to remain active until the price exceeds his or her own valuation of the object.

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Next, consider a second-price, sealed-bid auction: The highest bidder wins and pays the amount bid by the second-highest bidder. In this case, something remarkable happens: Each player has an incentive to bid precisely his or her own valuation of the item. Since each player bids his or her own valuation, the amount actually paid by the highest bidder is the valuation of the second-highest bidder, just as in the English auction.

Why should players bid their true valuation in a second-price auction? The reason is quite simple. Because the winner pays the bid of the second-highest bidder, not his or her own bid, it does not pay for players to bid more or less than their own valuations. To see this, suppose a player bid more than the item was worth to him to increase the likelihood of being the high bidder. If the second-highest bid is less than his valuation, this strategy yields no additional returns; he also would have won had he bid his true valuation. If the second-highest bid is above his valuation, then by bidding more than his valuation he may indeed win. But if he does win, he pays the second-highest bid, which we assumed is above his own valuation! In this case, he pays more for the item than the item is worth to him. Thus, it does not pay for a player to bid more than his or her valuation in a second-price auction. Will a player ever bid less than his valuation? No. A player who bids less merely reduces the chance of winning since the player never pays his or her own bid! For this reason, the dominant strategy for bidders in a second-price, sealed-bid auction is to bid their valuations.

The Optimal Bidding Strategy for a Second-Price, Sealed-Bid Auction

In a second-price, sealed-bid auction with independent private values, a player's optimal strategy is to bid his or her own valuation of the item. In fact, this is a dominant strategy.

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Finally, consider a first-price auction (which as we have seen is strategically equivalent to a Dutch auction). In this case, the high bidder wins and pays his or her own bid. Since players do not know the valuations or bids of others and must pay their own bid if they win, players have an incentive to bid less than their own valuation of the item. By bidding less than his or her own valuation of the item, a player reduces the probability of submitting the highest bid. But the profit the bidder earns if he or she does win more than offsets the reduced probability of winning. The amount by which a bidder shades down his bid depends on how many other bidders are competing for the item. The more competitive the auction (i.e., the greater the number of other bidders), the closer a player should bid to his or her true valuation. The following principle includes a formula you can use to explicitly compute your optimal bid in situations in which you and other bidders perceive that the lowest possible valuation of other bidders is L and the highest possible valuation is H.

The Optimal Bidding Strategy for a First-Price, Sealed-Bid Auction

In a first-price, sealed-bid auction with independent private values, a bidder's optimal strategy is to bid less than his or her valuation of the item. If there are n bidders who all perceive valuations to be evenly (or uniformly) distributed between a lowest possible valuation of L and a highest possible valuation of H, then the optimal bid for a player whose own valuation is v is given by

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$$b = v - \frac{v - L}{n}$$

where b denotes the player's optimal bid.

In this formula, notice that the greater the number of bidders (n) or the closer the bidder's valuation is to the lowest possible valuation of the other bidders (i.e., the closer $v - L$ is to zero), then the closer the optimal bid (b) is to the player's actual valuation of the item (v). The following demonstration problem shows how you can use this formula to determine your optimal bid in both first-price and Dutch auctions.

DEMONSTRATION PROBLEM 12–6

Consider an auction where bidders have independent private values. Each bidder perceives that valuations are evenly distributed between \$1 and \$10. Sam knows his own valuation is \$2. Determine Sam's optimal bidding strategy in (1) a first-price, sealed-bid auction with two bidders; (2) a Dutch auction with three bidders; and (3) a second-price, sealed-bid auction with 20 bidders.

ANSWER:

1. With only two bidders, $n = 2$. The lowest possible valuation is $L = \$1$, and Sam's own valuation is $v = \$2$. Thus, Sam's optimal sealed bid is
$$b = v - \frac{v - L}{n} = 2 - \frac{2 - 1}{2} = \$1.50$$
2. Because a Dutch auction is strategically equivalent to a first-price, sealed-bid auction, we can use that formula to determine the price at which Sam should declare his willingness to buy the item. Here, $n = 3$, the lowest possible valuation is $L = \$1$, and Sam's own valuation is $v = \$2$. Thus,
$$b = v - \frac{v - L}{n} = 2 - \frac{2 - 1}{3} = \$1.67$$
Sam's optimal strategy is to let the auctioneer continue to lower the price until it reaches \$1.67 and then yell, "Mine!"
3. Sam should bid his true valuation, which is \$2.

Strategies for Correlated Values Auctions

Optimal bidding strategies with affiliated (or correlated) values are more difficult to describe, for two main reasons. First, the bidders do not know their own valuations of the item, let alone the valuations of others. This not only makes it difficult for players to determine how much to bid, but as we will see, it makes them vulnerable to what is called the *winner's curse*. Second, the auction process itself may reveal information about how much the other bidders value the object. When players' value estimates are affiliated, optimal bidding requires that players use this information to update their own value estimates during the auction process.

To illustrate, suppose 100 firms bid for the rights to an oil lease in a first-price, sealed-bid common-values auction. Thus, each bidder is uncertain about the true amount of oil underneath the earth, but nevertheless it is worth the same to each bidder. Before participating in the bidding process, each firm runs an independent test to obtain an estimate of the amount of oil in the ground. Naturally, these estimates vary randomly from firm to firm.

winner's curse
The "bad news" conveyed to the winner that his or her estimate of the item's value exceeds the estimates of all other bidders.

Suppose the differences in their estimates of the amount of oil in the ground are due purely to random variations in test procedures. Some firms think there is more oil in the ground than others, not because they are better informed but due purely to random chance. In this case, the firm that submits the winning bid is the firm with the most optimistic estimate of the amount of oil in the ground. Expressed differently, one of the spoils of victory in a common-values auction is the **winner's curse**: Winning conveys news to the victor that all the

other firms think the lease is worth less than he or she paid for it. The chance that the other 99 firms are wrong and the winner is right is slim indeed. Notice that if the bidders could "pool" their information and average it, they would have a more precise estimate of the true amount of oil in the ground.

The winner's curse presents a danger that prudent managers must avoid. To illustrate, suppose a geologist for one of these firms estimated that the lease is worth $50 million. The manager of this firm, being naive, ignores the fact that $50 million is only an estimate of the common value. In fact, he calculates his firm's bid by using the formula described earlier for a first-price, sealed-bid auction with independent private valuations. He knows the number of bidders ($n = 100$), recognizes that some firms might think there is no oil underneath the earth ($L = 0$), and sets $v = \$50{,}000{,}000$ in the formula to arrive at a bid of $49.5 million. He submits this bid and wins but then learns that the second-highest bid was only $40 million. By the rules of the auction, his firm must pay $49.5 million for a lease that his firm's geologist thinks is worth $50 million. Chances are, the lease is worth millions of dollars less than this estimate of $50 million since the other 99 firms were not willing to pay more than $40 million for the lease. He should have realized that the only way he could win with a bid of $49.5 million is if the other 99 firms obtained more pessimistic value estimates. For this reason, a player who submits a bid based purely on his or her initial value estimate will, on average, pay more for the item than it is worth. To avoid the winner's curse, a bidder must revise downward his or her value estimate to account for this fact.

Avoiding the Winner's Curse

In a common-values auction, the winner is the bidder who is the most optimistic about the true value of the item. To avoid the winner's curse, a bidder should revise downward his or her private estimate of the value to account for this fact.

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The winner's curse is most pronounced in sealed-bid auctions because players do not learn anything about other players' value estimates until it is too late to act on it. In contrast, in an English auction the auction process provides information to the bidders. Each bidder shows up at the auction with an initial estimate of the item's value. During the auction process, each bidder gains information about the item's worth and can revise his or her value estimate accordingly. Specifically, as the price gets higher and higher and the other bidders continue to remain active, you should realize that the other bidders also estimate the object to be of high value—if their private information suggested the object was of low value, they would have already dropped out of the auction. By affiliation, you should revise upward your estimate of the item's worth since higher-value estimates by other bidders make it more likely that the value to you is also high. Conversely, if you observe that many bidders dropped out at a low price, you should revise downward your private estimate. The optimal strategy in an English auction with affiliated value estimates is to continue to bid so long as the price does not exceed the value estimate you obtain based not only on your private information but on information gleaned through the auction process.

Expected Revenues in Alternative Types of Auctions

Now that you have a basic understanding of bidding strategies in auctions, we can compare the prices that result, on average, in each type of auction. In particular, suppose an auctioneer is interested in maximizing her expected profits. Which type of auction will generate

Table 12–1

Comparison of Expected Revenues in Auctions with Risk-Neutral Bidders

Information Structure	Expected Revenues
Independent private values	English = Second-price = First-price = Dutch
Affiliated value estimates	English > Second-price > First-price = Dutch

the highest profits: English, second-price, first-price, or Dutch? As Table 12–1 shows, the "best" auction from the auctioneer's viewpoint depends on the nature of the information the bidders hold.

The first row in Table 12–1 indicates that, with independent private values, the auctioneer's expected revenues are the same for all four auction types. The reason for this result, known as *revenue equivalence*, is as follows.

With independent private values, players already know their own valuations and therefore learn nothing useful about the item's worth during the auction process. As we saw in the previous section, the price ultimately paid by the winner in an English auction is the second-highest valuation—the price at which the last competitor drops out. This is also the case in a second-price auction. In particular, each player bids his or her own value, and thus the price paid by the winner (the second-highest price) is the second-highest valuation. It follows that, with independent private values, the expected revenue earned by the auctioneer is the same in an English auction as a second-price auction.

In a first-price auction, each bidder has an incentive to shade his bid. In effect, each bidder estimates how far below his own valuation the next highest valuation is and then shrinks his or her bid by that amount. The player who wins the auction is the one with the highest valuation, and therefore he pays an amount to the auctioneer that is, on average, equal to the second-highest valuation. Thus, with independent private values, the expected revenue earned by the auctioneer in a first-price auction is identical to that in English and second-price auctions. Because the Dutch auction is strategically equivalent to a first-price auction, the expected revenues under the two auctions are the same. For these reasons, all four of these auctions generate the same expected revenues for the auctioneer when bidders have independent private values.

Table 12–1 shows that revenue equivalence does not hold for affiliated values. Players shrink their bids below what they would have bid based purely on their private value estimates in order to avoid the winner's curse. In an English auction, players gain the most information about the value estimates of others, and this additional information mitigates the winner's curse to some extent. Thus, bidders shrink their bids less in an English auction than in sealed-bid or Dutch auctions. In contrast, in first-price and Dutch auctions, players learn nothing about other players' value estimates during the auction process. Bidders thus shrink their bids most in first-price and Dutch auctions. In a second-price auction, bidders also learn nothing about the value estimates of others. However, the winner does not have to pay his or her own bid but rather the amount bid by the second-highest bidder. The fact that the second-highest bid is linked to information another bidder has about the item's valuation mitigates to some extent the winner's curse, thus inducing players to shrink their bids by less than they would in a first-price auction. As a result, with affiliated value estimates, the auctioneer earns greater expected revenues in an English auction than a second-price auction, and the lowest expected revenues in a first-price or Dutch auction.

INSIDE BUSINESS 12–5

Auctions with Risk-Averse Bidders

Risk aversion affects bidder behavior in some types of auctions but not in others. Consider the independent private values case. In an English auction, players know their own valuation and get to observe the bids of others. Therefore, risk aversion plays no real role in the analysis of bidding strategies: Risk-averse bidders will remain active until the price exceeds their valuation and then drop out. The winner will pay an amount that equals the second-highest valuation. Likewise, in a second-price auction, it is a dominant strategy for a risk-averse bidder to bid his or her true valuation, so this type of auction also results in a price that equals the second-highest valuation.

In contrast, risk aversion induces players to bid more aggressively in a first-price auction with independent private values. To see why, recall that risk-neutral bidders shade down their bids in a first-price auction. This increases the chance that some other player outbids them, but risk-neutral bidders are willing to accept this risk because of the greater profits they get if they win. Risk-averse bidders are less willing to accept this risk and therefore shrink their bids by a lower amount. Consequently, with risk-averse bidders and independent private values, the expected revenue of the auctioneer is greatest in first-price and Dutch auctions and lowest in English and second-price auctions:

$$\text{First-price} = \text{Dutch} > \text{Second-price} = \text{English}$$

What happens when risk-averse bidders have affiliated value estimates? Recall that the information revealed in an English auction lessens the winner's curse. This reduction in risk induces risk-averse bidders to bid more aggressively, on average, in an English auction than in a second-price auction. Consequently, the English auction always generates greater expected revenues than a second-price auction. It may, in fact, even generate higher revenues than a first-price or Dutch auction:

$$\text{English} > \text{Second-price} \gtrless \text{First-price} = \text{Dutch}$$

DEMONSTRATION PROBLEM 12–7

Suppose your firm is in need of cash and plans to auction off a subsidiary to the highest bidder. Which type of auction will maximize your firm's revenues from the sale if (1) The bidders are risk neutral and have independent private valuations? (2) The bidders are risk neutral and have affiliated value estimates?

ANSWER:

1. With independent private valuations, all four auction types will lead to identical expected revenues under these conditions.
2. With affiliated value estimates and risk-neutral bidders, the English auction will yield the highest expected revenues.

ANSWERING THE headLINE

The opening headline asked why one of the firms in the FCC auction dropped out of the bidding before the price reached its estimate of $85 million for a license. Since the spectrum rights auction was a common-values auction, or, more generally, an auction with affiliated value estimates, the firm that has the highest private estimate is the firm with the most optimistic estimate of the true value of the license. If firms as a whole form correct expectations of the value, this means that the winner's estimated value is likely to overestimate the true value of a license. In this case, a firm that bids its private estimate would expect to lose money over the 10-year life of the license. To circumvent this winner's curse, the firm correctly dropped out of the bidding before the price reached its private estimate of $85 million.

SUMMARY

In this chapter, we examined some of the complications uncertainty and asymmetric information add to managerial decision making. It should be clear that in many instances, consumers and firms' managers have imperfect information about demand functions, costs, sources of products, and product quality. Decisions are harder to make because the outcomes are uncertain. If your information is probabilistic in nature, you should take the time to find the mean, variance, and standard deviation of outcomes that will result from alternative actions. By doing this, you can use marginal analysis to make optimal decisions.

Consumers and producers have different risk preferences. Some people like to go to the mountains to ski treacherous slopes, while others prefer to sit in the lodge and take in the scenery outside. Similarly, some individuals have a preference for risky prospects, while others are risk averse. If you or the firm you work for has a preference for not taking risks (i.e., is risk averse), you will accept projects with low expected returns, provided the corresponding risk is lower than for projects with higher expected returns. However, if risk taking excites you, you will be willing to take on riskier projects.

Risk structures and the use of the mean, variance, and standard deviation also help identify how customers will respond to uncertain prospects. For example, those individuals who most actively seek insurance and are willing to pay the most for it frequently are bad risks. This results in adverse selection. Moreover, once individuals obtain insurance, they will tend to take fewer precautions to avoid losses than they would otherwise. This creates a moral hazard. Incentive contracts, signaling, and screening can be used to reduce some of the problems associated with asymmetric information.

We also examined how consumers will react to uncertainty about prices or quality through search behavior. Consumers will change their search for quality and "good" prices based on both their perceptions of the probability of finding a better deal and the value of their time. Putting this information to work can help you keep more of your customers. When your customers have a low value of time, you know you will need to lower prices to keep them because their opportunity cost of searching is low.

Finally, we examined auctions, which play a central role in capitalistic economies. We covered four types of auctions: the English auction; the Dutch auction; the first-price, sealed-bid auction; and the second-price, sealed-bid auction. Bidding strategies and expected revenues vary across auction types depending on the type of auction and whether bidders have independent private values or affiliated value estimates.

KEY TERMS AND CONCEPTS

adverse selection
affiliated (or correlated) value estimates
asymmetric information
common value
diversification
Dutch auction
English auction
first-price, sealed-bid auction
free recall
hidden action
hidden characteristics
independent private values
mean (expected value)
moral hazard
perfect information
replacement
reservation price
revenue equivalence
risk
risk averse
risk loving
risk neutral
screening
second-price, sealed-bid auction
self-selection device
signaling
standard deviation
uncertainty
variance
winner's curse

CONCEPTUAL AND COMPUTATIONAL QUESTIONS

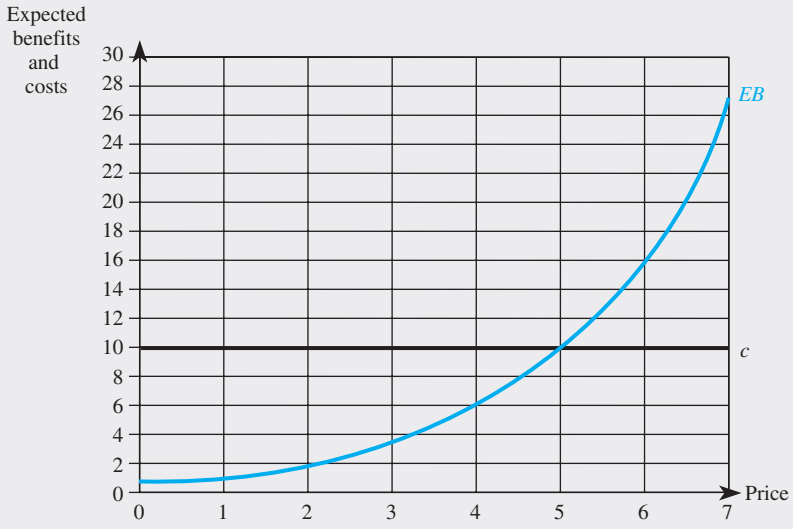


1. Consider the two options in the following table, both of which have random outcomes: *(LO1)*

Option 1		Option 2	
Probability of Outcome	Possible Outcomes ($)	Probability of Outcome	Possible Outcomes ($)
1/16	150	1/5	120
4/16	300	1/5	255
6/16	750	1/5	1,500
4/16	300	1/5	255
1/16	150	1/5	120

a. Determine the expected value of each option.
b. Determine the variance and standard deviation of each option.
c. Which option is most risky?

2. For each of the following scenarios, determine whether the decision maker is risk neutral, risk averse, or risk loving. *(LO1)*
   a. A manager prefers a 20 percent chance of receiving $1,400 and an 80 percent chance of receiving $500 to receiving $680 for sure.
   b. A shareholder prefers receiving $920 with certainty to an 80 percent chance of receiving $1,100 and a 20 percent chance of receiving $200.
   c. A consumer is indifferent between receiving $1,360 for sure and a lottery that pays $2,000 with a 60 percent probability and $400 with a 40 percent probability.
3. Your store sells an item desired by a consumer. The consumer is using an optimal search strategy; the accompanying graph shows the consumer's expected benefits and costs of searching for a lower price. *(LO1)*
   a. What is the consumer's reservation price?
   b. If your price is $3 and the consumer visits your store, will she purchase the item or continue to search? Explain.
   c. Suppose the consumer's cost of each search rises to $16. What is the highest price you can charge and still sell the item to the consumer if she visits your store?
   d. Suppose the consumer's cost of each search falls to $2. If the consumer finds a store charging $3, will she purchase at that price or continue to search?



4. You are the manager of a firm that sells a "commodity" in a market that resembles perfect competition, perfect competition, and your analytics team estimates that your cost function is $C(Q) = 2Q + 3Q^2$. Unfortunately, due to production lags, you must make your output decision prior to knowing for certain the price that will prevail in the market. You believe that there is a 70 percent chance the market price will be $200 and a 30 percent chance it will be $600. *(LO2)*
   a. Calculate the expected market price.
   b. What output should you produce in order to maximize expected profits?
   c. What are your expected profits?
5. A risk-neutral consumer is deciding whether to purchase a homogeneous product from one of two firms. One firm produces an unreliable product and the other a reliable product. At the time of the sale, the consumer is unable to distinguish between the two firms' products. From the consumer's perspective, there is an equal chance that a given firm's

product is reliable or unreliable. The maximum amount this consumer will pay for an unreliable product is $0, while she will pay $60 for a reliable product. *(LO3)*

a. Given this uncertainty, what is the most this consumer will pay to purchase one unit of this product?

b. How much will this consumer be willing to pay for the product if the firm offering the reliable product includes a warranty that will protect the consumer? Explain.



Excel Exercises

6. You are a bidder in an independent private values auction, and you value the object at $3,000. Each bidder perceives that valuations are uniformly distributed between $1,500 and $9,000. Determine your optimal bidding strategy in a first-price, sealed-bid auction when the total number of bidders (including you) is: *(LO4)*
   a. 2.
   b. 10.
   c. 100.
7. You are one of five risk-neutral bidders participating in an independent private values auction. Each bidder perceives that all other bidders' valuations for the item are evenly distributed between $30,000 and $70,000. For each of the following auction types, determine your optimal bidding strategy if you value the item at $45,000. *(LO4)*
   a. First-price, sealed-bid auction.
   b. Dutch auction.
   c. Second-price, sealed-bid auction.
   d. English auction.
8. The text points out that asymmetric information can have deleterious effects on market outcomes. *(LO3)*
   a. Explain how asymmetric information about a hidden action or a hidden characteristic can lead to moral hazard or adverse selection.
   b. Discuss a few tactics that managers can use to overcome these problems.
9. An advertisement in the local paper offers a "fully loaded" car that is only six months old and has only been driven 5,000 miles at a price that is 20 percent lower than the average selling price of a brand new car with the same options. Use precise economic terminology to explain whether this discount most likely reflects a "fantastic deal" or something else. *(LO3)*
10. Life insurance policies typically have clauses stipulating the insurance company will not pay claims arising from suicide for a specified term—typically two years from the date the policy was issued. Use precise economic terminology to explain the likely impact on an insurance company's bottom line if it were to eliminate such a clause. *(LO3)*

PROBLEMS AND APPLICATIONS

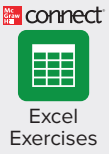


11. The FCC has hired you as a consultant to design an auction to sell wireless spectrum rights. The FCC indicates that its goal of using auctions to sell these spectrum rights is to generate revenue. Since most bidders are large telecommunications companies, you rationally surmise that all participants in the auction are risk neutral. Which auction type—first-price, second-price, English, or Dutch—would you recommend if all bidders value spectrum rights identically but have different estimates of the true underlying value of spectrum rights? Explain. *(LO4)*
12. As the manager of Smith Construction, you need to make a decision on the number of homes to build in a new residential area where you are the only builder. Unfortunately, you must build the homes before you learn how strong demand is for homes in this large neighborhood. There is a 60 percent chance of low demand and a 40 percent chance of high demand. The corresponding (inverse) demand functions for these two

scenarios are $P = 300{,}000 - 400Q$ and $P = 500{,}000 - 275Q$, respectively. Your cost function is $C(Q) = 140{,}000 + 240{,}000Q$. How many new homes should you build, and what profits can you expect? *(LO2)*

13. Life insurance companies require applicants to submit to a physical examination as proof of insurability prior to issuing standard life insurance policies. In contrast, credit card companies offer their customers a type of insurance called "credit life insurance" that pays off the credit card balance if the cardholder dies. Would you expect insurance premiums to be higher (per dollar of death benefits) on standard life or credit life policies? Explain. *(LO3)*
14. BK Books is an online book retailer that also has 10,000 "bricks-and-mortar" outlets worldwide. You are a risk-neutral manager within the Corporate Finance Division and are in dire need of a new financial analyst. You only interview students from the top MBA programs in your area. Thanks to your screening mechanisms and contacts, the students you interview ultimately differ only with respect to the wage that they are willing to accept. About 10 percent of acceptable candidates are willing to accept a salary of $140,000, while 90 percent demand a salary of $190,000. There are two phases to the interview process that every interviewee must go through. Phase 1 is the initial one-hour on-campus interview. All candidates interviewed in Phase 1 are also invited to Phase 2 of the interview, which consists of a five-hour office visit. In all, you spend six hours interviewing each candidate and value this time at $2,500. In addition, it costs a total of $8,000 in travel expenses to interview each candidate. You are very impressed with the first interviewee completing both phases of BK Books's interviewing process, and she has indicated that her reservation salary is $190,000. Should you make her an offer at that salary or continue the interviewing process? Explain. *(LO1)*
15. Congress enacted the Health Insurance Portability and Accountability Act (HIPAA) to potentially help millions of employees gain access to group health insurance. The key provision of HIPAA requires insurance companies and health insurance plans administered by employers who self-insure to provide all employees access to health insurance regardless of previous medical conditions. This provision is known as "guaranteed issue" and is a controversial topic in the insurance industry. Explain why this is controversial legislation. *(LO3)*
16. From the late 1990s through the early 2000s, more than 25 domestic steel companies filed for bankruptcy. A combination of low prices with strong competition by foreign competitors and so-called legacy costs of unions are cited as the primary reasons why so many steel companies filed for bankruptcy. In 2002, as Brownstown Steel Corp. was in the process of restructuring its loans to avoid bankruptcy, its lenders requested that the firm disclose full information about its revenues and costs. Explain why Brownstown's management was reluctant to release this information to its lenders. *(LO3)*
17. This past year, Used Imported Autos sold very few cars and lost over $500,000. As a consequence, its manager is contemplating two strategies to increase its sales volume. The low-cost strategy involves changing the dealership name to Quality Used Imported Autos to signal to customers that the company sells high-quality cars. The high-cost strategy involves issuing a 10-point auto inspection on all used cars on the lot and offering consumers a 30-day warranty on every used car sold. Which of these two strategies do you think would have the greatest impact on sales volume? Explain. *(LO3)*
18. Pelican Point Financial Group's clientele consists of two types of investors. The first type of investor makes many transactions in a given year and has a net worth of over $2.5 million. These investors seek unlimited access to investment consultants and are willing to pay up to $25,000 annually for no-fee-based transactions, or, alternatively, $50 per trade. The other type of investor also has a net worth of over $2.5 million but makes few transactions each year and therefore is willing to pay $130 per trade. As the

manager of Pelican Point Financial Group, you are unable to determine whether any given individual is a high- or low-volume transaction investor. Design a self-selection mechanism that permits you to identify each type of investor. *(LO3)*



19. CPT Inc. is a local manufacturer of conveyor systems. Last year, CPT sold over $2 million worth of conveyor systems that netted the company $100,000 in profits. Raw materials and labor are CPT's biggest expenses. Spending on structural steel alone amounted to over $500,000, or 25 percent of total sales. In an effort to reduce costs, CPT now uses an online procurement procedure that is best described as a first-price, sealed-bid auction. The bidders in these auctions utilize the steel for a wide variety of purposes, ranging from art to skyscrapers. This suggests that bidders value the steel independently, although it is perceived that bidder valuations are evenly distributed between $7,000 and $26,000. You are the purchasing manager at CPT and are bidding on three tons of six-inch hot-rolled channel steel against four other bidders. Your company values the three tons of channel steel at $18,000. What is your optimal bid? *(LO4)*

20. Recently the pharmaceutical company Mylan attempted a hostile takeover of generic drugmaker Perrigo. Perrigo reported a net loss the year before the attempted takeover, which was partially driven by a spike in administrative expenses. Suppose that Mylan perceives there is a 70 percent probability that Perrigo's loss is merely the transitory result of administrative expenses needed to fight the takeover. In this case, the present value of Perrigo's stream of profits is $30 billion. However, Mylan perceives that there is a 30 percent chance that Perrigo's net loss stems from long-term structural changes in the demand for Perrigo's services, and that the present value of its profit stream is only $6 billion. You are a decision maker at Mylan and know that your current takeover bid is $21 billion. You have just learned that a rival bidder—Abbott Laboratories—perceives that there is an 80 percent probability that the present value of Perrigo's stream of profits is $30 billion and a 20 percent probability of it being only $6 billion. Based on this information, should you increase your bid or hold firm to your $21 billion offer? Explain carefully. *(LO4)*

21. You are considering a $500,000 investment in the fast-food industry and have narrowed your choice to either a McDonald's or a Penn Station East Coast Subs franchise. McDonald's indicates that, based on the location where you are proposing to open a new restaurant, there is a 25 percent probability that aggregate 10-year profits (net of the initial investment) will be $16 million, a 50 percent probability that profits will be $8 million, and a 25 percent probability that profits will be −$1.6 million. The aggregate 10-year profit projections (net of the initial investment) for a Penn Station East Coast Subs franchise is $48 million with a 2.5 percent probability, $8 million with a 95 percent probability, and −$48 million with a 2.5 percent probability. Considering both the risk and expected profitability of these two investment opportunities, which is the better investment? Explain carefully. *(LO1)*

22. Online MBA programs significantly reduce the cost to existing managers of obtaining an MBA, as they permit students to maintain their existing residence and employment while working toward an advanced degree in business. Based on your knowledge of the economics of information and student characteristics, compare and contrast the likely characteristics of students enrolled in traditional MBA programs with those enrolled in online MBA programs, and discuss how potential employers might use information about where a candidate obtained his or her MBA degree to screen potential MBA job applicants. *(LO3)*

23. Prosecutors representing the Securities and Exchange Commission recently announced criminal charges against 13 individuals for engaging in insider trading. According to the SEC's director of enforcement, a trading ring acting on inside information "compromises the markets' integrity and investors' trust." Explain why. *(LO3)*

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MODULE GROUP

A

Strategies to Change the Business Environment

INTRODUCTION

In our examination of the quest for profitable business strategies, we have generally taken the business environment (the number of competitors, the timing of decisions, and, more generally, the decisions of rivals) as given and outside the manager's control. The following modules consider various changes in these aspects of the business environment. We identify strategies managers can use to change the business environment in order to enhance the firm's long-run profits. In short, the theme for this group of modules is, "If you don't like the game you're playing, look for strategies to change the game." Even if you have no intention of changing the game, your rivals may attempt to use these strategies against you. It is worthwhile for you to understand them so you are better positioned to protect your company's bottom line.

It is noteworthy upfront that Modules 1 and 2 involve potential tools for reducing the number of competitors and/or lessening competition. As a manager weighs the costs and benefits of such strategies, one of the more important cost considerations is legal in nature: Business tactics that attempt to boost a firm's profits purely by reducing competition may result in the manager and/or the company being sued by one or more antitrust authorities. Antitrust laws are often complex and differ not only across countries but among states or provinces within a given country. A business tactic may be legal at the national level but illegal according to the antitrust laws of a particular state or in a different country. Additionally, different judges sometimes interpret the same antitrust laws differently. Do not underestimate the potential costs of pursuing a strategy that is illegal in even one of the legal jurisdictions in which your company operates or competes. In addition to strong ethical reasons for abiding by federal and state antitrust laws, the potential costs of violating antitrust laws can swamp any profits achieved by the business strategies. These costs include legal fees, fines, adverse effects on a company's reputation, and even the forced breakup of a large company into smaller, independent firms. We provide more discussion of some antitrust issues in Module 5 (in Module Group B).

MODULE 1: ENTRY PREVENTION

LEARNING OBJECTIVE

After completing this module, you will be able to:

LO1 Explain the economic basis for limit pricing, and identify the conditions under which a firm can profit from such a strategy.

Limit Pricing to Prevent Entry

One of the unfortunate consequences of successful management is that it often leads to imitation or entry into the market by other firms. Of course, entry by competitors adversely affects the profits of existing firms. Faced with the threat of entry, a manager might consider a strategy like limit pricing. Limit pricing changes the business environment by reducing the number of competitors.

More formally, **limit pricing** occurs when a monopolist (or other firm with market power) prices below the monopoly price to prevent other firms from entering a market. As we will see, limit pricing is not always a profitable business strategy, and extreme care must be exercised when adopting such a strategy.

limit pricing
Strategy where an incumbent maintains a price below the monopoly level in order to prevent entry.

Theoretical Basis for Limit Pricing

Consider a situation in which a monopolist controls the entire market. The demand curve for the monopolist's product is D^M in Figure M1–1. Monopoly profits are maximized at the price P^M, and monopoly profits are given by π^M. Unfortunately for this incumbent, if a potential entrant were to learn about this profit opportunity and possesses the technological know-how to produce the product at the same cost as the incumbent, the profits enjoyed by the monopolist would be eroded if the potential entrant could profitably enter the market. Entry would move the industry from monopoly to duopoly and reduce the incumbent's profits. Over time, if additional firms entered the market, profits would be further eroded.

One strategy for an incumbent is to charge a price below the monopoly price in an attempt to discourage entry. To see the potential merits of this strategy, suppose for the moment that the entrant's costs are identical to those of the incumbent and that the entrant has complete information about the incumbent's costs as well as the demand for the product. In other words, imagine that the potential entrant knows all the information enjoyed by the incumbent.

To limit price, the incumbent produces Q^L (which exceeds the monopoly output of Q^M) and charges a price P^L that is lower than the monopoly price. This situation is shown in

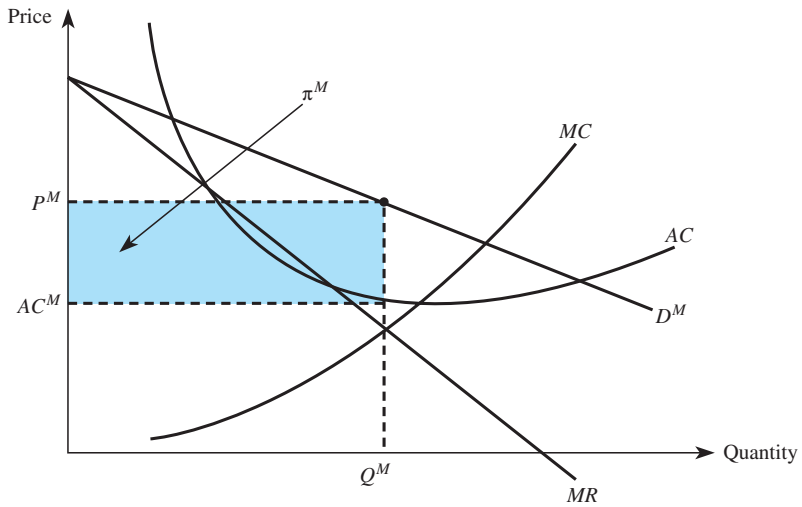


Figure M1–1
Monopoly Pricing

Figure M1–2

Limit Pricing and Residual Demand

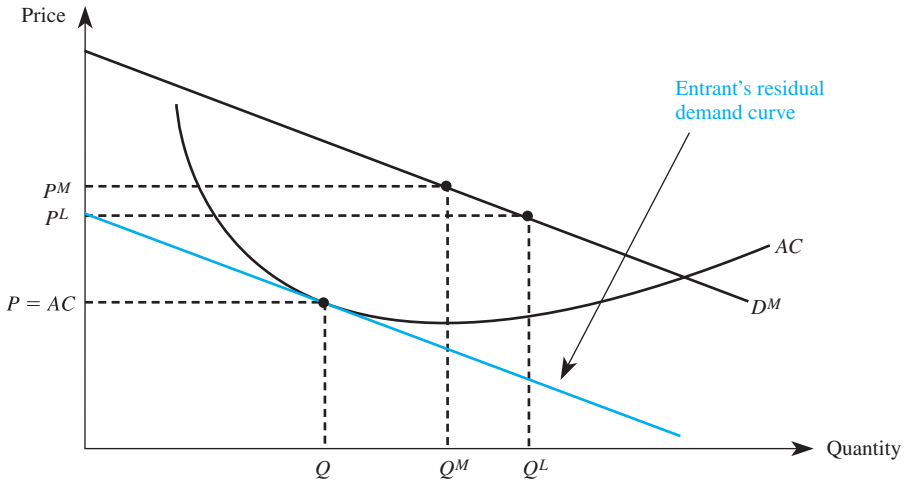


Figure M1–2. If the potential entrant believes the incumbent will continue to produce Q^L units of output if it enters the market, then the *residual demand* for the entrant's product is simply the market demand, D^M, minus the amount (Q^L) produced by the incumbent. This difference, $D^M - Q^L$, is the entrant's residual demand curve and is sketched in Figure M1–2. The entrant's residual demand curve starts out at a price of P^L (since $D^M - Q^L$ is zero at this price). For each price below P^L, the horizontal distance between the entrant's residual demand curve and the monopolist's demand curve is Q^L at each price.

Since the entrant's residual demand curve in Figure M1–2 lies below the average cost curve, entry is not profitable. To see this, note that the entrant loses money if it enters and produces more output or less output than Q units. By entering and producing exactly Q units, total market output increases to $Q + Q^L$. This pushes the price down to the point where $P = AC$ for the entrant, so its economic profits are zero. Thus, the entrant cannot earn positive profits by entering the market. Furthermore, if entry involves any extra costs whatsoever (even one cent), the entrant will have a strict incentive to stay out of this market. Thus, limit pricing prevents entry and the incumbent earns higher profits than those earned in the presence of entry (but profits under limit pricing are lower than if it were an uncontested monopoly).

Limit Pricing May Fail to Deter Entry

Now that you understand the basic rationale for limit pricing, let's take a more critical look at this strategy. In our example, the potential entrant was assumed to have complete information about demand and costs, so the strategy of limit pricing did not "hide" anything about the profitability of the incumbent's line of business. In fact, the low price charged by the incumbent played no real role in preventing entry: The entrant opted to stay out because it believed the incumbent would produce at least Q^L units if it entered.

In light of this observation, a better strategy for the incumbent would be to charge the monopoly price (P^M) and produce the monopoly output (Q^M), but threaten to expand output to Q^L if entry occurs. If the potential entrant believes this threat and stays out of the market, the incumbent will earn higher profits from this strategy than under limit pricing. Unfortunately, it is not credible for the incumbent to produce an output of Q^L if entry occurs. In particular, entry reduces the incumbent's marginal revenue, leading to an optimal output that is less than Q^L. Thus, the incumbent has an incentive to renege on its threat to produce Q^L if entry occurs.

Recognizing this, a rational entrant would find it profitable to enter the market if the incumbent sets its price at P^L.

In order to actually prevent entry, the incumbent must engage in an activity that lowers the postentry profits of the entrant. In the simple example considered here, postentry profits are completely independent of the preentry price charged by the incumbent. This, coupled with the fact that the "threat" to maintain output at Q^L in the face of entry is not credible, means that limit pricing will not protect an incumbent's profits unless other factors are present that link preentry prices to postentry profits.

Effective Limit Pricing

For limit pricing to effectively prevent entry by rational competitors, the preentry price must be linked to the postentry profits of potential entrants. PRINCIPLE

Linking the Preentry Price to Postentry Profits

In many real-world business settings, the preentry price may be linked to postentry profits through commitments made by incumbents, learning curve effects, incomplete information, or reputation effects. As discussed next, limit pricing may be profitable if one or more of these conditions are met, but care must be taken in evaluating the dynamic effects of limit pricing to ensure that deterring entry is actually the best strategy.

Commitment Mechanisms

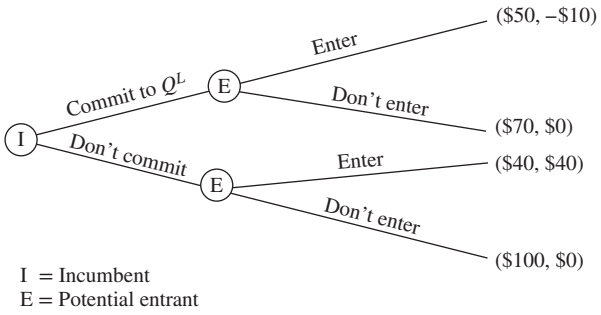
Returning to the example in Figure M1−2, the preentry price is not linked to postentry profits because rational entrants recognize that the incumbent does not have an incentive to maintain a postentry output of Q^L. The incumbent can overcome this problem by committing to produce at least Q^L units of output. More specifically, if the incumbent can somehow "tie its own hands" and credibly commit to not reducing output in the face of entry—and if this commitment is known by the potential entrant—then the strategy will indeed block entry.

The incumbent might make such a commitment by building a plant that is incapable of producing less than Q^L units of output. In this case, the incumbent may be able to produce more than Q^L units; the key is that all potential entrants know it cannot produce *less* than this amount. The incumbent can then set its price at P^L (which corresponds to the output Q^L), so that the preentry price is linked (through Q^L) to the postentry profits of the entrant. Since entrants realize that the incumbent will continue to produce at least Q^L units of output after entry, their residual demand curve lies below average costs. Therefore, it is not profitable for potential entrants to enter the market.

It may seem strange that the incumbent earns higher profits by "tying its hands" and committing to produce at least Q^L instead of maintaining the flexibility to adjust output as it sees fit should entry occur. To better understand why *commitment* is a profitable strategy, consider the extensive-form representation of the entry game presented in Figure M1–3. Here, the incumbent has a first-mover advantage that permits it to decide whether to (1) commit by building a plant that is incapable of producing less than Q^L units of output or (2) not commit by building a plant that can produce any range of output. Once this decision is made, the entrant decides to enter or not, given the decision of the incumbent. The payoffs in parentheses represent the profits the incumbent and entrant earn, respectively, in each possible scenario. For instance, if the incumbent does not commit to Q^L and the potential entrant does not enter, then the incumbent earns profits of $100 (the monopoly profits) and the potential entrant earns $0.

Figure M1–3

The Value of Commitment



Notice in Figure M1–3 that the monopoly payoff of $100 is the highest possible payoff for the incumbent. However, any attempt by the incumbent to realize this payoff (by not committing to Q^L) provides the entrant an incentive to enter since entry nets the entrant $40 instead of the $0 earned by not entering. Thus, we see that if the incumbent does not commit, it will earn $40 instead of the monopoly profits of $100 because it will end up sharing the market with the other firm.

In contrast, if the incumbent commits to produce Q^L, it alters the incentives confronting the potential entrant in a way that favorably changes the business environment. More specifically, commitment changes the postentry payoffs of the entrant and makes entry an unprofitable strategy. To see this, suppose the incumbent makes an irreversible decision to commit to produce Q^L. The potential entrant now earns a payoff of −$10 if it enters and $0 if it stays out of the market. In this case, the rational strategy by the entrant is not to enter since this is better than the $10 loss that will occur if it enters the market. In the vernacular of game theory, the unique subgame perfect Nash equilibrium for the game in Figure M1–3 results in no entry; the incumbent earns an equilibrium payoff of $70 by committing to produce Q^L. While the incumbent's payoff is lower than the monopoly payoff of $100 (which cannot be achieved in equilibrium), it is greater than the $40 payoff that would have been earned absent commitment by the incumbent.

How might a firm commit to such a strategy? Suppose Applebee's is the first mid-priced restaurant to open in a small town and wishes to prevent entry by a rival. One way to do this is to build a restaurant that is relatively large. Once the restaurant is built, and the number of tables is set, Applebee's has a strong incentive to price in a way that fills all the tables with customers. Observing this, potential entrants (e.g., Chili's) will see that Applebee's is committed to a low-price, high-volume strategy in this particular town. If this reduces Chili's residual demand curve enough, it will discourage Chili's from entering this market.

Learning Curve Effects

In some production processes, the cost of producing a good or service depends on the firm's level of experience. Firms with greater historical levels of output have more experience and can produce more efficiently than firms with little or no past experience in producing the good. These effects are known as **learning curve effects**.

learning curve effects
When a firm enjoys lower costs due to knowledge gained from its past production decisions.

Learning curve effects provide a link between the preentry price and postentry profits and therefore may permit an incumbent to use limit pricing to block entry. To be concrete, consider an incumbent who has a one-period jump on a potential entrant. This first-mover advantage permits the incumbent to produce and sell output for one period before the entrant has a chance to enter the market. In this case, the incumbent may find it profitable to produce more than the monopoly output in the first period. Doing so leads to lower first-period profits, but

this extra output gives the firm more experience and therefore permits it to produce in the second period at a lower cost. If these learning curve effects are sufficiently strong, this cost advantage may induce the potential entrant to stay out of the market. Notice that by producing more output in the first period, the incumbent drives down the first-period price. Since this lower price is linked to postentry profits (through output and the learning curve effect), this form of limit pricing can be effective in discouraging entry.

Incomplete Information

The assumption that the entrant and incumbent enjoy complete information is clearly not applicable in all situations. It is usually costly for entrepreneurs and other potential entrants to find profitable business opportunities. To the extent that preentry prices or profits are a signal that lowers potential entrants' costs of identifying profitable opportunities, a link between price and postentry profits may be forged. Limit pricing may help "hide" information about profits from potential entrants, and this may delay or (in rare cases) completely eliminate entry, depending on how costly it is for potential entrants to obtain information from other sources.

To be concrete, imagine a small town with one attorney who is a monopolist in the local market for legal services. In the absence of entry, the attorney is able to earn a handsome salary of $500,000 per year. If the attorney has an impressive collection of sports cars and regularly travels to exotic places (because she charges the monopoly price), hometown kids who graduate from law school may decide to come back home to get a piece of this action. On the other hand, if the attorney lives a more modest lifestyle (because she charges less than the monopoly price), she is less likely to attract such attention. In this latter case, the attorney is practicing limit pricing in an attempt to "hide" information from potential entrants. To the extent that this tactic makes it more costly for new graduates from law school to recognize the excellent profit opportunities in this small town, the strategy may delay or eliminate entry.

Alternatively, consider a situation in which the potential entrant does not know for certain the incumbent's costs. If the potential entrant knows that the incumbent has high costs, it will find it profitable to enter the market. If the potential entrant knows the incumbent's costs are low, on the other hand, it will find the market unprofitable to enter. If the entrant does not know the incumbent's costs, it has an incentive to use whatever information is available to infer the incumbent's costs. For instance, when the incumbent charges a low price, the entrant might infer that costs are low and conclude that it does not pay to enter the market. In situations such as these, the incumbent may be able to induce the potential entrant to stay out of the market by pricing below the monopoly price. In this case, there is a link between the preentry price and postentry profits, and limit pricing can be used to profitably deter entry.

Reputation Effects

We learned in Chapter 10 that incentives in one-shot games are different from those in repeated games. In games that are indefinitely repeated, trigger strategies link the past behavior of players to future payoffs. In the context of entry, such *reputation effects* can provide a link between the preentry price charged in a market and postentry profits. Permitting entry today is likely to encourage entry in future periods by other potential entrants. Depending on the relative costs and benefits of future entry, it may pay for a firm to invest in a reputation for being "tough" on entrants in order to deter future entry by other firms. To the extent that charging a low price today (to punish an entrant) discourages entry by other firms, such a strategy may increase long-run profits.

Dynamic Considerations

Even if the incumbent can forge a link between the preentry price and postentry profits to prevent entry, it may earn higher profits by allowing entry to occur. To see this, recall that when the interest rate is i and π^M represents the current profits a monopolist earns by charging P^M, the present value of current and future profits if the firm maintains its monopoly status indefinitely is

$$\begin{aligned}\Pi^M &= \pi^M + \left(\frac{1}{1+i}\right)\pi^M + \left(\frac{1}{1+i}\right)^2\pi^M + \left(\frac{1}{1+i}\right)^3\pi^M + \cdots \\ &= \left(\frac{1+i}{i}\right)\pi^M\end{aligned}$$

Suppose that, upon observing the current period price (P^M), a new entrant decides to enter the market to compete with the (incumbent) monopolist. Entry fosters competition in the product market during the second and following periods, and this reduces the incumbent's profits from the monopoly level (π^M) to the duopoly level (π^D). While different oligopoly settings will lead to different duopoly profits, in all cases the duopoly profits are less than those enjoyed under monopoly: $\pi^D < \pi^M$. If entry occurs, the present value of the incumbent's current and future profits falls to

$$\begin{aligned}\Pi^{MD} &= \pi^M + \left(\frac{1}{1+i}\right)\pi^D + \left(\frac{1}{1+i}\right)^2\pi^D + \left(\frac{1}{1+i}\right)^3\pi^D + \cdots \\ &= \pi^M + \frac{\pi^D}{i}\end{aligned}$$

In particular, the incumbent earns the monopoly profit during the first period, but this induces entry—which reduces profits to π^D in all remaining periods. The term π^D/i reflects the present value of the perpetuity of duopoly profits. It is clear that $\Pi^{MD} < \Pi^M$, so entry harms the incumbent.

Suppose that (through commitment, learning curve effects, incomplete information, or reputation effects) the incumbent can successfully thwart entry by charging a limit price. Is such a strategy profitable? Under the limit pricing strategy, the incumbent earns profits of π^L during each period, where $\pi^L < \pi^M$. Thus, under limit pricing, the present value of the firm's profit stream is

$$\begin{aligned}\Pi^L &= \pi^L + \left(\frac{1}{1+i}\right)\pi^L + \left(\frac{1}{1+i}\right)^2\pi^L + \left(\frac{1}{1+i}\right)^3\pi^L + \cdots \\ &= \left(\frac{1+i}{i}\right)\pi^L\end{aligned}$$

A necessary condition for limit pricing to be an optimal strategy is for the present value of profits under limit pricing to exceed those under entry: $\Pi^L > \Pi^{MD}$. Rearranging the previous equations for Π^L and Π^{MD} reveals that limit pricing is profitable ($\Pi^L > \Pi^{MD}$) whenever

$$\frac{(\pi^L - \pi^D)}{i} > \pi^M - \pi^L$$

The left-hand side of this inequality represents the present value of the benefits of limit pricing, and the right-hand side represents the up-front costs of limit pricing. Notice that a necessary condition for profitable limit pricing is for the per-period profits under limit pricing (π^L) to

exceed the per-period duopoly profits (π^D). However, this alone is not enough to warrant limit pricing. In addition, the present value of these benefits must exceed the up-front costs of generating the profit stream. In this case, the up-front cost is the profit forgone by limit pricing in the first period rather than charging the monopoly price.

Based on this analysis, it is clear that limit pricing is more attractive in situations where (1) the interest rate is low, (2) profits under the limit price are close to the monopoly price, and (3) duopoly profits are significantly lower than profits under the limit price. Absent these conditions, it will not be in a firm's best interest to fight entry by limit pricing. When a firm faces entrants but opts against limit pricing, its price will gradually decline over time as more and more firms enter the market.

DEMONSTRATION PROBLEM M1–1

For a video walkthrough of this problem, visit www.mhhe.com/baye10e

Baker Enterprises operates a midsized company that specializes in the production of a unique type of memory chip. It is currently the only firm in the market, and it earns $10 million per year by charging the monopoly price of $115 per chip. Baker is concerned that a new firm might soon attempt to clone its product. If successful, this would reduce Baker's profit to $4 million per year. Estimates indicate that, if Baker increases its output to 280,000 units (which would lower its price to $100 per chip), the entrant will stay out of the market and Baker will earn profits of $8 million per year for the indefinite future.

1. What must Baker do to credibly deter entry by limit pricing?
2. Does it make sense for Baker to limit price if the interest rate is 10 percent?

ANSWER:

1. Baker must "tie its hands" to prevent itself from cutting output below 280,000 units if entry occurs, and this commitment must be observable to potential entrants before they make their decision to enter or not enter.
2. Limit pricing is profitable if

$$\frac{(\pi^L - \pi^D)}{i} > \pi^M - \pi^L$$

or, in this case,

$$\frac{(\$8 - \$4)}{0.1} > \$10 - \$8$$

Since this inequality holds, limit pricing is profitable: The present value of the benefits of limit pricing (the left-hand side) is $40 million, while the up-front costs (the right-hand side) are only $2 million.

INSIDE BUSINESS M1–1

Limit Pricing and the "Southwest Effect"

In 1993, a Department of Transportation study noted what became well known as the "Southwest Effect." The study noted that pricing patterns on many short-haul routes could be attributed to the presence of Southwest Airlines on the route, or merely the presence of Southwest Airlines in the airports on each end of the route. The second component of the Southwest Effect—its presence at both endpoint airports—comes from Southwest posing a threat on the route. For example, if Southwest already flies routes out of Chicago and Atlanta, but not yet the Chicago–Atlanta route, it poses an imminent threat to start flying Chicago–Atlanta since it could do so without having to enter a new airport.

Why are prices also lower on these sorts of routes that Southwest threatens? Researchers Andrew Sweeting, James Roberts, and Chris Gedge argue that lower prices on threatened routes are due to limit pricing by rivals in markets with incomplete information. Specifically, the potential entrant (Southwest) does not know the incumbent airlines' costs. Therefore, by setting low prices, the incumbents may effectively signal to Southwest that their costs are low and that entry is unlikely to be profitable. Thus, Southwest's presence lowers price not only on its routes, but may lower prices on routes it does not currently serve.

SOURCES: A. Sweeting, J. Roberts, and C. Gedge, "A Model of Dynamic Limit Pricing with an Application to the Airline Industry," NBER working paper (2016); R.D. Bennett and J.M. Craun, *The Airline Deregulation Evolution Continues: The Southwest Effect* (Office of Aviation Analysis, U.S. Department of Transportation, Washington, DC, 1993).

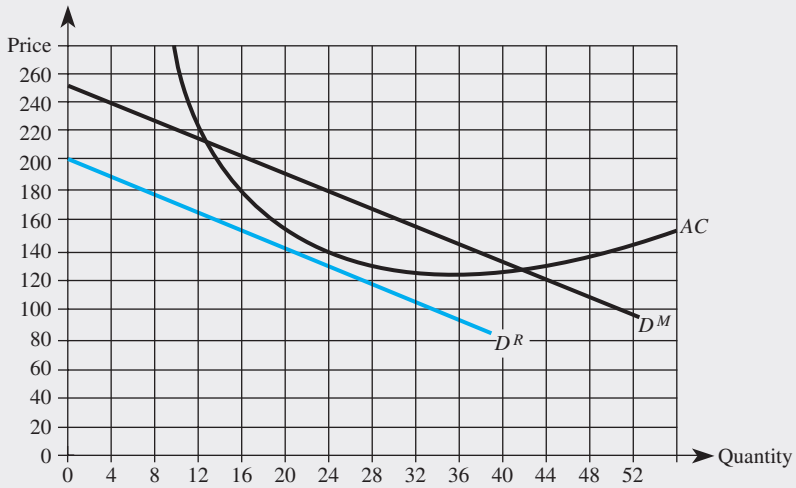
KEY TERMS AND CONCEPTS

commitment
learning curve effects
limit pricing
reputation effects
residual demand

PRACTICE PROBLEMS



1. A potential entrant can produce at the same cost as the monopolist illustrated in the accompanying figure. The monopolist's demand curve is given by D^M, and its average cost curve is AC. *(LO1)*
   a. What level of output does the monopolist have to produce in order for the entrant to face the residual demand curve, D^R?
   b. How much profit will the monopolist earn if it commits to the output that generates the residual demand curve, D^R?
   c. Can the monopolist profitably deter entry by committing to a different level of output? Explain.



2. A monopolist earns $30 million annually and will maintain that level of profit indefinitely, provided that no other firm enters the market. However, if another firm enters the market, the monopolist will earn $30 million in the current period and $15 million annually thereafter. The opportunity cost of funds is 10 percent, and profits in each period are realized at the beginning of each period. *(LO1)*
   a. What is the present value of the monopolist's current and future earnings if entry occurs?
   b. If the monopolist can earn $16 million indefinitely by limit pricing, should it do so? Explain.
3. Suppose that, prior to other firms entering the market, the maker of a new smartphone (Way Cool Inc.) earns $80 million per year. By reducing its price by 60 percent, Way Cool could discourage entry into "its" market, but doing so would cause its profits to sink to −$2 million. By pricing such that other firms would be able to enter the market, Way Cool's profits would drop to $30 million for the indefinite future. In light of these estimates, do you think it is profitable for Way Cool to engage in limit pricing? Is any additional information needed to formulate an answer to this question? Explain. *(LO1)*
4. Barnacle Industries was awarded a patent over 15 years ago for a unique industrial-strength cleaner that removes barnacles and other particles from the hulls of ships. Thanks to its monopoly position, Barnacle has earned more than $160 million over the past decade. Its customers—spanning the gamut from cruise lines to freighters—use the product because it reduces their fuel bills. The annual (inverse) demand function for Barnacle's product is given by $P = 400 - 0.0005Q$, and Barnacle's cost function is given by $C(Q) = 250Q$. Thanks to subsidies stemming from an energy bill passed by Congress nearly two decades ago, Barnacle does not have any fixed costs: The federal government essentially pays for the plant and capital equipment required to make this energy-saving product. Absent this subsidy, Barnacle's fixed costs would be about $4 million annually. Knowing that the company's patent will soon expire, Marge, Barnacle's manager, is concerned that entrants will qualify for the subsidy, enter the market, and produce a perfect substitute at an identical cost. With interest rates at 7 percent, Marge is considering a limit-pricing strategy. Would Marge's company be better off if she pursues a limit-pricing strategy with the subsidy or lobbying to reduce the subsidy and producing at the monopoly level? Explain. *(LO1)*
5. Discuss how price discrimination can enhance the effectiveness of a limit pricing strategy. *(LO1)*

MODULE 2: LESSENING COMPETITION

LEARNING OBJECTIVES

After completing this module, you will be able to:

- **LO1** Explain the economic basis for predatory pricing.
- **LO2** Show how a manager can profitably lessen competition by raising rivals' costs.
- **LO3** Identify some of the adverse legal ramifications of business strategies designed to lessen competition.

Predatory Pricing

predatory pricing
Strategy where a firm temporarily prices below its marginal cost to drive competitors out of the market.

While limit pricing changes the business environment by preventing *potential* competitors from entering a market, predatory pricing lessens competition by eliminating *existing* competitors. More formally, **predatory pricing** arises when a firm charges a price below its own marginal cost in order to drive a rival out of business. Once the "prey" (the rival) leaves the market, the "predator" (the firm engaging in predatory pricing) can raise its price to a higher level, thanks to the dampened competition. Thus, predatory pricing involves a trade-off between current and future profits: It is profitable only when the present value of the higher future profits offsets the losses required to drive rivals out of the market.

Since predatory pricing hurts not only the prey but also the predator, its success critically depends on the presumption that the predator is "healthier" than the prey. A firm engaging in predatory pricing must have "deeper pockets" (greater financial resources) than the prey in order to outlast it. Reputation effects enhance the benefits of predatory pricing. Taking tough actions today to drive a competitor out of the market may, in a repeated-play context, make it easier to drive future competitors out of the market. Establishing a reputation for playing tough against existing firms may induce other firms to stay out of the market. It may also provide smaller rivals an incentive to "sell out" to a large firm at a bargain price rather than risk being driven out of the market through predation.

A number of counterstrategies on the part of the prey can significantly reduce the profitability of predatory pricing. Since the predator is selling the product below its own cost, the prey might stop production entirely (in which case the predator will lose more money each period than the prey) or purchase the product from the predator and stockpile it to sell when predatory pricing ceases. The point is that a strategy of predatory pricing is typically more costly for the predator than for the prey. It is unlikely to be a profitable way of eliminating a rival that is similarly situated (in terms of size, costs, financial resources, and product appeal), but it can be successful in driving a small competitor (with "empty pockets") out of the market.

While businesses engaging in predatory pricing are vulnerable to prosecution under the Sherman Antitrust Act, predatory pricing is often difficult to prove in court. For example, in the early 2000s, American Airlines successfully defended itself against a charge from the Antitrust Division of the U.S. Department of Justice that it sought to drive small, start-up airlines out of Dallas/Ft. Worth International Airport by saturating its routes with additional flights and cutting fares. Even though the government alleged American Airlines raised fares after successfully driving out a new entrant, American Airlines prevailed at trial.

Many economists (and judges) believe that a number of practices that might be deemed "predatory" under legal definitions are, in fact, legitimate business practices. Entry generally heightens competition and results in more competitive pricing. In situations where there are substantial fixed costs, the end result of fierce price competition will be the departure of the weakest firms, and the surviving firm will raise its price. Efforts to prevent such competition would encourage entry by inefficient firms. Even worse, strict enforcement of rules against predatory pricing could lead to a collusive situation in which firms would be afraid to compete because such actions might be construed as predatory and lead to prosecution.

In addition, firms attempting to penetrate a market with a new product often find it advantageous to sell the product at a low price or even give it away for free initially, raising the price once consumers become aware of the product's value. As we will see toward the end of this chapter, the strategy of selling products below cost need not be motivated by a desire to drive rivals out of business. Quite to the contrary, such strategies are sometimes essential for new entrants to successfully compete against well-established firms.

We conclude by noting that the technical (legal) definition of predatory pricing requires the predator to price below its own marginal cost (and thus sustain losses in order to inflict damage on its prey). However, similar strategies can be used when the predator has a cost advantage over its prey. In this case, the predator does not have to price below its own marginal cost in order to drive a less efficient rival out of the market; it merely needs to set its price below the rival's cost. Similar to predatory pricing, the more efficient firm can raise its price after the less efficient firm exits the market.

DEMONSTRATION PROBLEM M2–1

Baker Enterprises operates a midsized company that specializes in the production of a fairly unique type of memory chip. If Baker were a monopolist, it could earn $10 million per year for an indefinite period of time by charging the monopoly price of $115 per chip. While Baker could have thwarted the entry of potential rivals by limit pricing (see Demonstration Problem M1–1), it opted against doing so, and it is now in a duopoly situation, earning annual profits of $4 million per year for the foreseeable future. If Baker drops its price to $68 per chip and holds it there for one year, it will be able to drive the other firm out of the market and retain its monopoly position indefinitely. Over the year in which it engages in predatory pricing, however, Baker will lose $60 million. Ignoring legal considerations, is predatory pricing a profitable strategy? Assume that the interest rate is 10 percent and, for simplicity, that any current period profits or losses occur immediately (at the beginning of the year).

ANSWER:

If Baker does not engage in predatory pricing, the present value of its earnings (including its current $4 million in earnings) will be Π^D, where

$$\begin{aligned}\Pi^D &= \$4 + \left(\frac{1}{1+0.1}\right)(\$4) + \left(\frac{1}{1+0.1}\right)^2(\$4) + \left(\frac{1}{1+0.1}\right)^3(\$4) + \cdots \\ &= \left(\frac{1+0.1}{0.1}\right)(\$4) \\ &= (11)(\$4) \\ &= \$44 \text{ million}\end{aligned}$$

If Baker uses predatory pricing, the present value of its current and future profits will be

$$\begin{aligned}\Pi^P &= -\$60 + \left(\frac{1}{1+0.1}\right)(\$10) + \left(\frac{1}{1+0.1}\right)^2(\$10) + \left(\frac{1}{1+0.1}\right)^3(\$10) + \cdots \\ &= -\$60 + \frac{\$10}{0.1} \\ &= -\$60 + \$100 \\ &= \$40 \text{ million}\end{aligned}$$

Since $\Pi^P < \Pi^D$, Baker earns less by engaging in predatory pricing than it does by not using predatory pricing (that is, maintaining its duopoly situation). It does not pay to use predatory pricing because it costs too much to drive the other firm out of the market.

INSIDE BUSINESS M2–1

Justice Department Uses a Page from Its Microsoft Playbook against Google

On October 20, 2020, the U.S. Department of Justice filed suit against Google under sections 1 and 2 of the Sherman Antitrust Act. The government's allegations are similar to allegations it levied against Microsoft two decades earlier. At the time, Microsoft was the world's largest supplier of computer software for personal computers. The government alleged that Microsoft employed a number of anticompetitive business strategies, including tying other Microsoft software products to Microsoft's Windows operating system; exclusionary agreements precluding companies from distributing, promoting, buying, or using products of Microsoft's software competitors or potential competitors; and exclusionary agreements restricting the right of companies to provide services or resources to Microsoft's software competitors or potential competitors.

According to the government, Netscape enjoyed a 70 to 80 percent share of the Internet browser market during the early 1990s. Microsoft invested hundreds of millions of dollars to develop, test, and promote Internet Explorer, but it faced the serious challenge of getting consumers to switch from Netscape Navigator to Internet Explorer. According to the government, a top executive at Microsoft—its vice president of the Platforms Group—summarized the company's strategy thusly: "We are going to cut off their air supply. Everything they're selling, we're going to give away for free." The government also alleged that Bill Gates made threats to Netscape and said, "Our business model works even if all Internet software is free . . . We are still selling operating systems. What does Netscape's business model look like? Not very good."

A lot has happened since then. Microsoft lost the suit; Netscape merged with America Online; America Online later merged with Time Warner, only to spin off again in 2009. And, in January of 2009, the European Commission ruled that Microsoft's practice of tying its browser to its operating system was illegal under European Union antitrust laws. Ultimately, Microsoft's strategy clearly strengthened its position against Netscape and other Internet browsers, but at the expense of many hundreds of millions of dollars in legal fees and lost rulings. While the U.S. Department of Justice is repeating a page from its 1998 playbook, it is unclear whether courts will do likewise and side with it in the 2020 Google case.

SOURCES: Antitrust Complaint: United States of America v. Google, October 20, 2020. N. Economides and I. Lianos, "The Elusive Antitrust Standard on Bundling in Europe and the United States in the Aftermath of the Microsoft Cases," *Antitrust Law Journal* 76, no. 3 (2009); Robert Wielaard, "EU: Microsoft Must Unbundle Browser," Associated Press, January 17, 2009; "AOL Time Warner to Drop 'AOL' from Corporate Name," *The Wall Street Journal*, September 11, 2003; *The Wall Street Journal Online Edition*, Front Page, October 9, 2001; Antitrust Complaint: *United States of America v. Microsoft Corporation*, May 18, 1998.

Raising Rivals' Costs

raising rivals' costs
Strategy in which a firm gains an advantage over competitors by increasing their costs.

Another way a manager may be able to profitably change the business environment is by **raising rivals' costs**. By increasing rivals' costs, a firm distorts rivals' decision-making incentives, and this can ultimately affect their prices, output, and entry decisions. Provided the costs of implementing such a strategy are sufficiently low, the firm that raises rivals' costs may gain at the expense of other firms.

For instance, consider a large software manufacturer that is the sole producer of the most popular operating system. This firm also has a presence in other software markets; it competes against smaller rivals who sell different brands of word processing software. The large software maker might attempt to raise the costs of rivals who produce competing word processing software by making it difficult for them to access the operating system's code. In extreme cases, the large firm might refuse to release the operating system's code to firms that compete in other software markets. In both cases, this increases the cost to rivals of creating and updating their own word processing software, with little or no increase in the large firm's costs. In addition to increasing the rivals' fixed cost of producing software, this strategy may also increase the rivals' marginal cost of marketing their software, as customers are more likely to require their technical support to resolve conflicts and other problems.

A firm can also raise its rivals' costs by making it more costly for other firms to distribute their products through the retail chain. For instance, in the famous Microsoft case, the government alleged that Microsoft entered into exclusive contracts with PC suppliers, precluding them from loading Netscape's Internet browser on PCs loaded with the Windows operating system. This strategy presumably raised Netscape's cost of distributing its browser software relative to Microsoft's cost of distributing its own browser.

Strategies Involving Marginal Cost

To illustrate how a firm can gain by raising a rival's marginal cost, consider Figure M2–1, which shows a Cournot duopoly (see Chapter 9). Recall that r_1 and r_2 are the reaction functions of the two competing firms. The firms produce outputs of Q_1 and Q_2, and the reaction functions summarize each firm's profit-maximizing output given the output produced by the rival. For example, r_1 identifies the profit-maximizing output of firm 1 for each potential level of output by firm 2. These reaction functions are downward sloping because each firm produces its output simultaneously, and the market price adjusts to clear whatever output is brought to market. The greater the amount of output firm 2 brings to market, the lower the resulting market price and thus the lower the optimal output of firm 1.

Point A in Figure M2–1 represents the initial Cournot equilibrium. Firm 1's profits are π_1^A and are associated with the isoprofit curve through point A. These profits are clearly lower than the profits that would result if firm 1 were a monopolist (the point where firm 1 produces Q_1^M units of output and firm 2 produces zero units of output).

Now suppose that firm 1 uses a business tactic that raises its rival's marginal cost of production. Due to the higher cost, firm 2 now has an incentive to produce less output than before. Geometrically, by raising its rival's marginal cost, firm 1 shifts its rival's reaction function down to r_2^* in Figure M2–1. The new equilibrium moves to point B. Due to its higher marginal cost, firm 2 reduces its output. This has the effect of raising the market price, and firm 1 takes advantage of this higher price by expanding its own output. Ultimately, firm 1 ends up with more market share and higher profits. In particular, notice that firm 1's profits at point B are π_1^B. Since this level of profits is associated with an isoprofit curve that is closer to the monopoly point, firm 1 has benefited by raising its rival's marginal cost.

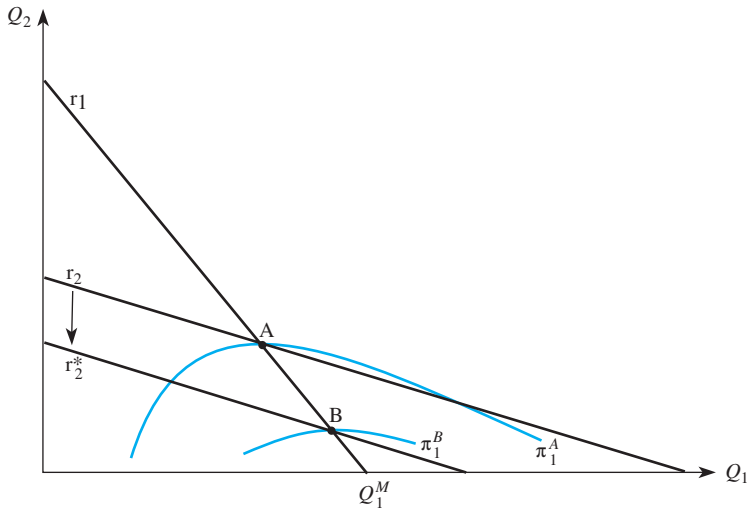


Figure M2–1
Raising a Rival's Marginal Cost

Strategies Involving Fixed Costs

A firm may also gain by raising its rivals' fixed costs. Perhaps surprisingly, such benefits may accrue to a firm even when the strategy also raises the firm's own costs. To see this, consider an incumbent that earns monopoly profits of $200 if no other firms enter the market. However, if a rival enters the market, the competition that ensues reduces the incumbent's profit to $70, with the entrant also earning $70. Since the entrant earns zero if it does not enter but earns $70 by entering, the monopolist will be unable to sustain its monopoly profit unless it can successfully change the business environment.

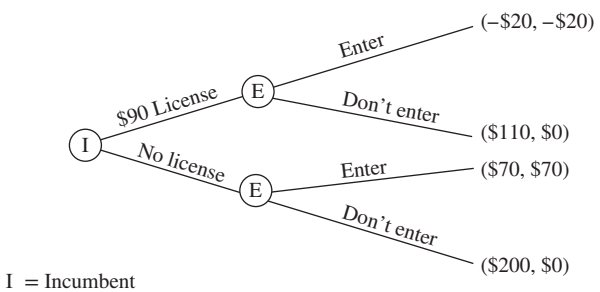
Suppose the incumbent successfully lobbies for a regulation requiring any firm operating in the market (including itself) to obtain a license from the government that costs $90. Notice that the incumbent has raised its own fixed costs by $90, but more importantly, it also has raised its rival's costs by $90. Now if the rival enters the market it loses $20 (the original $70 less the $90 license fee). Since the rival earns $0 by not entering, this strategy of raising all firms' costs by $90 changes the rival's entry decision, and the incumbent maintains its monopoly position. Notice that the resulting profits of the incumbent are $110 (the original $200 monopoly profit less the $90 license fee). While this is not as profitable as before the license was required and the firm enjoyed a monopoly ($200), it is better than the $70 that would be earned if no license was required and the rival entered.

This scenario is depicted in the extensive form shown in Figure M2–2. Here, the incumbent has two strategies: support a $90 license fee or do not support it. The potential entrant gets to observe whether there is a license fee before making its entry decision. In the absence of a license fee, the entrant has an incentive to enter and thus the incumbent earns profits of only $70. If the incumbent supports the $90 license fee, the entrant's best strategy is to stay out of the market (since $0 > −$20). In this case the incumbent earns $110. This is clearly the best strategy for the incumbent, and we see that the incumbent earns $110 in the unique subgame perfect equilibrium to this game.

Strategies for Vertically Integrated Firms

In Chapter 6 we learned that vertically integrated firms produce in both the upstream (input) market and the downstream (output) market. A vertically integrated firm with market power in an upstream market may be able to exploit this market power in order to raise rivals' costs in downstream markets. In particular, actions taken by the vertically integrated firm to increase input prices in the upstream market will increase the costs of rivals competing in downstream markets. In what follows, we discuss two strategies of this sort: vertical foreclosure and the price–cost squeeze.

Figure M2–2
Raising a Rival's Fixed Cost



Vertical Foreclosure An extreme form of raising rivals' costs, called **vertical foreclosure**, occurs when a firm that controls an essential upstream input competes against other firms in the downstream market. By refusing to sell other downstream firms the needed input, it forces them to seek out less efficient substitutes. This increases their cost of production. When no substitutes are available, the rivals are completely driven out of the downstream market because they are unable to acquire the essential input.

vertical foreclosure Strategy wherein a vertically integrated firm charges downstream rivals a prohibitive price for an essential input, thus forcing rivals to use more costly substitutes or go out of business.

While vertical foreclosure may be profitable in some instances, it is not always the most profitable strategy. In particular, by charging input prices so high that it drives nonintegrated firms out of the market, the vertically integrated firm forgoes upstream profits from the sale of the input. Vertical foreclosure is profitable only when the higher profits earned in the downstream market (due to the increased market power) more than offset the profits lost in the upstream input market.

The Price–Cost Squeeze In specialized circumstances, a vertically integrated firm may potentially benefit from raising rivals' costs through a **price–cost squeeze**. Here, the vertically integrated firm raises rivals' costs on the input side while holding constant (or even lowering) the price charged for the final product. This squeezes the margins of downstream competitors. The ultimate effect of a severe price–cost squeeze is similar to that under predatory pricing: It drives competitors out of the market. Since this tactic requires the vertically integrated firm to charge prices that do not maximize current profits in the upstream and downstream markets, the firm trades off lower short-term profits for the potential of higher future profits once rivals exit the downstream market. Depending on the magnitude of this trade-off and the level of interest rates, a price–cost squeeze may be profitable.

price–cost squeeze Tactic used by a vertically integrated firm to squeeze the margins of its competitors.

Price–cost squeezes also can be used by large vertically integrated firms to "punish" rivals who do not participate in market-sharing and other collusive arrangements in downstream markets. While the vertically integrated firm may lose short-term profits by using price–cost squeezes to discipline rivals, this investment in a reputation for being "tough" can generate higher future profits in markets where there is repeated interaction.

KEY TERMS AND CONCEPTS

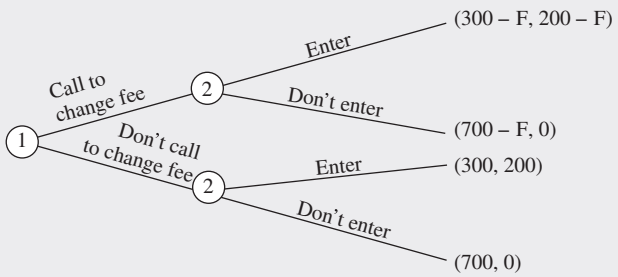
predatory pricing
price–cost squeeze
raising rivals' costs
vertical foreclosure

PRACTICE PROBLEMS



1. Two firms compete in a Cournot fashion. Firm 1 successfully engages in an activity that raises its rival's marginal cost of production. *(LO2)*
   a. Provide two examples of activities that might raise rivals' marginal costs.
   b. In order for such strategies to be beneficial, is it necessary for the manager of firm 1 to enjoy hurting the rival? Explain.
2. The market for taxi services in a Midwestern town is monopolized by firm 1. Currently, any taxi services firm must purchase a $40,000 "medallion" from the city in order to offer its services. A potential entrant (firm 2) is considering entering the market. Because entry would adversely affect firm 1's profits, the owner of firm 1 is planning to call her friend (the mayor) to request that the city change the medallion fee by $\$F$ thousand. The extensive form representation of the relevant issues is summarized in the accompanying

graph (all payoffs are in thousands of dollars and include the current medallion fee of $40,000). Notice that when $F > 0$, the medallion fee is increased and profits decline; when $F < 0$, the fee is reduced and profits increase. *(LO2)*



a. What are firm 1's profits if it does not call to change the fee (i.e., if it opts for a strategy of maintaining the status quo)?
b. How much will firm 1 earn if it convinces the mayor to *decrease* the medallion fee by $40,000 ($F = -\$40$) so that the medallion fee is entirely eliminated?
c. How much will firm 1 earn if it convinces the mayor to *increase* the medallion fee by $300,000 ($F = \$300$)?
d. Determine the change in the medallion fee that maximizes firm 1's profits.
e. Do you think it will be politically feasible for the manager of firm 1 to implement the change in part (*d*)? Explain.

3. Two firms compete in a homogeneous product market where the inverse demand function is $P = 20 - 5Q$ (quantity is measured in millions). Firm 1 has been in business for one year, while firm 2 just recently entered the market. Each firm has a legal obligation to pay one year's rent of $2 million regardless of its production decision. Firm 1's marginal cost is $2 and firm 2's marginal cost is $10. The current market price is $15 and was set optimally last year when firm 1 was the only firm in the market. At present, each firm has a 50 percent share of the market. *(LO1)*
   a. Why do you think firm 1's marginal cost is lower than firm 2's marginal cost?
   b. Determine the current profits of the two firms.
   c. What would happen to each firm's current profits if firm 1 reduced its price to $10 while firm 2 continued to charge $15?
   d. Suppose that, by cutting its price to $10, firm 1 is able to drive firm 2 completely out of the market. After firm 2 exits the market, does firm 1 have an incentive to raise its price? Explain.
   e. Is firm 1 engaging in predatory pricing when it cuts its price from $15 to $10? Explain.
4. You are the manager of an international firm headquartered in Antarctica. You are contemplating a business tactic that will permit your firm to raise prices and increase profits in the long run by eliminating one of your competitors. Do you think it would make economic sense to expend resources on legal counsel before implementing your strategy? Explain. *(LO3)*
5. Between 1995 and 1997, American Airlines competed in the Dallas/Ft. Worth Airport against several other low-cost carriers. In response to these low-cost carriers, American Airlines reduced its price and increased service on selected routes. As a result, one of the low-cost carriers stopped service, which led American Airlines to increase its price. Why do you think a lawsuit was filed against American Airlines? Why do you think American Airlines prevailed at trial? *(LO1, LO3)*

6. A number of professional associations, such as the American Medical Association and the American Bar Association, support regulations that make it more costly for their members (e.g., doctors and lawyers) to practice their services. While some of these regulations may stem from a genuine desire for higher-quality medical and legal services, self-interest may also play a role. Explain. (*LO2*)
7. Argyle is a large, vertically integrated firm that manufactures sweaters from a rare type of wool produced on its sheep farms. Argyle has adopted a strategy of selling wool to companies that compete against it in the market for sweaters. Explain why this strategy may, in fact, be rational. Also, identify at least two other strategies that might permit Argyle to earn higher profits. *(LO2)*
8. In 2015 Qualcomm Inc., an American multinational semiconductor company, came under scrutiny for its business practices by the United States and the European Union. It was argued that Qualcomm was paying a major customer to exclusively use its chips. In addition, Qualcomm was accused of selling its chips below cost in order to drive one of its competitors, Icera Inc., out of the market. Based on what you have learned in this chapter, briefly discuss whether these behaviors, if proven to have occurred, could be at odds with U.S. antitrust law. *(LO3)*
9. The CEO of a regional airline recently learned that its only competitor is suffering from a significant cash-flow constraint. The CEO realizes that its competitor's days are numbered but has asked whether you would recommend the carrier significantly lower its airfares to "speed up the rival's exit from the market." Provide your recommendation. *(LO1, LO3)*
10. Evaluate the following: "Since a rival's profit-maximizing price and output depend on its marginal cost and not its fixed costs, a firm cannot profitably lessen competition by implementing a strategy that raises its rival's fixed costs." *(LO2)*
11. Discuss how price discrimination can enhance the effectiveness of predatory pricing and strategies that raise rivals' costs. *(LO1, LO3)*

MODULE 3: RESTRUCTURING GAME TIMING

LEARNING OBJECTIVES

After completing this module, you will be able to:

LO1 Assess whether a firm's profits can be enhanced by changing the timing of decisions or the order of strategic moves and whether doing so creates first- or second-mover advantages.

First-Mover Advantages

A *first-mover advantage* permits a firm to earn a higher payoff by committing to a decision before its rivals get a chance to commit to their decisions. The Stackelberg model of oligopoly we examined in Chapter 9 is a classic example of a strategic environment in which the first mover enjoys an advantage. Recall that, in this setting, one firm (called the Stackelberg leader) gets to commit to a higher level of output before its rivals (followers) make their own output decisions. The Stackelberg leader earns higher profits than it would if it did not have the opportunity to move first.

Table M3–1

Simultaneous-Move Production Game

		Firm B	
	Strategy	**Low Output**	**High Output**
Firm A	**Low Output**	\$30, \$10	\$10, \$15
	High Output	\$20, \$5	\$1, \$2

The rationale for changing the timing of decisions to achieve a first-mover advantage can be easily illustrated. Consider two firms (firm A and firm B) that must make output decisions (low or high). We will consider two scenarios. In the first situation, both firms make their decisions simultaneously (and thus there is no scope for a first-mover advantage). We will see that the outcome of the game changes in the second situation, where firm A makes its decision before firm B.

The normal form representation for the simultaneous-move version of the game is presented in Table M3–1. For each pair of strategies by firm A and firm B, the first number in each cell represents the payoff to firm A, while the second entry represents firm B's payoff. For instance, if firm A produces a low level of output and firm B produces a low level of output, then firm A earns \$30 and firm B earns \$10.

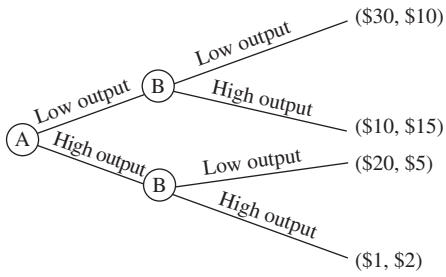
In this simultaneous-move game, firm A has a dominant strategy: Regardless of whether firm B produces a low or high level of output, firm A's profits are highest if it produces a low level of output. Firm B, being rational, recognizes this and has an incentive to produce the high output (since the \$15 earned from doing so exceeds the \$10 that would be earned if it produced a low output). We conclude that the unique Nash equilibrium in this simultaneous-move production game is for firm A to produce a low output and firm B to produce a high output. In equilibrium, firm A earns profits of \$10 and firm B earns profits of \$15.

Now suppose firm A changes the timing of its decision so that it gets to move before firm B. Just as importantly, assume firm B actually observes firm A's decision before it makes its own decision, and firm A knows this. The extensive form for this sequential-move production game is given in Figure M3–1. Notice that the payoffs at the end of the game tree are identical to those in Table M3−1. The only difference between these two games is that, in Figure M3−1, firm A gets to move first and firm B gets to observe A's decision before making its own decision.

What should firm A do when it gets to move first? If it chooses a low level of output, firm B's best response would be to produce a high level of output. If it does so, firm A earns a payoff of \$10. However, if firm A chooses a high level of output, firm B's best response is to produce a low level of output. In this case, firm A earns a payoff of \$20. Thus, in the unique

Figure M3–1

Sequential-Move Production Game



subgame perfect equilibrium to the game in Figure M3–1, firm A produces a high level of output. Firm B observes this and responds with a low level of output. Firm A's equilibrium payoff is $20, and firm B's equilibrium payoff is $5.

The fact that firm A's equilibrium payoff is higher ($20) when it gets to move first compared to its equilibrium payoff in the simultaneous-move game ($10) represents a first-mover advantage. In effect, the ability to move first gives firm A an advantage over its rival. In contrast, notice that firm B suffers from a second-mover disadvantage: It earns $5 when it moves second, which is lower than the $15 that is earned when both firms make decisions simultaneously.

INSIDE BUSINESS M3–1

First to Market, First to Succeed? Or First to Fail?

During the early era of personal computers, companies were inaccurate in forecasting PC demand. As a result, many firms lost sales to competitors or were stuck with unsold inventories. This all changed in 1984, when Michael Dell founded the Dell Computer Corporation. Dell's business model permitted it to sell a 12-megahertz computer for $1,995, compared to the price of $3,995 that IBM was charging for a 6-megahertz machine. Ultimately, Dell pioneered the direct sales model for computers (selling computers directly to end users) and later expanded his direct sales model to the Internet. While many other businesses have attempted to imitate this strategy (Compaq began selling direct in 1998), Dell's first-mover advantage placed it at the top of the industry by the year 2000 in terms of sales and profit growth. Dell is an example of a firm that successfully capitalized on its first-mover advantage (although due to entry, the industry is becoming more and more competitive each day, which has led Dell to supply popular retail chains with its computers).

Unfortunately, being the first to market an idea or product does not guarantee success. A number of well-known companies have been first to introduce new products, but being first has not always formed the basis for an "advantage." The first disposable diaper—a product called Chux—lost out to Procter & Gamble, which later introduced Pampers. A company called Ampex pioneered the video recorder, but most remember Sony as being the first mover when it introduced VCRs based on the now-defunct Beta format. Ultimately, JVC won the market with its VHS format. Prodigy Services was the main visionary regarding online services but ultimately lost out to a second mover (AOL).

Get the picture? Being first is not always an advantage; sometimes it pays to be patient. And even if you capitalize on a first- or second-mover advantage, remember that markets are dynamic. As illustrated by the longer-run experiences of Dell, AOL, and other companies, such advantages may not be sustainable in the long run.

SOURCES: "Being There First Isn't Good Enough," *The Wall Street Journal*, June 8, 1996; Michael Dell, *Direct from Dell* (New York: Harper Collins, 1999); various company Internet sites.

It is important to stress that firm A's first-mover advantage in this example relies on three crucial things: (1) Firm A's decision to produce a high level of output is irreversible, (2) firm B observes this decision before making its own output decision, and (3) both of these facts are common knowledge (firm B knows firm A's decision is irreversible, firm A knows firm B knows this, and so on).

First-mover advantages are common in many business environments. Consider an innovator who is the first to market a new product. Being first may permit her to enjoy monopoly profits throughout the life of the patent. Due to learning curve effects, additional first-mover benefits may accrue in the form of lower costs. First-mover advantages due to learning curve effects can persist long after the patent expires, and also can be present even if there is not a patent in the first place. In Module 4, we show that first-mover advantages are particularly strong in industries with significant network effects.

Second-Mover Advantages

Being first is not always advantageous; sometimes *second-mover advantages* are even greater. For example, being the second to introduce a new product can yield higher payoffs than being first if it permits the second mover to free-ride on investments made by the first mover. This permits the second mover to produce at a lower cost than the firm that moves first. In addition, a second mover may gain an advantage because it can learn from the first mover's mistakes. In this case, the second mover may be able to produce a better product at a lower cost than the firm that moves first. Inside Business M3 documents that, while many firms have benefited from being the first mover, some have benefited from being the second mover.

DEMONSTRATION PROBLEM M3–1

Determine how much you would be willing to pay for the privilege of moving first in these two different games:[1]

1. There are two players, you and a rival. The player announcing the larger positive integer gets a payoff of $10, while the other player gets $0.
2. There are two players, you and a rival. The player announcing the smaller positive integer gets a payoff of $20, while the other player gets $2.

ANSWER:

1. This game has a second-mover advantage; the second player can guarantee a payoff of $10 by simply announcing a positive integer that is larger than that announced by the first mover. Since there is not a first-mover advantage, you should not be willing to pay anything to move first (but note that you would be willing to pay up to $10 for the right to move second).
2. This game has a first-mover advantage; the first mover can guarantee a payoff of $20 by announcing "1." Since there is a first-mover advantage and you stand to earn $18 more by moving first rather than second, you should be willing to pay up to $18 for the right to move first in this game.

KEY TERMS AND CONCEPTS

first-mover advantage second-mover advantage

PRACTICE PROBLEMS



1. Consider the following simultaneous move game: *(LO1)*

		Player 2	
	Strategy	**Yes**	**No**
Player 1	**Yes**	400, 400	200, 375
	No	600, 500	300, 525

[1]In working this problem, note that the positive integers consist of the numbers {1, 2, 3, 4, . . .}, and "infinity" is not an integer.

a. What is the maximum amount player 1 should be willing to pay for the opportunity to move first instead of moving at the same time as player 2? Explain carefully.
b. What is the maximum amount player 2 should be willing to spend to keep player 1 from getting to move first?

2. In the following game, determine the maximum amount you would be willing to pay for the privilege of moving (*a*) first, (*b*) second, or (*c*) third: There are three players, you and two rivals. The player announcing the largest integer gets a payoff of $10, that announcing the second largest integer gets $0, and that announcing the third largest integer gets $5. *(LO1)*
3. You are the manager of 3D Designs—a large imaging company that does graphics and web design work for companies. You and your only competitor are contemplating the purchase of a new 3-D imaging device. If only one of you acquires the device, that firm will earn profits of $20 million and the other firm will lose $9 million. Unfortunately, there is only one 3-D imaging device in the world, and additional devices will not be available for the foreseeable future. Recognizing this fact, an opportunistic salesperson for the company that makes this device calls you. She indicates that, for an additional up-front payment of $23 million (not included in the previous figures), her firm will deliver the device to your company's premises tomorrow. Otherwise, she'll call your competitor and offer it the same deal. Should you accept or decline her offer? Explain. *(LO1)*
4. Tom Jackson has been running a successful steakhouse that specializes in serving upscale steak dinners. His current marketing campaign targets residential households. Recently, it was announced that a new conference hotel was to open near his steakhouse, bringing in many potential business customers. Speculation followed that Morton's steakhouse—an upscale steakhouse chain currently marketing to business customers nationally—was considering opening one of its restaurants near the new hotel and would therefore compete with Tom's restaurant. In light of the potential threat from Morton's, Tom began considering the possibility of making a significant investment to change his marketing campaign and target businesses rather than households. In doing so, he estimated the following profit outcomes (in thousands of dollars) resulting from the strategies that he and Morton's might implement:

		Morton's	
	Marketing Target	**Enter**	**Don't Enter**
Tom	**Businesses**	−$200, −$50	$90, $0
	Households	$50, $100	$105, $0

When analyzing this situation, Tom quickly noticed that his dominant strategy was to continue marketing to households and was disappointed in the resulting profits. Is this Tom's only option, or could he adopt another strategy that could result in much higher profits? Explain. *(LO1)*

MODULE 4: OVERCOMING NETWORK EFFECTS

LEARNING OBJECTIVES

After completing this module, you will be able to:

LO1 Identify examples of networks and network externalities, and determine the number of connections possible in a star network with *n* users.

LO2 Explain why networks often lead to first-mover advantages and how to use strategies such as penetration pricing to favorably change the strategic environment.

What Is a Network?

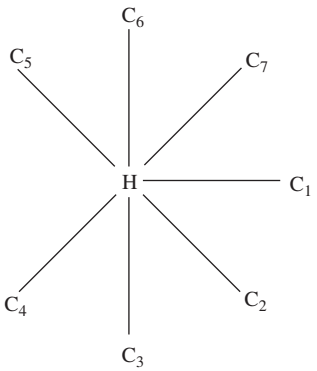
A *network* consists of links that connect different points (called *nodes*) in geographic or economic space. Networks play a profound role in the organization of many industries, including railroads, airlines, trucking, telecommunications, and a host of other sectors of the "new" economy, such as the Internet.

The simplest type of network is a *one-way network* in which services flow in only one direction. Residential water service is a commonly used example of a one-way network: Water typically flows one way, from the local water company to homes. Not surprisingly, one-way networks can lead to first-mover advantages because of economies of scale or scope. Because a network provider (the local water company) often enjoys economies of scale in creating a network to deliver service to its customers, new entrants typically find it difficult to build a network that supplants the network services of a well-established incumbent. The distinguishing feature of a one-way network is that its value to each user does not *directly* depend on how many other people use the new network.

As we will see, this is not the case for two-way networks (such as telephone systems, e-mail, or many facets of the Internet, including instant messages). In a *two-way network*, the value to each user depends *directly* on how many other people use the network. This may permit an existing two-way network provider to enjoy significant first-mover advantages even in the absence of any significant economies of scale.

An example of a two-way network is the *star network* shown in Figure M4–1. The points C_1 through C_7 represent nodes—for example, consumers who own a telephone. The point in

Figure M4–1
A Star Network



the middle (denoted H) represents the *hub*—for example, a switch owned by the telephone company. Consumer C_1 can call consumer C_2 through the connection C_1HC_2. Star networks are common not only in telecommunications, but also in other sectors of the economy, including the airline industry. For example, a consumer wishing to fly from Indianapolis to Philadelphia on Delta Airlines generally will first fly from Indianapolis to Atlanta (one of Delta's hubs) and then from Atlanta to Philadelphia.

Network Externalities

Two-way networks that link users exhibit positive externalities called **direct network externalities**: The per-unit value of the services provided by a network increases as the size of the network grows. A telephone network with only one user is worthless. A telephone network that connects two users is more valuable, but worth less to each consumer than a network that connects three users, and so on. With only two users, there are two potential connection services created by the network: User 1 can call user 2, and user 2 can call user 1. Adding one more user increases the number of potential connection services from two to six: User 1 can call user 2, user 1 can call user 3, user 2 can call user 1, user 2 can call user 3, user 3 can call user 1, and user 3 can call user 2. More generally, if there are n users, there are $n(n-1)$ potential connection services. Adding one user to the network directly benefits all users by adding $2n$ potential connections.

direct network externality
The direct value enjoyed by the user of a network because others also use the network.

Direct Network Externalities

A two-way network linking n users provides $n(n-1)$ potential connection services. If one new user joins the network, all the existing users directly benefit because the new user adds $2n$ potential connection services to the network.

PRINCIPLE

In addition to these direct externalities present in two-way networks, **indirect network externalities** also can exist. Indirect externalities that stem from the growing use of a particular network are called **network complementarities** and can arise in both one-way and two-way networks. For instance, the growing use of the Internet has led to many complementary products and services, such as teleconferencing software. Due to the sizable fixed costs required to develop such software, a large number of Internet users are needed to justify the associated software development costs. As more and more software are developed for use on the Internet, the associated network complementarities make the Internet even more valuable to each user.

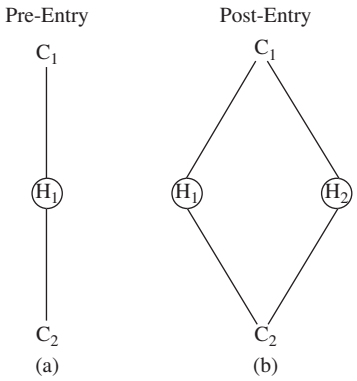
indirect network externality (network complementarities)
The indirect value enjoyed by the user of a network because of complementarities between the size of a network and the availability of complementary products or services.

Similarly, the growing use of electricity in the early twentieth century led to the development of millions of different types of electrical appliances. The availability of these appliances and the associated network complementarities increased the value of electricity networks. Analogous indirect externalities arise in non-network industries. For example, growth in the number of cars using 85 percent ethanol fuel (E85) has led to an increase in the number of E85 gas stations in the United States.

Negative externalities such as *bottlenecks* also can arise in networks. As the size of a network grows, it may eventually reach a point where the existing infrastructure cannot handle additional users. Beyond this point, additional users create congestion. This makes it harder for users to make network connections, and the value per user of the services provided by the network declines. Examples of bottlenecks include traffic jams on highway networks, delays at airports, dropped calls on telecommunication networks, slow server responses on the Internet, and power outages on local electricity networks.

Figure M4–2

Entry Creates a Competing (but Exclusive) Network



First-Mover Advantages Due to Consumer Lock-In

Because of network externalities, it is often difficult for new networks to replace or compete with existing networks—even if the new network is technologically superior to the existing one. In particular, since the established network is likely to have many users and complementary services, the total value of the existing network will be greater for each user (due to direct and/or indirect network externalities) than a new network with relatively few users or complementary services.

To see the nature of the problem, consider the simple two-way network shown in Figure M4–2(a) providing connection services between users C_1 and C_2. Imagine that this network is owned by the monopolist identified as the hub H_1 and that each user values these network services at $10 per month.

Now suppose another firm decides to enter the market to compete against the existing monopoly network. Since creating such a network will likely involve substantial fixed costs, let us suppose that the new firm has a superior technology such that, at full capacity, each user values the new network at $20 per month. Once the new network is built, the situation looks like that in Figure M4–2(b), where H_1 and H_2 represent the duopolists' hubs. In this figure, the two networks are exclusive. This means that both consumers must subscribe to the same network for the services of that network to be useful (see Inside Business M4).

Will the new entrant be able to enter the market with its superior technology? Table M4–1 illustrates the underlying issues. The players in this game are users who must choose a network provider. Both users are initially using network provider H_1, thanks to its first-mover advantage. In the initial situation, each user receives $10 in value each month from the network. Notice that, when the new network becomes available, neither user has a unilateral incentive to change network providers. Given the choice of the other user, neither user has an incentive to change to H_2, even though, if both consumers switched simultaneously, each would be

Table M4–1

A Network Game

		User 2	
	Network Provider	**H_1**	**H_2**
User 1	**H_1**	$10, $10	$0, $0
	H_2	$0, $0	$20, $20

INSIDE BUSINESS M4–1

Network Externalities and Penetration Pricing in Online Auctions

Online auctions are a classic example of an *exclusive network*. In particular, companies like eBay may be viewed as hubs that provide connections for buyers and sellers. The more buyers that visit the site, the more valuable the site is to sellers. Similarly, the more sellers that list items for sale at the site, the more valuable the site is to buyers.

Once a first-mover like eBay establishes itself as "the site" for buying and selling items on the Internet, it can be very difficult for a new entrant to gain a foothold with a competing auction site. After all, if no sellers list their products at the new site, buyers have no incentive to visit the site. And if no buyers visit the site, sellers have no incentive to pay for the privilege of listing items for sale at the new site. In this manner, a first mover into online auctions (such as eBay) may be able to sustain market power through network effects and its first-mover advantage.

This exact scenario presented a challenge for Yahoo!, which wanted to enter the market for online auctions to compete against eBay. Recognizing the problem of network effects and eBay's first-mover advantage, Yahoo! adopted a penetration pricing strategy, allowing both buyers and sellers to use its auction site for free. It reasoned that, since eBay was charging sellers a fee, this strategy would permit the Yahoo! auction site to grow to its critical mass. Once a sufficiently large number of buyers and sellers had begun using the site, the network effects would kick in and Yahoo! would be able to charge fees for its auction services.

Unfortunately for Yahoo!, this strategy did not permit it to overcome eBay's network effects and first-mover advantages. Ultimately, Yahoo! closed its U.S. online auction site.

SOURCES: Michael R. Baye and John Morgan, "Information Gatekeepers on the Internet and the Competitiveness of Homogeneous Product Markets," *American Economic Review* 91, no. 3 (June 2001), pp. 454–74; Yahoo! Auction site at http://help.yahoo.com/help/auctions/asell/, accessed October 6, 2001; "Yahoo! US Auction Sites Are Retired!" http://auctions.shopping.yahoo.com/, accessed March 7, 2009.

better off. This is a classic coordination problem (see Chapter 10). The network externalities create a consumer *lock-in*: The consumers are stuck in a situation (equilibrium) where they are using the inferior network.

Using Penetration Pricing to "Change the Game"

While a lock-in with only two users might be easily resolved by communication between the two users (each consumer agreeing to switch to the other network), the transaction costs of such a strategy make it unfeasible when there are hundreds or potentially millions of users who do not know one another. In these more realistic settings, what can a business like firm 2 do to establish its network?

One strategy, called **penetration pricing**, entails charging an initial price that is very low—potentially even giving the product away for free or *paying* customers to try out the new product—to gain a critical mass of customers. This protects users from the risk that other users will not switch to the new technology: Users can maintain their use of the existing network while experimenting with the new network.

penetration pricing Charging a low price initially to penetrate a market and gain a critical mass of customers; useful when strong network effects are present.

To see how a penetration pricing strategy can help firm 2 attract a critical mass of users on its network, notice that the value to users of having access to both networks is at least as large as the value of using either network individually. Consequently, if the new network provider actually pays users a small amount (say $1) to try out its service, then during this "trial" period the game facing consumers would change from the one in Table M4–1 to the one in Table M4–2. In this case, each consumer has an incentive to try the new network since the choice "H_1 & H_2" is a dominant strategy for each user.

Table M4–2

The Network Game with Penetration Pricing

		User 2	
	Network Provider	**H_1**	**H_1 & H_2**
User 1	**H_1**	$10, $10	$10, $11
	H_1 & H_2	$11, $10	$21, $21

Once consumers try the two networks, they will soon realize that H_2 is better and eventually quit using H_1. Once a critical mass of users (in this case, both users) begins using H_2, the owner of network H_2 can eliminate the $1 payment (and ultimately increase the price charged for access to its network) since each consumer now receives $20 in benefits from H_2, compared to the $10 in benefits when both consumers used H_1. In this manner, the new entrant can use penetration pricing to overcome the incumbent's first-mover advantage that stems from these network externalities. Looking again at Table M4–1, penetration pricing is exactly the tool needed to move consumers from the equilibrium in the top left cell to the bottom right cell.

DEMONSTRATION PROBLEM M4–1

A firm is contemplating the establishment of a potential two-way network linking 100 users. A feasibility study reveals that each user is willing to pay an average of $1 for each potential connection service provided by the network. If the total cost of establishing the network is $500,000, should the firm establish the network? Explain.

ANSWER:

A network linking 100 users provides $100(100 - 1) = 9{,}900$ potential connection services. Valued at an average of $1 each, the firm can generate revenues of $9,900 from each user who subscribes to the network. If the firm gets all 100 users to subscribe to the network, its total revenues would be $990,000, which clearly exceeds the $500,000 in costs required to establish the network. However, note that the firm earns the $490,000 in profits only if all 100 users subscribe. Due to network effects and consumer lock-in, there is no guarantee that these profits will be realized. Penetration pricing or some other method will likely be needed to "jump start" the network. This will obviously impact the firm's revenues and profits in the short run.

KEY TERMS AND CONCEPTS

bottleneck
direct network externality
exclusive network
hub
indirect network externality (network complementarity)
lock-in
network
node
one-way network
penetration pricing
star network
two-way network

PRACTICE PROBLEMS



1. A firm is considering building a two-way network that links 12 users. The cost of building the network is $10,000. *(LO1)*
   a. How many potential connection services does this network provide?
   b. If each user is willing to pay $150 to connect to the network, will the firm profit by building the network?
   c. If each user is willing to pay an average of $12 for each potential connection service provided by the network, will the firm profit by building the network?
   d. What happens to the number of potential connection services if one additional user joins the network?
2. On November 18, 2012, Nintendo released its eighth-generation video game console, the Wii U. In November 2013, Microsoft and Sony followed suit by releasing the Xbox One and PlayStation 4, respectively. Although these three video game consoles have dominated the video game console market, new microconsoles, which download games from application stores such as Google Play, have begun entering the market. One such microconsole is Ouya, which entered the market in 2013. If you were in charge of pricing at Ouya as it entered the market, what strategy would you pursue? Explain. *(LO1, LO2)*
3. During the early days of the Internet, most dot-coms were driven by revenues rather than profits. A large number were even driven by "hits" to their site rather than revenues. This all changed in early 2000, however, when the prices of unprofitable dot-com stocks plummeted on Wall Street. Most analysts have attributed this to a return to rationality, with investors focusing once again on fundamentals like earnings growth. Does this mean that, during the 1990s, dot-coms that focused on "hits" rather than revenues or profits had bad business plans? Explain. *(LO1, LO2)*
4. During the dot-com era, mergers among some brokerage houses resulted in the acquiring firm paying a premium on the order of $100 for each of the acquired firm's customers. Is there a business rationale for such a strategy? Do you think these circumstances are met in the brokerage business? Explain. *(LO1)*
5. Bank 1 and Bank 2 are considering entering a compatibility agreement that would permit the users of each bank's automated teller machines (ATMs) access to the other bank's ATMs. Bank 1 has a network of branches and ATMs extending from Connecticut to Florida. Bank 1's 12 million customers currently have access only to the 10,000 ATMs solely owned by the company on the East Coast. While Bank 2's core account holders are located on the West Coast and southwestern portion of the United States, the company is expanding to the East Coast. Bank 2 has 15 million customers who can use any of its 14,000 ATMs. Using the idea of network externalities, describe how such an agreement between Bank 1 and Bank 2 would benefit consumers. *(LO1)*

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MODULE GROUP B

Government in the Marketplace

INTRODUCTION

Throughout most of this text, we have treated the market as a place where firms and consumers come together to trade goods and services with no intervention from government. But as you are aware, rules and regulations that are passed and enforced by government enter into almost every decision firms and consumers make. As a manager, it is important to understand the regulations passed by government, why such regulations have been passed, and how they affect optimal managerial decisions.

In Modules 5 and 6, we examine four reasons free markets may fail to provide the socially efficient quantities of goods: (1) market power, (2) externalities, (3) public goods, and (4) incomplete information. Our analysis includes an overview of government policies designed to alleviate these "market failures" and an explanation of how the policies affect managerial decisions. The power of politicians to institute policies that affect the allocation of resources in markets provides those adversely affected with an incentive to engage in lobbying activities. We illustrate the underlying reasons for these types of rent-seeking activities. Finally, in Module 7, we examine how these activities can lead politicians to impose restrictions such as quotas and tariffs in markets affected by international trade.

MODULE 5: REGULATORY CONSTRAINT ON MARKET POWER

LEARNING OBJECTIVES

After completing this module, you will be able to:

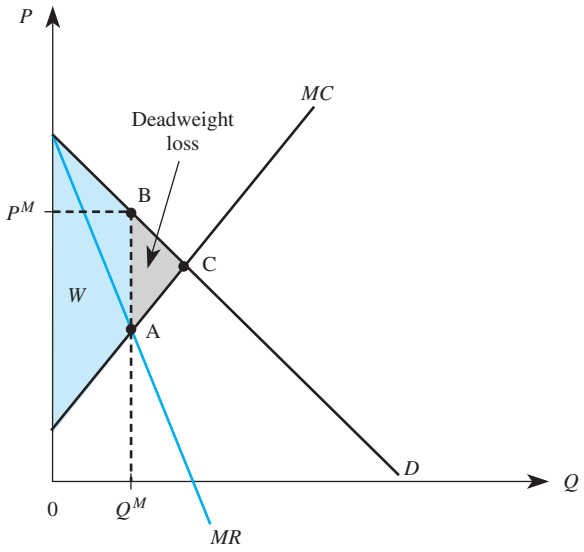
- **LO1** Explain why market power reduces social welfare, and identify two types of government policies aimed at reducing deadweight loss.
- **LO2** Explain why government attempts to solve market failures can lead to additional inefficiencies because of "rent-seeking" activities.

Market Power

One of the main reasons for government involvement in the marketplace is that free markets do not always result in the socially efficient quantities of goods at socially efficient prices. A prominent reason for such "market failure" is the existence of market power.

Figure M5–1

Welfare and Deadweight Loss under Monopoly



You learned in Chapters 2 and 8 that social welfare—defined as the sum of consumer and producer surplus—is maximized at the output where price equals marginal cost. The socially efficient price and output arise naturally if the industry is perfectly competitive. In contrast, a firm that has **market power** produces less than the socially efficient level of output because it charges a price that exceeds its marginal cost of production. In such instances, the value to society of another unit of the good is greater than the cost of the resources needed to produce that unit; there would be a net gain to society if additional output were produced. In these instances, government may intervene in the market and regulate the actions of firms in an attempt to increase *social welfare*.

market power
The ability of a firm to set its price above marginal cost.

To see the potential benefits of government intervention in a market, consider a market serviced by a monopoly. Figure M5–1 shows the monopolist's demand, marginal cost, and marginal revenue curves. Assuming that the monopolist must charge the same price to all consumers in the market, the profit-maximizing output is Q^M units, and these units are sold at the monopoly price of P^M. At this price, consumers pay more for the last unit of output than it costs the producer to manufacture and sell it. Total social welfare under monopoly is the region labeled *W* in Figure M5–1.

Notice in Figure M5–1 that the area of triangle ABC is the **deadweight loss** of the monopoly—welfare that would have accrued to society if the industry were perfectly competitive but is not realized because of the market power the monopolist enjoys. The failure of the market to fully maximize social welfare is due to market power; the deadweight loss triangle provides a measure of this welfare loss to society.

deadweight loss of monopoly
The consumer and producer surplus that is lost due to the monopolist charging a price in excess of marginal cost.

Government Tools to Constrain Market Power

The government uses antitrust policy to enact and enforce laws that restrict the formation of monopolies. The rationale for these policies is that by preventing monopoly power from emerging, the deadweight loss of monopoly can be avoided. In some instances, however, the presence of economies of scale makes it desirable to allow the formation of a monopoly. In these cases, government attempts to reduce the deadweight loss by regulating the price charged by the monopolist.

Antitrust Policy

antitrust policy
Government policies designed to keep firms from monopolizing their markets.

Antitrust policy attempts to eliminate the deadweight loss of monopoly by making it illegal for managers to engage in activities that foster monopoly power, such as price-fixing agreements and other collusive practices. The cornerstone of U.S. antitrust policy is contained in Sections 1 and 2 of the *Sherman Antitrust Act* of 1890:

> **Sec. 1**
> Every contract, combination in the form of trust or otherwise, or conspiracy, in restraint of trade or commerce among the several states, or with foreign nations, is hereby declared to be illegal. Every person who shall make any such contract or engage in any such combination or conspiracy shall be deemed guilty of a felony, and, on conviction thereof, shall be punished by fine not exceeding five thousand dollars (one million dollars if a corporation, or, if any other person, one hundred thousand dollars) or by imprisonment not exceeding one (three) years, or by both said punishments, in the discretion of the court.
>
> **Sec. 2**
> Every person who shall monopolize, or attempt to monopolize, or combine or conspire with any person or persons, to monopolize any part of the trade or commerce among the several States, or with foreign nations, shall be deemed guilty of a felony, and, on conviction thereof, shall be punished by fine not exceeding five thousand dollars (one million dollars if a corporation, or, if any other person, one hundred thousand dollars) or by imprisonment not exceeding one (three) years, or by both said punishments, in the discretion of the court.[1]

Among other things, the Sherman Act makes it illegal for managers of U.S. firms to collude with other domestic or foreign firms. Thus, even though OPEC is not bound by U.S. law (it is composed of foreign nations), the manager of a U.S. oil company cannot legally participate in the OPEC oil cartel.

The interpretation of antitrust policy is largely shaped by the courts, which rule on ambiguities in the law and previous cases. For example, the first successful use of the Sherman Antitrust Act was in 1897, when the Supreme Court held that rate agreements are illegal in *United States v. Trans-Missouri Freight Association*. This ruling was again upheld in *United States v. Joint Traffic Association* (1898). The court extended its interpretation to include collusive bidding in *Addyston Pipe & Steel Company v. United States* (1899). The full power of the Sherman Antitrust Act was not realized until the conclusion of *United States v. Standard Oil of New Jersey* in 1911. The last case is interesting and provides useful caveats to future managers.

Standard Oil of New Jersey, along with Standard Oil of Ohio, was charged with attempting to fix the prices of petroleum products and the prices at which the products would be shipped. Standard Oil, in particular, was accused of numerous activities designed to enhance monopoly power: using physical threats to shippers and other producers, setting up bogus companies, using espionage by bribing employees of other companies, engaging in restraint of trade, and making several attempts to monopolize the oil industry. Managers, of course, should avoid all of these practices; as a result of these actions, the court dissolved Standard Oil into 33 subsidiaries, many of which survive today under the names ExxonMobil, Chevron, and BP America. More important than breaking up the Standard Oil Trust, however, was the Supreme Court's new *rule of reason*, as defined in Justice White's majority opinion:

> Thus not specifying, but indubitably contemplating and requiring a standard, it follows that it was intended that the standard of reason which had been applied at the common law and in this country in dealing with subjects of the character embraced by the statute was intended to be the measure used for the purpose of determining whether, in a given case, a particular act had or had not brought about the wrong against which the statute provided.

[1]The penalties have been amended twice, in 1955 and in 1970. The penalties in parentheses represent the 1970 change.

The rule of reason has since become the code of decision making used by the court for determining antitrust cases. Effectively, the rule of reason stipulates that not all trade restraints are illegal; rather, only those that are "unreasonable" are prohibited. For example, in applying this rule, the courts determined that the size of a firm alone is not sufficient evidence to convict a firm under Section 2 of the Sherman Act:

> To hold to the contrary would require the conclusion either that every contract, act, or combination of any kind or nature, whether it operated in restraint of trade or not, was within the statute.

Effectively, this means that a firm must take an explicit action designed to lessen competition before it can be found guilty of violating Section 2 of the Sherman Act. For example, the rule of reason was used in the decision against American Tobacco, which was found guilty of monopolizing a U.S. tobacco market by engaging in predatory pricing—pricing below cost to drive away competitors and thus enhance the firm's own monopoly power.

The problem with the rule of reason is that it makes it difficult for managers to know in advance whether particular pricing strategies used to enhance profits are in fact violations of the law. Congress attempted to clarify its intent by more precisely defining illegal actions in the *Clayton Act* (1914) and its amendment, the *Robinson-Patman Act* (1936). For example, Section 2(a) of the Robinson-Patman Act amends Section 2 of the Clayton Act and makes price discrimination illegal if it is designed to lessen competition or create a monopoly:

> **Sec. 2(a)**
> That it shall be unlawful for any person engaged in commerce, in the course of such commerce, either directly or indirectly, to discriminate in price between different purchasers of commodities of like grade and quality, . . . where such discrimination may be substantially to lessen competition or tend to create a monopoly in line of commerce, or to injure, destroy, or prevent competition.

Price discrimination that arises because of cost or quality differences is permitted under the act, as is price discrimination when it is necessary to meet a competitor's price in a market. Still, there is considerable ambiguity regarding whether a particular type of price discrimination is illegal under the law, and laws differ across countries. In the United States, for instance, legal actions against price discrimination are generally brought by private plaintiffs and relate to wholesale prices (but see Inside Business M5–1 for a glimpse of the European antitrust landscape).

The Clayton Act contains more than 20 sections that, among other things, make it illegal for firms to (1) hide kickbacks as commissions or brokerage fees, (2) use rebates unless they

INSIDE BUSINESS M5–1

European Commission Moves to Protect Small Businesses

In 2008, the European Commission passed the Small Business Act for Europe. This act consists of principles and legislative proposals specifically designed to aid small and medium-sized enterprises (SMEs), defined as companies with fewer than 250 employees. Among other directives, the act requires that rules be designed according to the "Think Small First Principle," where all new legislative and administrative proposals should be subjected to an "SME test" to determine their impact on SMEs.

There is no counterpart to the Small Business Act for Europe in the United States. This asymmetry highlights a key difference in competition policy between the United States and Europe: European competition policy explicitly aims to protect small businesses, while U.S. competition policy generally does not cater to businesses of any particular size.

SOURCES: Eleanor M. Fox, "US and EU Competition Law: A Comparison," Global Competition Policy, Peterson Institute for International Economics (1997), pp. 339–54; European Commission, *Putting Small Business First*, 2008.

are made available to all customers, (3) engage in exclusive dealings with a supplier unless the supplier adds to the furnishing of the buyer and/or offers to make like terms to all other potential suppliers, (4) fix prices or engage in exclusive contracts if such a practice will lead to lessening of competition or monopoly, and (5) acquire one or more other firms if such an acquisition will lead to a lessening of competition.

The *Celler-Kefauver Act* (1950) strengthened Section 7 of the Clayton Act by making it more difficult for firms to engage in mergers and acquisitions without violating the law:

> **Sec. 7**
> That no corporation engaged in commerce shall acquire, directly or indirectly, the whole or any part of the stock or other share capital and no corporation subject to the jurisdiction of the Federal Trade Commission shall acquire the whole or any part of the assets of another corporation engaged also in commerce, where in any line of commerce in any section of the country, the effect of such acquisition may be substantially to lessen competition, or to tend to create a monopoly.

Merger policy changed, however, when new horizontal merger guidelines were written in 1982, amended in 1984, and revised in 1992, 1997, and 2010. In Chapter 7 you learned that these guidelines are based on the **Herfindahl-Hirschman index (HHI)**,

Herfindahl-Hirschman index (HHI)
The sum of the squared market shares of firms in a given industry multiplied by 10,000.

$$HHI = 10{,}000\sum_{i=1}^{N} w_i^2$$

where w_i is the market share of firm i. More precisely, w_i represents firm i's sales in the relevant market as a fraction of the total sales of all firms in that market. Under the *Horizontal Merger Guidelines*, a merger that increases HHI by less than 100 or leads to an unconcentrated market (post-merger HHI < 1,500) is ordinarily allowed. Markets in which the postmerger HHI is between 1,500 and 2,500 are considered moderately concentrated. In moderately concentrated markets, mergers that increase HHI by more than 100 points potentially raise antitrust concerns. Markets in which the postmerger HHI exceeds 2,500 are deemed highly concentrated. In highly concentrated markets, an increase in the HHI of between 100 and 200 points also potentially raises antitrust concerns. If a merger increases HHI by more than 200 and leads to a highly concentrated market, it is *presumed* to be likely to enhance market power.

It is important to stress that these are only guidelines; mergers are often allowed even when HHI indexes are large, provided there is a significant likelihood of potential entry into the market by domestic or foreign firms, an emerging new technology, or increased efficiency, or one of the firms has financial problems.

As a practical matter, efficiencies make a difference in antitrust enforcement only when adverse competitive effects are not that great. As the 2010 revision to the *Horizontal Merger Guidelines* states, ". . . efficiencies almost never justify a merger to monopoly or near-monopoly."[2] Additionally, the *Guidelines* recognize that efficiencies are difficult to verify and quantify. Merging firms must substantiate any efficiency claims; "vague or speculative" claims do not count.

The *Antitrust Division of the Department of Justice (DOJ)* and the *Federal Trade Commission (FTC)* are charged with the task of enforcing antitrust regulations. The *Hart-Scott-Rodino Antitrust Improvement Act* of 1976 requires that parties to an acquisition notify both the DOJ and the FTC of their intent to merge, provided that the dollar value of the transaction exceeds a certain threshold (currently about $94 million). Following this premerger notification, the parties must wait 30 days before they may complete the merger. If the DOJ or

[2]Department of Justice and the Federal Trade Commission, *Horizontal Merger Guidelines,* 2010.

FTC decides that further examination of the merger is warranted, a so-called second request is issued: The parties are asked to provide additional information to the government. A second request automatically extends the waiting period. Once the parties comply with the second request, the government has 30 days to review the information and either file a complaint to block the merger or permit the merger to take place.

In practice, less than 3 percent of all premerger notifications lead to a second request. In those cases where a second request is issued, the government and the parties usually reach an agreement before going to court. Typically, the firms sell to third parties assets in those product or geographic markets where there is considerable business overlap. This eliminates the government's antitrust concerns and allows the parties to consummate the merger. If the government and the parties cannot come to an agreement about which assets will be divested, the government may file suit to block the merger.

Price Regulation

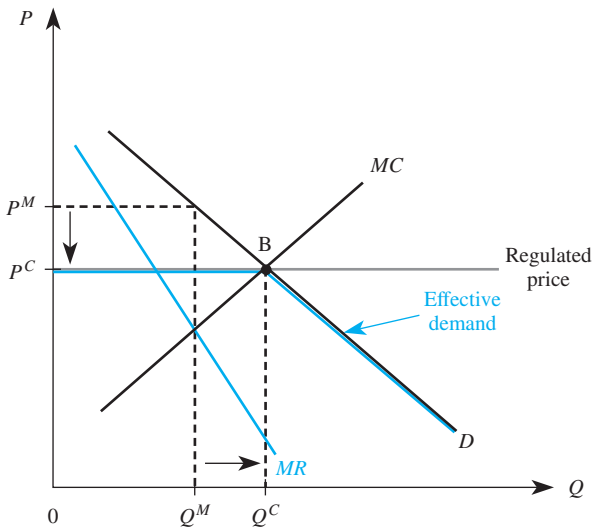
In the presence of large economies of scale (as is the case for some utility companies), it may be desirable for a single firm to service a market. In these instances, government may allow a firm to exist as a monopoly but choose to regulate its price to reduce the deadweight loss. In this section, we will see how such regulation affects managerial decisions and social welfare.

Consider the situation depicted in Figure M5–2, where an unregulated monopolist produces Q^M units of output at a price of P^M. A competitive industry would produce Q^C units, where marginal cost intersects the demand curve. Suppose the government imposed and enforced a regulated price of P^C, which corresponds to the price a competitive industry would charge for the product given identical demand and cost conditions. How should the manager respond to maximize the firm's profits?

The monopolist cannot legally charge a price above P^C, so the maximum price it can charge for units less than Q^C is P^C. For units above Q^C, the maximum price it can charge is the price along the inverse demand curve since the amount consumers are willing to pay is less than the ceiling. As a consequence, the effective inverse demand curve of the monopolist is given by P^CBD. Notice that for points to the left of B, the demand curve is horizontal, just as it is for a perfectly competitive firm. But if the monopolist wishes to sell more than Q^C units of output, it can do so only by lowering price below P^C.

Figure M5–2

Regulating a Monopolist's Price at the Socially Efficient Level



Since the monopolist can sell each unit up to Q^C at a price of P^C, the marginal revenue for these units is simply P^C: Each additional unit of output up to Q^C adds exactly P^C to the firm's revenue. In effect, the ceiling creates a situation where the demand curve the monopolist faces is just like that of a perfectly competitive firm for these output levels. To maximize profits, the regulated monopolist will produce where the marginal revenue of the effective demand curve (P^C) equals marginal cost, which in this case is at point B. This corresponds to an output of Q^C. Thus, when the monopolist's price is regulated at P^C in Figure M5–2, the firm maximizes profits by producing Q^C units and selling them at the regulated price of P^C.

Notice that the impact of the price regulation is to induce the profit-maximizing monopolist to produce the perfectly competitive output at the perfectly competitive price. The result of the price regulation is to completely eliminate the deadweight loss of the monopoly. The government policy thus reduces monopoly profits but increases social welfare.

On the basis of Figure M5–2, one might be tempted to conclude that it is always beneficial to regulate the price charged by a monopolist. This is not the case, however. To see why, consider the monopoly situation in Figure M5–3. Suppose the government regulates the price at the level P^*. Given the regulated price, the effective demand curve for the monopolist is now P^*FD, and the corresponding marginal revenue curve for units produced below Q^* is given by line P^*F. To maximize profits, the regulated monopolist will produce where the marginal revenue of the effective demand curve (P^*) equals marginal cost, which is at point G. This corresponds to an output of Q^R, which is less than the output the monopolist would have produced in the absence of regulation. Moreover, the quantity demanded at a price of P^* is Q^*, so there is a shortage of $Q^* - Q^R$ units under the regulated price. Furthermore, the deadweight loss under this regulated price (regions $R + W$) is actually larger than the deadweight loss in the absence of regulation (region W). If the government lacks accurate information about demand and costs, or for some other reason regulates the price at too low a level, it can actually reduce social welfare and create a shortage of the good.

It is very important to note that the analysis in Figures M5–2 and M5–3 suppresses the position of the average total cost curve. To see why it is important to consider the position of the average total cost curve before reaching conclusions about the welfare loss arising from monopoly, consider the situation in Figure M5–4, where the monopolist is just breaking even

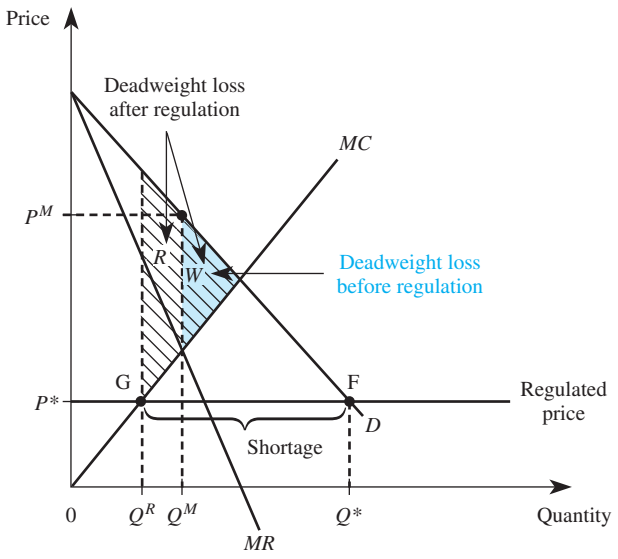
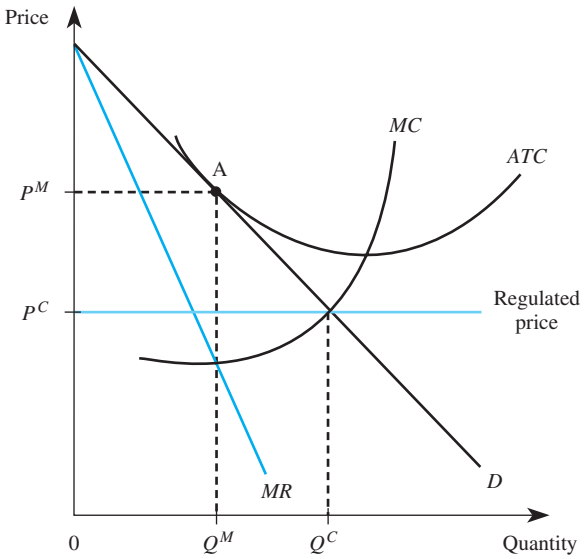


Figure M5–3

Regulating a Monopolist's Price Below the Socially Efficient Level

Figure M5–4

A Case Where Price Regulation Drives the Monopolist Out of Business



INSIDE BUSINESS M5–2

Electricity Deregulation

Historically, due to economies of scale in the capital-intensive electric power industry, prices of electricity have been regulated through "rate-of-return" regulation. These price restrictions allowed electric companies to earn a profit based on the value of their capital or rate base (but companies were not guaranteed a profit). The Public Utility Regulatory Policies Act (PURPA) of 1978 and the Energy Policy Act of 1992 opened the *wholesale* electricity market to unregulated independent power producers. By 1996, the Federal Energy Regulatory Commission (FERC) ordered that the bulk transmission lines that carried high voltage electricity geographically be opened to anyone wishing to supply power to an end user. Deregulation plans differed by state, but many required the once vertically integrated utilities to divest some or all of their generation capacity in an effort to promote competition.

Today, about 15 states allow choice for electricity consumers, but choice is limited solely to the generation of power. The *delivery* of electric power to end users remains a natural monopoly owing to the fact that the "poles and wires" used to transmit power are a substantial fixed cost. Consequently, what deregulation in the electric power industry has really boiled down to is a "restructuring" of the industry. For the states that have allowed deregulation, the power industry has become less vertically integrated. Generation is theoretically competitive, but regardless of who generates the customer's power, the local electric company still transmits and delivers that power, and charges for these services are still established under basic "rate-of-return" regulation.

Customers taking the fullest advantage of choice in electricity are mostly industrial facilities. Small commercial and residential customers find switching costs to be significant and, for the most part, the marginal benefits under choice (lower power prices) were small. Also, electricity marketers found that the acquisition costs to gain small customers were higher than originally expected, which lessened the incentive to sell power to small customers in new markets. Thus, in the states that have experimented with deregulated electricity, most small customers have few, if any, power suppliers to actually choose from.

SOURCE: Interview with Vincent Marra, former rate analyst, Delmarva Power, February 28, 2007.

at point A. In this instance, an unregulated monopolist would produce Q^M units and charge a price of P^M. Since price is equal to the average total cost of production, this monopolist earns zero economic profits in the absence of regulation.

Now suppose the price is regulated at P^C. In the long run, how much output will the firm produce? The answer is zero output. To see why, note that under the regulated price, average total cost lies above the regulated price, so the monopolist would experience a loss if it produced. Thus, in the long run the monopolist in Figure M5–4 would exit the market if the price were regulated at P^C, and everyone in the market would be made worse off (there would be no product to consume). To keep this from happening, the government would have to subsidize the monopoly by agreeing to compensate it for any losses incurred. These funds would come from taxes, and thus consumers would indirectly be paying for the lower price through higher taxes. Moreover, the manager of a subsidized monopoly would have no incentive to keep costs low; any losses that resulted would be subsidized by the government. Consequently, the manager would have an incentive to spend enormous sums of money on plush offices, corporate jets, and the like, since losses would be reimbursed by the government.

The analysis in Figure M5–4 points out a very important caveat regarding comparisons of monopoly and perfect competition. One key source of monopoly power is the presence of economies of scale. These economies of scale may render it impossible for output to be produced in a competitive industry. For example, a competitive industry could not sustain an output of Q^C in Figure M5–4 because the intersection of the marginal cost and demand curves lies below the average total cost curve.

DEMONSTRATION PROBLEM M5–1

Many firms that sell in small markets are effectively monopolies; they are the sole provider of a good in their geographic area. Most of these firms earn positive economic profits, yet they are allowed to operate as monopolies without regulation by government. Why?

ANSWER:

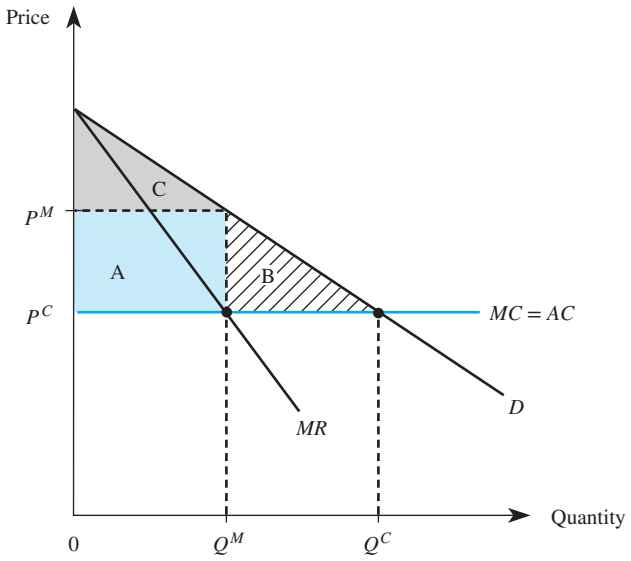
In situations where economies of scale are large relative to market demand, only a single firm will be able to service the market. In these instances, it is not desirable to break the firm up into smaller firms using antitrust policy. There would, however, be a potential gain in social welfare if the firm's price were regulated at the socially efficient level. This gain must be weighed against the cost of setting up a regulatory body to administer the regulation. If the cost of setting up and running the regulatory body exceeds the deadweight loss of monopoly—as it likely will in small markets—there will be a net loss in social welfare by regulation. In these instances, social welfare would be better served by leaving the firm alone even though it creates a deadweight loss. In effect, it would cost more to fix the problem than would be gained by eliminating the deadweight loss.

Rent Seeking

The preceding analysis, as well as analyses in Module 6, shows how government policies can improve the allocation of resources in the economy by alleviating the problems associated with market failure. It is important to note, however, that government policies

Figure M5–5

The Incentives to Engage in Rent-Seeking Activities



generally benefit some parties at the expense of others. For this reason, lobbyists spend considerable sums in attempts to influence government policies. This process is known as **rent seeking**.

rent seeking
Selfishly motivated efforts to influence another party's decision.

While rent seeking can occur for a range of government policies, it is perhaps best illustrated in the context of price regulation. For our illustration, suppose a politician has the power to regulate the monopoly in Figure M5–5. The monopoly currently charges a price of P^M, produces Q^M units of output, and earns profits described by the shaded region A. At the monopoly price and output, consumer surplus is given by triangle C.

If consumers could persuade the politician to regulate the monopolist's price at the competitive level (P^C), the result would be an output of Q^C. If this happened, the monopoly would lose all of its profits (rectangle A). Consumers, on the other hand, would end up with total consumer surplus of regions A, B, and C.

Since the monopolist stands to lose rectangle A if the regulation is imposed, it has an incentive to lobby very hard to prevent the regulation from being imposed. In fact, the monopolist is willing to spend up to the amount A to avoid the regulation. These expenditures may be in the form of legal activities, such as campaign contributions or wining and dining the politician, or illegal activities such as bribes.

Notice that the consumers in Figure M5–5 also would be willing to spend money to persuade the politician to regulate the monopoly. In fact, as a group they would be willing to spend up to A + B to impose the competitive solution since this is the additional consumer surplus enjoyed when the price is P^C. Of course, each individual consumer stands to gain much less than the group (regulation is a public good in that it benefits all consumers; see Module 6 for discussion of public goods). Consequently, each consumer has an incentive to "free ride," and in the end the amount the consumers spend as a group will be very low. The monopolist, on the other hand, is a single entity. Avoiding regulation is not a public good to the monopolist; the monopolist will receive private gains if it can avoid the legislation. As a result, the monopolist generally will spend much more on lobbying activities than the consumers and thus will often avoid legislation by engaging in rent-seeking activities.

DEMONSTRATION PROBLEM M5–2

You are the manager of a monopoly that faces an inverse demand curve of $P = 10 - Q$ and has a cost function of $C(Q) = 2Q$. The government is considering legislation that would regulate your price at the competitive level. What is the maximum amount you would be willing to spend on lobbying activities designed to stop the regulation?

ANSWER:

If the regulation passes, your firm's price will be regulated at marginal cost ($2) and the firm will earn zero profits. If not, the firm can continue to produce the monopoly output and charge the monopoly price. The monopoly output is determined by the point where $MR = MC$:

$$10 - 2Q = 2$$

Solving for Q yields the monopoly output of $Q^M = 4$ units. The monopoly price is obtained by inserting this quantity into the demand function to obtain

$$P^M = 10 - 4 = 6$$

Thus, your firm stands to lose monopoly profits of $P^M Q^M - C(Q^M) = \$16$ if the regulation is imposed. The most you would be willing to spend on lobbying activities thus is $16.

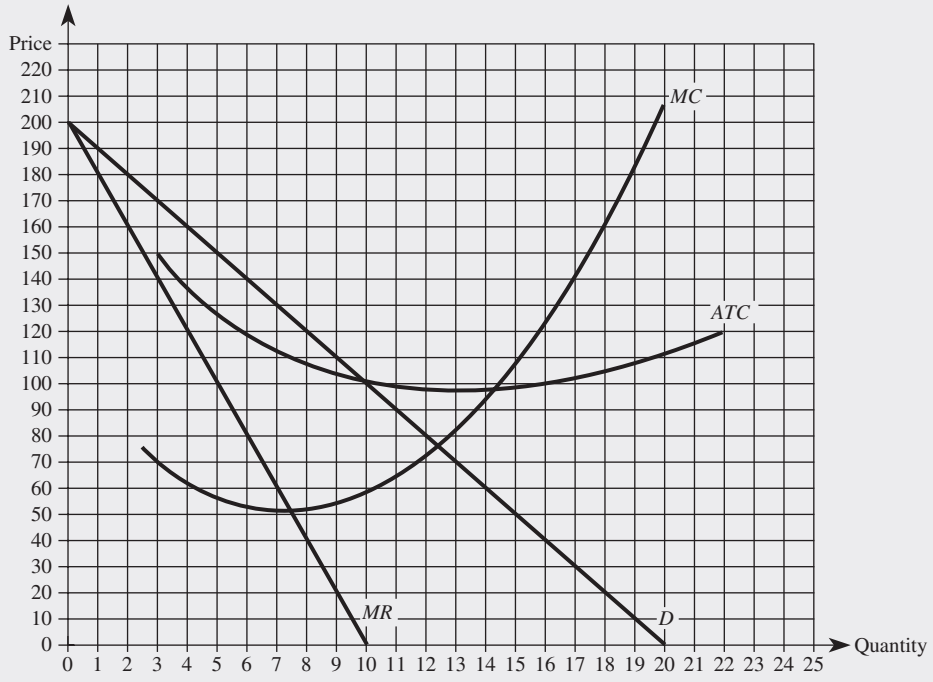
KEY TERMS AND CONCEPTS

Antitrust Division of the Department of Justice (DOJ)
antitrust policy
Celler-Kefauver Act (1950)
Clayton Act (1914)
deadweight loss of monopoly
Federal Trade Commission (FTC)
Hart-Scott-Rodino Antitrust Improvement Act (1976)
Herfindahl-Hirschman index (HHI)
Horizontal Merger Guidelines
market power
rent seeking
Robinson-Patman Act (1936)
rule of reason
Sherman Antitrust Act (1890)
social welfare

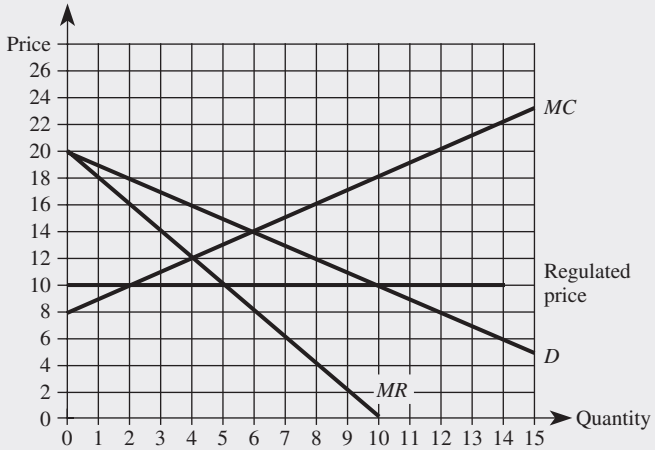
PRACTICE PROBLEMS



1. You are the manager in a market composed of eight firms, each of which has a 12.5 percent market share. In addition, each firm has a strong financial position and is located within a 100-mile radius of its competitors. *(LO1)*
   a. Calculate the premerger Herfindahl-Hirschman index (HHI) for this market.
   b. Suppose that any two of these firms merge. What is the postmerger HHI?
   c. Based only on the information contained in this question and on the *Horizontal Merger Guidelines* described in this chapter, do you think the Justice Department (or FTC) would attempt to block a merger between any two of the firms? Explain.
2. Use the accompanying graph to answer the questions that follow. *(LO1)*
   a. Suppose this monopolist is unregulated.
      (1) What price will the firm charge to maximize its profits?
      (2) What is the level of consumer surplus at this price?
   b. Suppose the firm's price is regulated at $80.
      (1) What is the firm's marginal revenue if it produces 7 units?
      (2) If the firm is able to cover its variable costs at the regulated price, how much output will the firm produce in the short run to maximize its profits?
      (3) In the long run, how much output will this firm produce if the price remains regulated at $80?



3. As the manager of a monopoly, you face potential government regulation. Your inverse demand is $P = 40 - 2Q$, and your costs are $C(Q) = 8Q$. *(LO1, LO2)*
   a. Determine the monopoly price and output.
   b. Determine the socially efficient price and output.
   c. What is the maximum amount your firm should be willing to spend on lobbying efforts to prevent the price from being regulated at the socially optimal level?
4. The accompanying diagram depicts a monopolist whose price is regulated at $10 per unit. Use this figure to answer the questions that follow. *(LO1)*
   a. What price will an unregulated monopoly charge?
   b. What quantity will an unregulated monopoly produce?
   c. How many units will a monopoly produce when the regulated price is $10 per unit?
   d. Determine the quantity demanded and the amount produced at the regulated price of $10 per unit. Is there a shortage or a surplus?
   e. Determine the deadweight loss to society (if any) when the regulated price is $10 per unit.
   f. Determine the regulated price that maximizes social welfare. Is there a shortage or a surplus at this price?



5. The fighters of the Ultimate Fighting Championship (UFC) filed suit against the UFC, alleging that the UFC unlawfully monopolized the output and input markets in mixed martial arts. In particular, the fighters claimed that UFC used long-term exclusive contracts to permanently lock them into the UFC and foreclose rival mixed martial arts promotions. Under which act do you think the UFC was charged? *(LO1)*
6. Between 1972 and 1981, Texaco sold gasoline to independent Texaco retailers at "retail tank wagon prices" but granted substantial discounts to distributors Gull and Dompier. Gull resold the gas under its own name. Dompier resold the gas under the Texaco brand name to retail stations and entered the retail market directly. Since neither Gull nor Dompier had significant storage facilities, both distributors picked up gas directly from the Texaco plant and delivered it to their retail outlets. As a result, the sales volume increased substantially at the retail stations purchasing gas from these distributors, while independent Texaco retailers suffered a corresponding sales decline. In 1976, independent Texaco retailers filed suit against Texaco. In 1990, the Supreme Court of the United States found that Texaco had indeed violated antitrust law. Which law do you think Texaco was found guilty of violating? *(LO1)*
7. Social Dynamo Corporation earned profits last year of $49 million on sales of $500 million. During the same period, its major competitor—EIO Corp.—enjoyed sales of $490 million and earned profits of $52 million. Currently, Social Dynamo is negotiating a deal in which it would acquire the assets of EIO in a transaction Wall Street values at $120 million. A successful merger between the two companies is expected to raise prices in the market by 2 percent. Is Social Dynamo obligated to notify the U.S. Justice Department and the Federal Trade Commission of its merger intentions? Explain. *(LO1)*
8. Moses Inc. is a small electric company that provides power to customers in a small rural area in the Southwest. The company is currently maximizing its profits by selling electricity to consumers at a price of $0.15 per kilowatt-hour. Its marginal cost is $0.05 per kilowatt-hour, and its average cost is $0.15 per kilowatt-hour. A government regulator is considering a proposal to regulate the firm's price at $0.05 per kilowatt-hour. Would such a policy improve social welfare? Explain. *(LO1)*
9. The Federal Trade Commission (FTC) issued a complaint against Nestlé and Ralston Purina alleging that a proposed merger between the two companies would violate, among other things, section 7 of the Clayton Act. While these two companies sell many products that raise no antitrust concerns, the FTC argued that Ralston and Nestlé controlled 34 percent and 11 percent of the dry cat food market, respectively, so a merger between these two companies would substantially increase concentration in this market. More specifically, the FTC alleged that the merger would increase the HHI by more than 750 points, to over 2,400, and increase the likelihood that the merged company could unilaterally exercise market power and raise prices in the market for dry cat food. Several months later, however, the FTC conditionally approved the $10.3 billion merger between the two companies. In light of the FTC's concerns, how do you think the parties ultimately obtained its approval? (*LO1*)

MODULE 6: REGULATION OF MARKETS WITH EXTERNALITIES, PUBLIC GOODS, OR INCOMPLETE INFORMATION

LEARNING OBJECTIVES

After completing this module, you will be able to:

- **LO1** Show why externalities can lead competitive markets to provide socially inefficient quantities of goods and services, and explain how government policies, such as the Clean Air Act, can improve resource allocation.
- **LO2** Show why competitive markets fail to provide socially efficient levels of public goods, and explain how the government can mitigate these inefficiencies.
- **LO3** Explain why incomplete information compromises the efficiency of markets, and identify five government policies aimed at mitigating these problems.

One of the main reasons for government involvement in the marketplace is that free markets do not always result in the socially efficient of quantities of goods at socially efficient prices. Besides market power, the presence of externalities, public goods, or incomplete information can all be sources of such market failure. We discuss each in turn.

Externalities

negative externalities
Costs borne by parties who are not involved in the production or consumption of a good.

Unfortunately, some production processes create costs for people who are not part of the production or consumption process for the good. These external costs are called **negative externalities**.

The most common example of a negative externality is pollution. When a firm creates wastes that either do not easily biodegrade or have harmful effects on other resources, it does not pay the full cost of production. For example, a firm that produces textiles usually creates waste products that contain dioxin, a cancer-causing chemical. When a textile manufacturer can dispose of this waste "for free" by dumping it into a nearby river, it has an incentive to dump more waste into the river than is socially optimal. While the firm benefits from dumping waste into the river, the waste reduces the oxygen content of the water, clogs normal waterway routes, and creates reproduction problems for birds, fish, reptiles, and aquatic animals. These results negatively affect people who are not involved in the production or consumption process.

To see why the market fails to provide the efficient level of output when there are externalities in production, consider Figure M6–1. If a firm emits pollutants into the water as a by-product of producing steel, a cost, or negative externality, is borne by members of society. Figure M6–1 shows the negative externality as the marginal cost of pollution to society. This cost represents the cost to society of dirtier water due to increases in steel production. The production of only a little steel results in only minor damage to water, but as increasing amounts of steel are produced, more and more pollutants collect in the water. The marginal cost of pollution to society thus increases as more steel is produced.

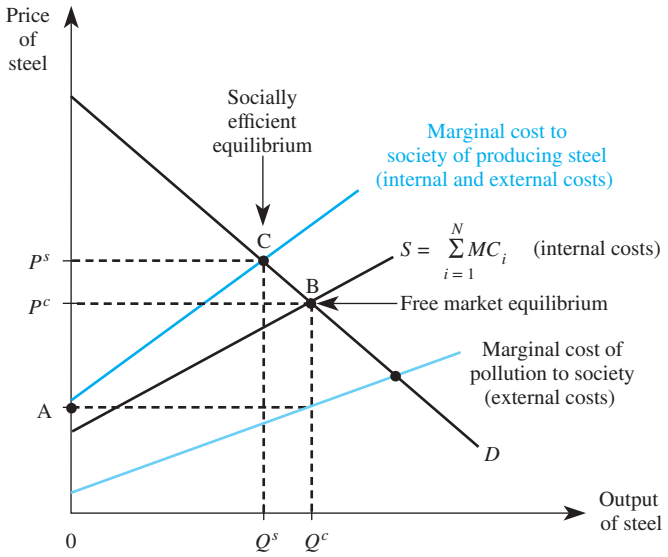


Figure M6–1

The Socially Efficient Equilibrium in the Presence of External Costs

Assuming the market for steel is perfectly competitive, the market supply curve is S in Figure M6–1, which is the sum of the marginal costs of the firms producing in the industry. The supply curve is based on the costs paid by the steel firms; thus, if they are allowed to dump pollutants into the water for free, the market equilibrium is at point B, where the market demand and supply curves intersect. The result is that Q^C units will be produced and purchased at a price of P^C per unit of steel.

However, at this quantity of output, society pays a marginal price of A, on top of the price of P^C paid to the steel firms. This amount is the additional cost to society of the pollution. In particular, since the firms are dumping pollutants into the water for free, the cost of pollution is not internalized by those who buy and sell steel; rather, society pays for the dumping of pollutants by having to endure polluted water. If the firms were to take into account the cost of pollution to society, their marginal cost curves would become the vertical sum of the supply curve and the marginal cost of pollution to society. This sum is shown as the marginal cost to society of producing steel in Figure M6–1. The socially efficient level of output, which takes into account all the costs and benefits of producing steel, is at point C, where the marginal cost to society of producing steel intersects the market demand curve. The socially efficient level of steel output is Q^S, which is less than the output produced in the perfectly competitive market. The socially efficient price of steel is P^S, which is greater than the perfectly competitive price of P^C. In other words, in the presence of external costs, the market equilibrium output is greater than the socially efficient level and the market price is below the socially efficient level. In effect, consumers get to purchase too much output at too low a price.

The basic reason for the "market failure" is the absence of well-defined *property rights*; the steel firms believe they have the right to use the river to dump waste, and environmentalists believe they have the right to a clean river. This failure often can be solved when government defines itself to be the owner of the environment. It can then use its power to induce the socially efficient levels of output and pollution.

To induce the socially efficient level of output, government may force firms to internalize the costs of emitting pollutants by enacting policies that shift the internal cost of production up to where it actually equals the social cost of production. A prime example of a government policy designed to do this is the Clean Air Act.

The Clean Air Act

To solve the externality problem caused by pollution, Congress passed the *Clean Air Act* in 1970 and a sweeping amendment in 1990. The amended Clean Air Act covers 189 toxic air pollutants and was the most comprehensive antipollution act passed by any country as of 1992. The Clean Air Act now covers any industry that releases over 10 tons per year of any of the listed pollutants or 25 tons per year of any combination of those pollutants. Previous law covered only industries that released 100 tons per year of a much smaller list of pollutants, but the new act covers a much broader set of industries. The amended Clean Air Act is so voluminous that guidelines for compliance usually comprise several hundred pages. Due to the comprehensive nature of the act, we will examine only one aspect of the new law that specifically uses the market as an enforcement mechanism.

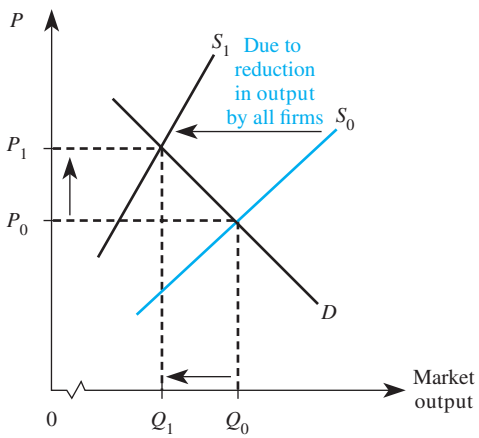
A firm in an industry covered by the Clean Air Act is required to obtain a permit to be able to pollute. These permits are limited in availability and require the firm to pay a fee for each unit of pollutants emitted. For an existing firm, these permits increase both the fixed and variable costs of producing goods. They are a variable cost because as output increases, the level of pollutants emitted rises, and a fee must be paid on each of these units of pollution. The fixed-cost component is the fee required to obtain a permit in the first place. Along with the permit, the Clean Air Act requires new entrants into an industry to match or improve on the most effective pollution removal system used in the industry. Existing firms must follow suit and upgrade within three years. Once purchased from the government, the permits may be bought from and sold to other firms.

The Clean Air Act causes firms to internalize the cost of emitting pollutants since a fee must be paid for each unit emitted. This raises each firm's marginal cost and therefore induces them to produce less output. As shown in Figure M6–2, this leads to a decrease in the market supply of the good; less of the product is available in the market at any price. Consequently, the Clean Air Act ultimately decreases the market equilibrium quantity from Q_0 to Q_1 in Figure M6–2 and raises the market price from P_0 to P_1. The change caused by the permits is exactly what is called for in Figure M6–1 to solve the negative externality of pollution: less output at a higher price.

An interesting aspect of this new legislation is the fact that permits can be sold by one firm to another both within and across industries. This does two things that allow the market to reduce pollution. First, it allows new firms to enter an industry when demand increases. Second, it provides an incentive for existing firms to invest in new technology to create cleaner production methods.

Figure M6–2

Impact of the Clean Air Act



To see this, suppose demand in a nonpolluting industry increases. As a result, the price increases, economic profits will be earned in the short run, and in the long run new firms will enter the market until economic profits return to zero. However, in a polluting industry that is not allowed to buy and sell permits to pollute, entry cannot occur; the fixed number of pollution permits is already allocated, and new entrants face a barrier to entry because of their inability to obtain a permit. In contrast, if the permits can be traded across industries, a potential entrant can purchase these rights from a firm in another industry or bring less polluting technology into the existing industry and buy some of the rights to pollute from existing firms. Thus, by making the pollution rights marketable, new firms can enter markets when consumer preferences indicate that more of the good is desired. Firms wishing to enter an industry that produces a highly valued product can purchase permits from firms that produce products that consumers do not value as highly.

The ability to sell the permits also provides an incentive for firms to develop and innovate new technologies that produce less pollution. In particular, a firm that develops a pollution-reducing technology can sell the pollution rights it no longer needs to firms in industries where the technology is not available. This allows the innovating firm to recover a portion of the cost of developing pollution-reducing technologies.

DEMONSTRATION PROBLEM M6–1

For a video walkthrough of this problem, visit www.mhhe.com/baye10e

Suppose the external marginal cost of producing steel is

$$MC_{External} = 3Q$$

and the internal marginal cost is

$$MC_{Internal} = 6Q$$

The inverse demand for steel is given by

$$P = 100 - Q$$

1. What is the socially efficient level of output?
2. How much output would a competitive industry produce?
3. How much output would a monopoly produce?

ANSWER:

1. The socially efficient level of output occurs where the marginal cost to society of producing another unit equals demand. The social marginal cost is

   $$MC_{Social} = MC_{External} + MC_{Internal} = 3Q + 6Q = 9Q$$

   Equating this with price yields

   $$9Q = 100 - Q$$

   or $Q = 10$ units.
2. A competitive industry produces where the internal marginal cost equals price:

   $$6Q = 100 - Q$$

   or about $Q = 14.3$ units. Thus, a competitive industry produces too much steel because it ignores the cost society pays for the pollution.

3. A monopolist produces where marginal revenue equals the internal marginal cost. Since $MR = 100 - 2Q$, we have

$$100 - 2Q = 6Q$$

or $Q = 12.5$ units. Thus, given these demand and cost functions, a monopolist will produce more than the socially efficient level of steel with these cost conditions. Note, however, that since the monopolist has a tendency to restrict output, given these cost and demand functions it produces closer to the socially efficient level than does a competitive industry.

Public Goods

public good
A good that is nonrival and nonexclusionary in consumption.

Another source of market failure is the provision of **public goods**—goods that are nonrival and nonexclusionary in nature and therefore benefit persons other than those who buy the goods. Public goods differ from most goods you consume, which are rivalrous in nature. This simply means that when you consume the good, another person is unable to consume it as well. For example, when you buy and wear a pair of shoes to protect your feet, you prevent someone else from wearing the same pair; the consumption of shoes is rivalrous in nature.

nonrival good
A good is nonrival in consumption if the consumption of the good by one person does not preclude other people from also consuming the good.

Nonrival goods include radio signals, lighthouses, national defense, and protecting the environment. When you receive a radio signal in your car, you do not prevent other drivers from picking up the same station in their cars. This is in sharp contrast to your purchasing a pair of shoes.

The second aspect of a public good is that it is **nonexclusionary**: Once a public good is made available, everyone gets it; no one can be excluded from enjoying the good. Most goods and services are by nature exclusionary. For example, when a car manufacturer produces a car, it can keep people from using the car by putting a lock on the door and giving the key only to the person who is willing to pay for the car.

nonexclusionary good
A good or service is nonexclusionary if, once provided, no one can be excluded from consuming it.

Goods and services such as clean air, national defense, and radio waves are nonexclusionary goods. For example, when the air is clean, everyone gets to consume the clean air; it cannot be allocated to a single person.

What is it about public goods that leads the market to provide them in inefficient quantities? The answer is that since everyone gets to consume a public good once it is available, individuals have little incentive to purchase the good; rather, they prefer to let other people pay for it. Once it becomes available, they can "free ride" on the efforts of others to provide the good. But if everyone thinks this way, no one will buy the good and it will not be available. One person alone may be unable to afford to purchase the good.

DEMONSTRATION PROBLEM M6–2

Every time you go to your firm's lounge to get a cup of coffee, the pot is empty. Why?

ANSWER:

There is a free-rider problem caused by the public-goods nature of making a pot of coffee. If you make a pot when it is empty, you benefit by getting a cup, but so do the next seven people who come into the lounge after you. Thus, people typically wait to let someone else make the coffee, which results in an empty coffee pot.

A concrete example will help you see why public goods are not provided in the socially efficient quantity. Suppose individuals value streetlights in their neighborhood because

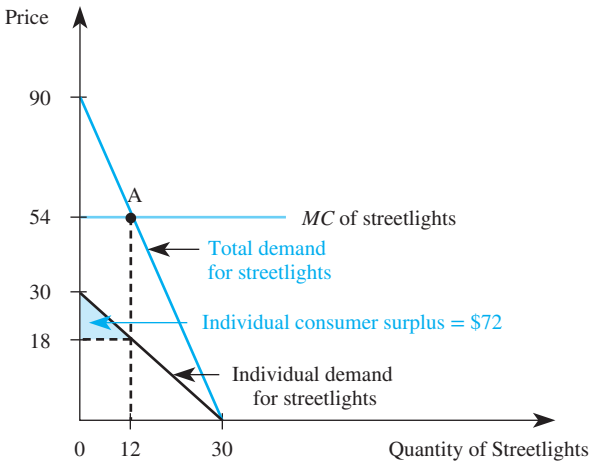


Figure M6–3
The Demand for a Public Good

streetlights help prevent crime. Three people live in the neighborhood: A, B, and C. All three individuals have identical inverse demand functions for streetlights: $P_A = 30 - Q$, $P_B = 30 - Q$, and $P_C = 30 - Q$. The inverse demand curves reveal how much each person values another streetlight.

Because streetlights are nonexclusionary and nonrival in nature, everyone benefits once a streetlight is installed. For this reason, the total demand for a public good such as streetlights is the vertical sum of the individual inverse demand curves; it reveals the value of each additional streetlight to everyone in the neighborhood. Given A's, B's, and C's individual demands, the total demand for streetlights is given by

$$P_A + P_B + P_C = 90 - 3Q$$

The individual and total demand curves are graphed in Figure M6–3. Notice that the total demand curve is the vertical sum of all three individual demand curves, and thus every point on it is three times higher than each point on the individual demand curves.

The socially efficient level of streetlights is at point A in Figure M6–3, where the marginal cost of producing streetlights exactly equals the total demand for streetlights. Algebraically, if the marginal cost of providing streetlights is $54 per light, the socially efficient quantity of streetlights is the quantity that equates

$$54 = 90 - 3Q$$

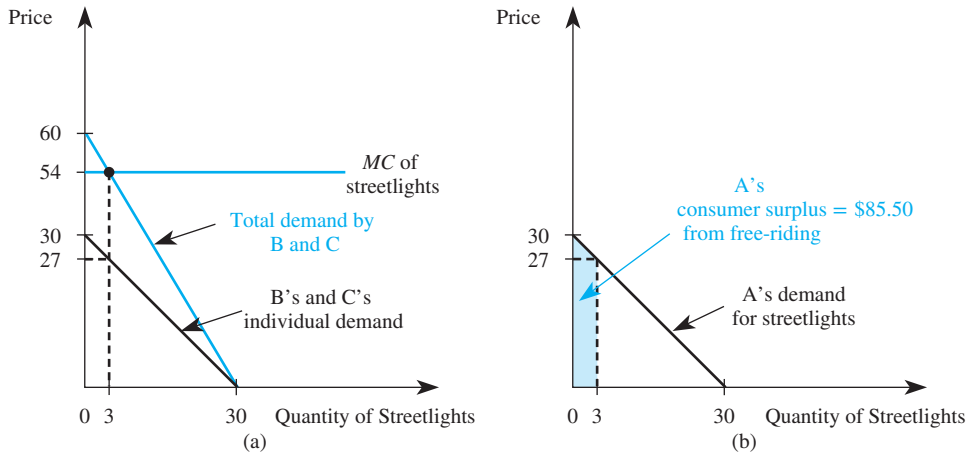
which is 12 lights.

Since the marginal cost of each streetlight is $54 and lies above each individual's demand curve for streetlights in Figure M6–3, none of them will be willing to pay for even one streetlight on their own. However, if each person paid $18 per light, together they would pay $54 per light and could afford to purchase the socially efficient quantity of lights. The only way the people in this neighborhood can achieve the socially efficient quantity of lights is to pool their resources. If they accomplish this and each pays $18 per light, each will enjoy a consumer surplus of the shaded region in Figure M6–3, which is $72.

The problem, however, is that each individual would be better off by letting the other two install the streetlights. In particular, it is strategically advantageous for each person to misrepresent his or her true personal demand function (valuation of the public good). If A claimed she did not want streetlights, and let the others pay for them, she would get to enjoy the lights

Figure M6–4

The Free-Rider Problem



for free (due to the nonrival and nonexclusionary nature of the good). This is similar to "cheating" on a cooperative agreement and is called *free riding*.

To illustrate this idea, suppose that instead of revealing her true demand for streetlights, A stated that she does not value streetlights at all. If A is the only one who did this, the revealed demand function would be the vertical sum of B's and C's inverse demand functions, which is shown in Figure M6–4(a). Since this demand curve intersects the $54 marginal cost at three streetlights, B and C would each pay $27 per light and purchase three lights. A, on the other hand, would get to enjoy the three streetlights for free because she misrepresented her true demand for streetlights. By consuming three streetlights for free, she would enjoy a consumer surplus of $85.50, which corresponds to the shaded region in Figure M6–4(b). In contrast, if she had truthfully revealed her demand for streetlights, her consumer surplus would be only $72—the shaded region in Figure M6–3. Thus, A is better off by misrepresenting her true preferences for streetlights and letting B and C buy them.

Of course, the same is true of the other two individuals: If they think the others will contribute to buying streetlights, they are better off claiming not to want them. And if they think no one else will pay for streetlights, they will not pay for even one since the cost is greater than their own individual demand. In the end, no streetlights are provided; the market has failed to provide the public good.

Government solves the public-goods problem by forcing everyone to pay taxes regardless of whether or not a given taxpayer claims to want government services. Government then uses this revenue to fund public projects such as streetlights and national defense, which would not be provided in the absence of government intervention in the marketplace. Thus, while few of us enjoy paying taxes, it does provide a means for obtaining funds for public goods.

It is important to note that government may not provide the socially efficient quantity of public goods; it may in fact provide too much of them. The reason is that when a government official asks a citizen how much of a public good she or he desires, the person may misrepresent the quantity desired. Because most people believe their tax bill is an extremely small percentage of the total funds used to provide public goods, they perceive that the personal cost of the goods is zero and report to the official how many units of the public good they would desire if it were free. In our streetlight example, this means that all three people would tell the official they wanted 30 streetlights—more than twice the socially efficient quantity.

DEMONSTRATION PROBLEM M6–3

A firm has 20 employees, each of whom desires a more pleasant work environment. Accordingly, they are considering planting shrubs near the firm's parking lot. Each employee has an inverse demand for shrubs of $P = 10 - Q$, where Q is the number of shrubs. The marginal cost of planting shrubs is $20 each.

1. What is the socially efficient quantity of shrubs to plant?
2. How much would each person have to pay per shrub to achieve the efficient quantity?
3. How many shrubs are likely to be planted? Why?

ANSWER:

1. The total demand for shrubs (a public good) is

$$P = 200 - 20Q$$

Equating this with the marginal cost of planting shrubs yields the socially efficient quantity of shrubs:

$$200 - 20Q = \$20$$

or $Q = 9$ shrubs.

2. If each person paid his or her marginal valuation of another shrub, which is

$$P = 10 - 9 = \$1$$

the 20 employees together would pay $20 for each shrub.

3. Since there is a free-rider problem, no shrubs are likely to be planted unless the boss exerts "moral suasion" and collects $9 from each employee to plant nine shrubs.

We conclude by pointing out that it may be advantageous for a firm to contribute to public goods in its market area. Doing things such as cleaning up a local park or giving money to public television creates goodwill toward the firm and as a result may create brand loyalty or increase the demand for the firm's product. Because public goods are nonrival and nonexclusionary, $1 spent on cleaning up a park or subsidizing public TV is $1 spent on everyone who finds a clean park or public TV appealing. This makes the provision of public goods an inexpensive way for a firm to "benefit" numerous consumers and thus may be a useful advertising strategy in some situations. Another advantage is that it may put the firm on more favorable terms with politicians, who have considerable latitude in affecting the environment in which the firm operates. Unfortunately, there is no easy way to explicitly calculate the optimal amount that a firm should voluntarily contribute to public goods. But ultimately, if the firm's goal is to maximize profits, the last dollar spent on contributions to public projects should bring in one additional dollar in revenue.

Incomplete Information

For markets to function efficiently, participants must have reasonably good information about things such as prices, quality, available technologies, and the risks associated with working in certain jobs or consuming certain products. When participants in the market have *incomplete information* about such things, the result will be inefficiencies in input usage and in firms' output.

Consider the consumption of cigarettes. If individuals are not told that cigarettes are hazardous, some people who currently do not smoke because of the known health risks would smoke out of ignorance of the dangers of smoking. The decision to smoke would be based on incomplete information about the dangers of smoking. For reasons such as these, government serves as a provider of information in many markets, dispensing information to consumers about the ingredients of certain foods, the dangers of certain products and drugs, and the like. Firms print some of this information on the labels of their products due to regulations imposed by government. Government even regulates the work environment by ensuring that workers are aware of the dangers of chemicals such as asbestos and the benefits of precautions such as wearing hard hats in construction jobs. In these instances, the regulations are carried out by the Occupational Safety and Health Administration (OSHA).

One of the more severe causes of market failure is asymmetric information, a situation where some market participants have better information than others. As we saw in Chapter 12, the presence of asymmetric information can lead buyers to refuse to purchase from sellers out of fear that the seller is willing to get rid of the product because it is worth less than they are willing to pay. In the extreme case, the market can collapse altogether. For this reason, several government policies are designed to alleviate the problems caused by asymmetric information. A few of the policies that affect managers are discussed next.

Rules against Insider Trading

One example of a government regulation designed to alleviate market failures due to asymmetric information is the law against *insider trading* in the stock market. The purpose of the law is to ensure that asymmetric information (better information by insiders) does not destroy the market by inducing outsiders to stay out of it.

For example, suppose Jane Insider has just learned that her research staff has made a discovery that will revolutionize the industry. If Jane can keep the discovery quiet for a short time while she purchases some of her company's stock at its present price, she will make a bundle. When the announcement of the discovery is made public and the market price of the stock increases dramatically, she can resell the stock and make a large profit. Unfortunately, if potential investors believe the market is dominated by insiders who buy and sell stock based on inside information, they will stay out of the market. The only time the insiders will sell is when they know the price will fall, and they will buy only when they know the price will rise. There is no way for outsiders to earn money in a market dominated by insiders, and they will refuse to buy or sell stock. This reduces the marketability of assets in markets dominated by insiders, which decreases the welfare of all potential market participants.

To prevent insider trading from destroying the market for financial assets, the government has enacted rules against insider trading. The regulations on insider trading come from Section 16 of the *Securities and Exchange Act* (1934). They were amended in 1990 and again in 2002. Most recently, Section 16 was amended by the Sarbanes-Oxley Act of 2002, which made sweeping changes in governance and reporting obligations.

Certification

Another policy government uses to disseminate information and reduce asymmetric information is the certification of skills and/or authenticity. The purpose of *certification* is to centralize the cost of gathering information. All licensing done by the government falls under certification; this includes all nonprofit organizations, such as charities. Certification can also be a set of minimum standards, such as those for schools and physicians. The purpose is to assure consumers that the products or services have been certified as meeting a certain set of minimum standards. Without a central authority to fulfill this information-gathering role, each individual would have

to pay the cost of gaining knowledge about the quality of a product or service. This would lead to inefficiencies due to duplication of information-gathering efforts.

Schools are an example of a potential asymmetric information problem. Without the government certifying a school as satisfying some minimum standard, anyone could open a school. Parents who wanted to educate their children would choose a school based on appearance, cost, proximity to their home, advertising, and reputation. When the school first opened, it might look like a very good deal. But to save money, the school might choose to use unsafe equipment, hire undereducated teachers, and crowd classrooms far beyond a size that is conducive to learning. In the long run, the market would correct these problems; their reputation for poor quality would drive bad schools out of business. In the short run, however, parents who had enrolled their children would lose their investment in education, and the students would have wasted potentially valuable time.

Physician certification is another example of the short-run benefits of government certification. In the absence of physician certification, some less-than-reputable person could hang a sign stating "Medical Service Here." If improperly trained, this person might prescribe a medicine that could make a patient worse, cause a drug addiction, or even lead to death. In the presence of a government-enforced set of standards, however, this short-run scenario is less likely to happen.

Truth in Lending

A set of legislation over the years has made gathering information for borrowing purposes less difficult. Confusion caused by the *Truth in Lending Act* (1969) led Congress to pass the *Truth in Lending Simplification Act (TLSA)* in 1980. TLSA is enforced by the Federal Reserve Board (FRB) and has been revised several times. In 1980, the FRB passed *Regulation Z* to provide guidelines for enforcement; it amended Regulation Z in 1982.

Regulation Z and TLSA require that all creditors comply with the act. A creditor is defined as anyone who loans money subject to a finance charge, where the money is to be paid back in four or more installments. A creditor must also be the person to whom the original obligation is payable. TLSA has some exemptions regarding the types of loans covered, the most notable being business, agricultural, and commercial loans.

TLSA requires that creditors disclose certain information to debtors in writing before the consummation of loans. This information includes an itemization of all finance charges, the total purchase price, the annual interest rate charged, and over a dozen other items. The purpose of this law is to ensure that all debtors are given an opportunity to understand all aspects of borrowing money from a specific creditor, thus creating more symmetric information between borrowers and lenders.

The Truth in Lending Act affects both the supply of and the demand for credit. Potential borrowers now have more complete information about what a loan involves. This increased knowledge reduces the risk involved in repayment for the borrower. The reduced risk shifts the demand curve for loans to the right. The suppliers of loans (creditors) are affected mainly by the increased cost of complying with the government regulations. This shifts the creditors' supply curve to the left. Since the demand curve for loans shifts to the right and the supply curve shifts to the left, the effect of this law is to increase the price of loans (the interest rate).

Truth in Advertising

Often firms have better information about their products than do consumers. This advantage may give firms an incentive to make false claims about the merits of their products to capitalize on consumers' lack of information. In some instances, such practices can lead consumers to

switch from one firm's product to a competitor's product. In extreme cases, the asymmetric information can induce consumers to ignore advertising messages altogether, out of fear that the messages are false. Government often can alleviate these market failures by regulating the advertising practices of firms.

Advertising regulation, which encourages *truth in advertising*, usually is enforced by civil suits. Under Section 43 of the *Lanham Act*, false and misleading advertising is prohibited. Technically, the FTC can bring suit against any false advertising using the Lanham Act, although most cases are filed in civil court by those harmed by deceptive advertising rather than by the FTC.

The Lanham Act, in concert with the Clayton Act, allows someone who is harmed by false or misleading advertising to stop the deceptive practice and receive treble damages. If a firm finds that a competitor's deceptive advertising reduces the demand for its product, it may sue under the Lanham Act. The plaintiff first must prove that the advertisement either is false or misleads consumers. The plaintiff also must prove that the misleading or false advertising harmed it. If the plaintiff wins, the defendant must cease running the advertisement, recall any units of the product that have the false or misleading claim on their label, and pay the plaintiff three times the damages the advertisement caused the plaintiff.

INSIDE BUSINESS M6–1

Canada's Competition Bureau

The Competition Bureau is an independent law enforcement agency responsible for promoting and maintaining fair competition in Canada. Its authority stems from *The Competition Act*, a federal law that contains both criminal and civil provisions aimed at preventing anticompetitive practices in the marketplace. The Competition Bureau's principal responsibilities were restructured in 2015 to streamline the number of branches from nine into the following four:

- *The Mergers and Monopolistic Practices Branch* reviews proposed merger transactions and investigates practices that could negatively impact competition.
- *The Cartels and Deceptive Marketing Practices Branch* fights criminal or deceptive business practices that hurt consumers and competition in the marketplace.
- *The Competition Promotion Branch* actively encourages the adoption of pro-competitive positions, policies, and behaviors by businesses, consumers, regulators, government and international partners. The Branch also provides economic analysis in support of enforcement, and leads the Bureau's planning and reporting processes.
- *The Corporate Services Branch* provides advice, planning and services for the effective operation of the Bureau's financial, asset, information management and human resource activities, as well as access to information, privacy, values and ethics, security and procurement matters. The Branch also provides expertise in complaint management and evidence collection and preservation in support of the Bureau's mandate.

In addition to these four branches, *The Commissioner's Office* provides strategic advice and support to the Commissioner, and coordinates the Commissioner's relationship with the Bureau's branches, Innovation, Science and Economic Development Canada and external stakeholders. Finally, *Legal Services* are provided by Competition Bureau Legal Services (Department of Justice) and the Competition Law Section (Public Prosecution Service of Canada).

SOURCE: Competition Bureau website, October 20, 2020 and July 31, 2012.

Enforcing Contracts

Another way government solves the problems of asymmetric information is through *contract enforcement*. In Chapters 6 and 10, we learned that contracts are written to keep the parties from behaving opportunistically in the final period of a game. For example, suppose your boss "promised" you payment for labor services at the end of the month. After you have worked for a month, your boss refuses to pay you—in effect gaining a month's worth of your labor for free. In Chapters 6 and 10 we saw that these types of problems do not arise when reputation is important or when there is the potential for repeated interaction among the parties. In these instances, the onetime gain to behaving opportunistically will be more than offset by future losses.

In short-term relationships, however, one or more parties may take advantage of the "end period" by behaving opportunistically. If you knew your boss would not pay you at the end of the month, you would refuse to work. The problem, however, is that you do not know what your boss will do at the end of the month—only she does. In effect, you are uncertain whether your boss is honest (will keep a promise) or dishonest (will break a promise). This asymmetric information can destroy the ability of individuals to use contracts to solve the problem of opportunism; even if a contract is written, a boss may not honor it. Because of this, you may refuse to work for your boss even if she is honest because you do not *know* whether she is honest.

One solution to this problem is for government to enforce contracts. By enforcing contracts, government effectively solves the "end-of-period" problem by requiring dishonest people to honor the terms of contracts. In this case, even if you do not know whether your boss is honest, you will be willing to work under contract. If she turns out to be dishonest, the government will force her to pay you. Thus, government enforcement of contracts can solve market failures caused by the end-of-period problem.

KEY TERMS AND CONCEPTS

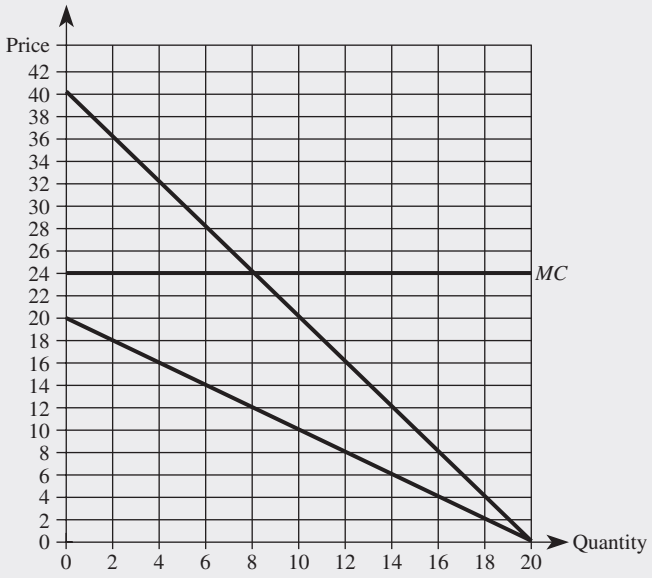
certification
Clean Air Act (1990)
contract enforcement
free riding
incomplete information
insider trading
Lanham Act
negative externalities
nonexclusionary good
nonrival good
property rights
public good
Regulation Z
Securities and Exchange Act (1934)
truth in advertising
Truth in Lending Act (1969)
Truth in Lending Simplification Act (TLSA) (1980)

PRACTICE PROBLEMS



1. You are an industry analyst who specializes in an industry where the market inverse demand is $P = 200 - 4Q$. The external marginal cost of producing the product is $MC_{External} = 6Q$, and the internal cost is $MC_{Internal} = 12Q$. *(LO1)*
   a. What is the socially efficient level of output?
   b. Given these costs and market demand, how much output would a competitive industry produce?
   c. Given these costs and market demand, how much output would a monopolist produce?
   d. Discuss actions the government might take to induce firms in this industry to produce the socially efficient level of output.

2. There are two workers. Each worker's demand for a public good is $P = 20 - Q$. The marginal cost of providing the public good is \$24. The accompanying graph summarizes the relevant information. *(LO2)*
   a. What is the socially efficient quantity of the public good?
   b. How much will each worker have to pay per unit to provide the socially efficient quantity?
   c. Suppose the two workers contribute the amount needed to provide the quantity of public good you identified in parts (*a*) and (*b*). A third worker values the public good just like the two contributing workers, but she claims *not* to value the good because she wants to "free ride" on the payments of the other two workers.
      (1) Given the three workers' true demands for the public good, is the amount of the public good provided by the two workers socially efficient?
      (2) Compare the level of consumer surplus enjoyed by these three workers. Which worker(s) enjoys the most surplus?



3. Explain, using precise economic terminology, the economic rationale for laws against insider trading. *(LO3)*
4. Is "fairness" the economic basis for government laws and regulations designed to remedy market failures? If so, why; if not, what is the economic basis? *(LO1)*
5. A well-known conglomerate that manufactures a multitude of noncompeting consumer products instituted a corporatewide initiative to encourage the managers of its many divisions to share consumer demographic information. However, since the initiative was implemented, the CEO has noticed that less information is available than ever. Why do you think the CEO's plan backfired? *(LO2)*
6. You are the manager of a paper mill and have been subpoenaed to appear before a joint session of the Senate Consumer Affairs and the Senate Environmental subcommittees. The Consumer Affairs Subcommittee is interested in your testimony about the pricing practices of your company because a recent news magazine reported that your markups are 250 percent. The Environmental Subcommittee is interested in exploring ways to reduce the pollution associated with your paper mill. In particular, you know that one senator on the Environmental Subcommittee will ask you to justify why the firm should not be charged a per-unit tax on the firm's output to compensate for the pollution it discharges into a major river. Devise a game plan for responding to the questions that will be raised in the joint session of the subcommittees. *(LO1)*

7. Section 16(a) of the Securities and Exchange Act of 1934, as amended in 1990, requires that the officers, directors, and principal shareholders of companies disclose the extent of their ownership of equity securities of the company and any changes in the ownership. Section 16(b) permits companies to recover trading profits realized by such people arising from short-swing transactions in the company securities. Do you think that, as a result of these laws, the government will be forced to spend more money on its auditing and enforcement efforts? Explain. *(LO3)*
8. Enrodes is a monopoly provider of residential electricity in a region of northern Michigan. Total demand by its 3 million households is $Q^d = 1{,}500 - 2P$, and Enrodes can produce electricity at a constant marginal cost of $4 per megawatt-hour. Consumers in this region of Michigan have recently complained that Enrodes is charging too much for its services. In fact, a few consumers are so upset that they are trying to form a coalition to lobby the local government to regulate the price Enrodes charges. If all the consumers of this region joined the coalition against Enrodes, how much would each consumer be willing to spend to lobby the local government to regulate Enrodes's price? Do you think the consumers will be successful in their efforts? Explain. *(LO2)*
9. Suppose that, prior to the passage of the Truth in Lending Simplification Act and Regulation Z, the demand for consumer loans was given by $Q^d_{pre\text{-}TILSA} = 12 - 100P$ (in billions of dollars) and the supply of consumer loans by credit unions and other lending institutions was $Q^S_{pre\text{-}TILSA} = 5 + 100P$ (in billions of dollars). The TILSA now requires lenders to provide consumers with complete information about the rights and responsibilities of entering into a lending relationship with the institution, and as a result, the demand for loans has increased to $Q^d_{post\text{-}TILSA} = 18 - 100P$ (in billions of dollars). However, the TILSA also imposed "compliance costs" on lending institutions, and this reduced the supply of consumer loans to $Q^S_{post\text{-}TILSA} = 3 + 100P$ (in billions of dollars). Based on this information, compare the equilibrium price and quantity of consumer loans before and after the Truth in Lending Simplification Act. *(LO3)*

MODULE 7: GOVERNMENT POLICY AND INTERNATIONAL MARKETS

LEARNING OBJECTIVES

After completing this module, you will be able to:

LO1 Show how government policies in international markets, such as quotas and tariffs, affect the prices and quantities of domestic goods and services.

Sometimes rent seeking manifests itself in the form of government involvement in international markets. Such policies usually take the form of tariffs or quotas that are designed to benefit specific firms and workers at the expense of others. In this Module, we will examine how government tariff and quota policies affect managerial decisions.

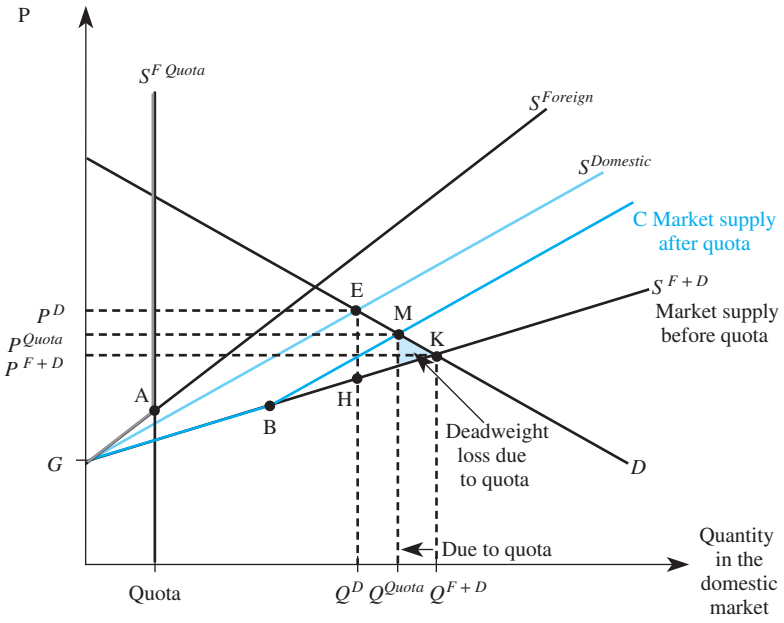
Quotas

The purpose of a **quota** is to limit the number of units of a product that foreign competitors can bring into the country. For example, a quota on Japanese automobile imports limits the number of cars Japanese automakers can sell in the United States. This reduces competition in the domestic automobile market, which results in higher car prices, higher profits for domestic

quota
A restriction that limits the quantity of imported goods that can legally enter the country.

Figure M7–1

The Impact of a Foreign Import Quota on the Domestic Market



firms, and lower consumer surplus for domestic consumers. Domestic producers thus benefit at the expense of domestic consumers and foreign producers.

To see why these results occur, consider Figure M7–1, which shows the domestic market for a product. Before the imposition of a quota, the domestic demand curve is D, the supply curve for foreign producers is $S^{Foreign}$, the supply curve for domestic producers is $S^{Domestic}$, and the market supply curve—the horizontal summation of the foreign and domestic supply curves—is S^{F+D}. Equilibrium in the absence of a quota is at point K, where the equilibrium price is P^{F+D} and the equilibrium quantity is Q^{F+D}.

Now suppose a quota is imposed on foreign producers that restricts them from selling more than the quota in the domestic market. Under the quota, foreign supply is $GAS^{F\ Quota}$, while the supply by domestic firms remains at $S^{Domestic}$. Thus, market supply in the domestic market after the quota is GBC, resulting in an equilibrium at point M. The quota increases the price received by domestic producers to P^{Quota}, and domestic firms now earn higher profits. The shaded triangle in Figure M7–1 represents the deadweight loss due to the quota. Total welfare declines as a result of the quota even though domestic producers earn higher profits. The reason for the decline in total welfare is that domestic consumers and foreign producers are harmed more than domestic producers gain from the quota. Domestic producers therefore have a strong incentive to lobby for quotas on foreign imports into their market.

DEMONSTRATION PROBLEM M7–1

Suppose the supply of a good by domestic firms is $Q^{SD} = 10 + 2P$ and the supply by foreign firms is $Q^{SF} = 10 + P$. The domestic demand for the product is given by $Q^d = 30 - P$.

1. In the absence of a quota, what is the total supply of the good?
2. What are the equilibrium price and quantity of the good?
3. Suppose a quota of 10 units is imposed. What is the total supply of the product?
4. Determine the equilibrium price in the domestic market under the quota of 10 units.

ANSWER:

1. The total supply is the sum of foreign and domestic supply, which is

$$Q^T = Q^{SD} + Q^{SF} = (10 + 2P) + (10 + P) = 20 + 3P$$

2. Equilibrium is determined by equating total demand and supply:

$$30 - P = 20 + 3P$$

Solving for P yields the equilibrium price of $P = \$2.50$. Given this price, domestic firms produce

$$Q^{SD} = 10 + 2(2.5) = 15 \text{ units}$$

and foreign firms produce

$$Q^{SF} = 10 + 2.5 = 12.5 \text{ units}$$

for a total equilibrium output of $Q^T = 27.5$ units.

3. With a quota of 10 units, foreign firms will sell only 10 units in the domestic market. Thus, total supply is

$$Q^T = Q^{SD} + Q^{SF} = (10 + 2P) + 10 = 20 + 2P$$

4. Equilibrium is determined by equating total demand and total supply under a quota:

$$30 - P = 20 + 2P$$

Solving for P yields the equilibrium price of $P = \$3.33$. The quota increases the price of the good in the domestic market due to the reduction in foreign competition.

Tariffs

Tariffs, like quotas, are designed to limit foreign competition in the domestic market to benefit domestic producers. The benefits to domestic producers accrue at the expense of domestic consumers and foreign producers.

We will address two types of tariffs: lump-sum tariffs and excise or per-unit tariffs. A **lump-sum tariff** is a fixed fee that foreign firms must pay the domestic government to be able to sell in the domestic market. In contrast, a **per-unit or excise tariff** requires the importing firms to pay the domestic government a fee on each unit they bring into the country.

lump-sum tariff
A fixed fee that an importing firm must pay the domestic government in order to have the legal right to sell the product in the domestic market.

per-unit (or excise) tariff
The fee an importing firm must pay to the domestic government on each unit it brings into the country.

Lump-Sum Tariffs

Figure M7–2 shows the marginal and average cost curves for an individual foreign firm before and after the imposition of a lump-sum tariff. The first thing to notice about the lump-sum tariff is that it does not affect the marginal cost curve. This is because the importer must pay the same amount of tariff regardless of how much of the product it brings into the country. Because the lump-sum tariff raises average costs from AC^1 to AC^2, an importer is unwilling to pay the tariff to enter the domestic market unless the price in the domestic market is at least P^2.

Figure M7–3 shows the effect of a lump-sum tariff on the market. Before the tariff is imposed, the supply curve for foreign competitors is ES^F, that for domestic producers is ES^D, and the market supply curve—the summation of domestic and foreign supply—is ES^{D+F}. After the lump-sum tariff is imposed, the foreign supply curve becomes AS^F because

Figure M7–2

Impact of a Lump-Sum Tariff on a Foreign Firm

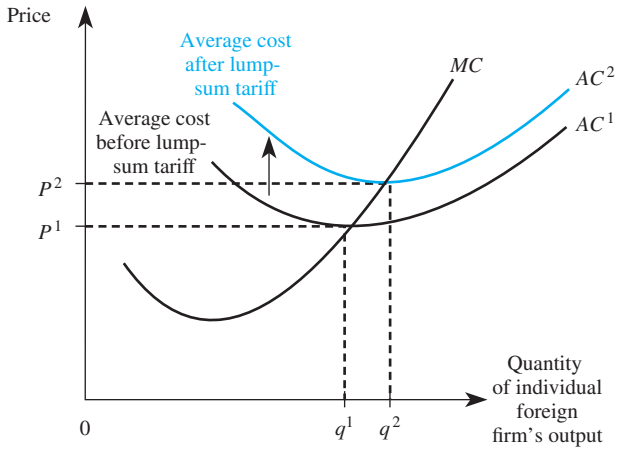
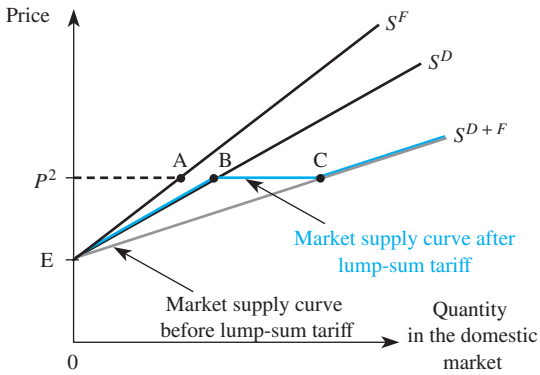


Figure M7–3

Impact of a Lump-Sum Tariff on Market Supply



importers will not pay the lump-sum tariff to enter the domestic market unless the price is above P^2. Thus, the market supply curve in the presence of a lump-sum tariff is given by $EBCS^{D+F}$. The overall effect of this policy is to remove foreign competitors from the domestic market if the demand curve crosses the domestic supply curve at a price below P^2. A lump-sum tariff increases the profits of domestic producers if demand is low but has no effect on their profits if demand is high.

Excise Tariffs

If an excise tariff is imposed on foreign producers instead of a lump-sum tariff, domestic producers benefit at all levels of demand. To see this, consider Figure M7–4, which shows the effect of an excise tariff. S^F is the supply by foreign producers before the tariff, S^D is the supply by domestic producers, and ABS^{D+F} is the market supply curve before an excise tariff. Equilibrium in the absence of a tariff is at point H.

When a tariff of T is imposed on each unit of the product, the marginal cost curve for foreign firms shifts up by the amount of the tariff, which in turn decreases the supply of all foreign firms to S^{F+T} in Figure M7–4. The market supply under a per-unit tariff is now ACS^{D+F+T}, and the resulting equilibrium is at point E. The tariff raises the price domestic consumers must pay for the product, which raises the profits of domestic firms at the expense of domestic consumers and foreign producers.

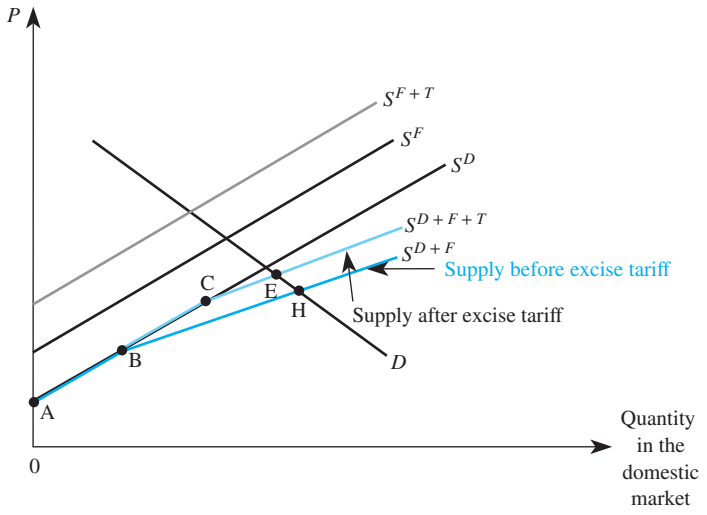


Figure M7–4
Impact of an Excise Tariff on Market Supply

KEY TERMS AND CONCEPTS

lump-sum tariff per-unit (or excise) tariff quota

PRACTICE PROBLEMS

connect

1. Consider a competitive market served by many domestic and foreign firms. The domestic demand for these firms' product is $Q^d = 600 - 2P$. The supply function of the domestic firms is $Q^{SD} = 200 + P$, while that of the foreign firms is $Q^{SF} = 250$. *(LO1)*
   a. Determine the equilibrium price and quantity under free trade.
   b. Determine the equilibrium price and quantity when foreign firms are constrained by a 100-unit quota.
   c. Are domestic consumers better or worse off as a result of the quota?
   d. Are domestic producers better or worse off as a result of the quota?
2. Suppose that the U.S. Congress passes legislation that imposes a one-time lump-sum tariff on the product that a foreign firm exports to the United States. *(LO1)*
   a. What happens to the foreign firm's marginal cost curve as a result of the lump-sum tariff?
   b. Will the lump-sum tariff cause the foreign firm to export more or less of the good? Explain carefully.
3. China's entry into the World Trade Organization (WTO) in 2001 created more competition between local and foreign firms, and also provided China greater access to the market for exports. This was particularly true in the market for rubber since, at the time, China was the world's second largest consumer of rubber (China is now the world's largest consumer of rubber). Shortly after joining the WTO, China eliminated its import quota on rubber. What impact do you think the import quota reduction likely had on the price of rubber and the quantity of rubber exchanged in China? What implications do you think the elimination of the quota on rubber had on China's social welfare? *(LO1)*

connect
Excel Exercises

4. After seven years of negotiations, 12 countries—including the United States, Japan, Vietnam, and nine other Pacific Rim countries—crafted the Trans-Pacific Partnership (TPP). A key feature of the TPP was the lifting of tariffs on many products traded between the member countries, ranging from agriculture to footwear. Before the United States ultimately pulled out of the deal, each member country went through the process of ratifying the agreement, with numerous domestic firms and collective interests voicing opposition. In the United States, New Balance was one of these opposing firms, specifically stating its disapproval of phasing out U.S. tariffs on shoes made in Vietnam. What would a reduction of U.S. tariffs on Vietnamese shoes do to the supply of Vietnamese shoes in the United States? What impact would this have on the equilibrium quantity of shoes sold in the United States? Would the tariff reduction cause the equilibrium price for shoes in the United States to increase or decrease? Explain. *(LO1)*



5. Canada's forestry industry (composed mainly of those involved in the lumber industry) directly employs about 370,000 workers and indirectly employs an additional 510,000 people in support services. Forestry products account for nearly 3 percent of Canada's gross domestic product (GDP) and 14.1 percent of its exports. Lobbyists for the U.S. lumber and timber producers recently filed a complaint with the U.S. International Trade Commission (ITC) and the U.S. Department of Commerce (DOC) alleging that the Canadian government provided a subsidy to its lumber producers and caused harm to U.S. lumber and timber producers. As a result of these concerns, one U.S. lobbyist proposed the imposition of a 15 percent excise tariff on all Canadian forestry products. Determine the likely impact of the proposed 15 percent excise tariff on the equilibrium price and quantity of lumber exchanged in the United States. Would domestic consumers and producers benefit from the proposed tariff? Explain carefully. *(LO1)*
6. Evaluate this statement: "If the United States imposed a uniform excise tariff on all foreign imports, all U.S. businesses and workers would benefit. Consequently, if a bill to impose a uniform excise tariff were introduced in the U.S. Congress, it would unanimously pass." *(LO1)*

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CASE

Spectrum—the Spawn of Time Warner Cable and Charter Communications—Navigates Challenges from Cord Cutting and Mobile Competition

PREAMBLE: NOTE TO STUDENTS AND INSTRUCTORS

Those who cannot remember the past are condemned to repeat it.

—George Santayana

Managers who cannot apply managerial economics are destined for failure.

—Michael Baye and Jeffrey Prince

The case-study method is a pedagogical tool for applying managerial economics to real business scenarios. Two things are required for this approach to yield optimal results. First, since hindsight is always 20–20, put yourself in the shoes of decision makers at the time of their decisions—July 2016 in this case, before the name "Spectrum" was spawned—rather than at the time you read the case. This is your job. Second, the case being studied must involve economic issues that transcend time. That's our job.

We've written this timeless case especially for *Managerial Economics and Business Strategy.* Regardless of whether you've covered a single chapter or every chapter in the text, the case provides an opportunity to apply tools from managerial economics to a real-world business situation. The case includes a plethora of issues and may be used in a variety of ways to hone your decision-making skills.

For example, your instructor may choose to use the case as a capstone experience where you and/or team members present your analysis and make recommendations for the company. For this reason, when you read the case, you will observe that it provides information about the company and its business environment, but it does not identify specific problems or ask specific questions. As in the business world, the onus is on you to identify key issues and to defend your recommendations. Different students are likely to focus on different issues and to make different recommendations, depending on the chapters covered and their mastery of the material.

Alternatively, or in addition, your instructor may use this case as "an extended problem" throughout the course to illustrate concepts developed in specific chapters. The case includes a variety of memos—some at the end of the case and others available online at www.mhhe.com/baye10e—that permit you to apply concepts on a chapter-by-chapter basis.

We hope you enjoy the case. Remember that an important component of any case exercise is to use the information provided along with your knowledge of managerial economics and business strategy to identify key issues and to guide your recommendations and decisions. Consider this a practice run for when you leave the classroom and enter the business world.

headLINE

When Andreas finished his MBA 10 years ago and joined the company, he envisioned an exciting career in a growing industry. However, economic and technological changes have been rapid, and he has already been through spin-offs and mergers. Now, thanks to Time Warner Cable's most recent merger, he is potentially poised to join Charter Communications. He recently met with the Executive Board, and the Leadership Team singled him out for having "tremendous leadership potential."

While it felt good to be recognized, Andreas faces significant pressure to turn things around. Cable television is plagued with declines in video subscribers that seem unlikely to stop. The other product and service markets in which his company competes are highly competitive. Andreas is not interested in spending the next 20 years of his career plugging leaks in subscribers and market value; rather, his goal is to create sustainable growth through innovative business strategies.

The evolution of the industry has left Andreas—and his superiors—with a plethora of questions requiring immediate answers. He is glad that his MBA equipped him with the economic and business tools needed to deal with new problems—problems that didn't even exist back in the day. Sadly, Andreas's immediate predecessor lacked these tools and lost his job following the merger. He has no intention of following in those footsteps.

Andreas closed the July 1, 2016, edition of *The Wall Street Journal* on his laptop. He set aside his morning coffee to review the company's operations before replying to the first memo in his inbox.

[1] We prepared this case with Kyle Anderson for use as a teaching tool rather than to illustrate Spectrum's, Charter Communications', or Time Warner Cable's effective or ineffective handling of difficult managerial challenges. The information contained in this case is based on information that is publicly available and that was collected from a variety of industry sources. The memos contained at the end of this case—as well as those available online at www.mhhe.com/baye10e—were written by the authors of the case purely for use as a teaching tool; they do not represent actual company memos. Any relation between these memos and memos actually sent by personnel at these or any other company is purely coincidental.

BACKGROUND

In order to better understand Andreas's challenges in responding to the memos presented at the end of this case, it is useful to trace the evolution of his company and to provide a brief overview of the market segments in which it competes.

Time Warner Cable History

Time Warner Cable traces its roots back to 1968 with the founding of American Television and Communications (ATC). In the 1970s, Time Inc., primarily a magazine publisher, would acquire ATC. In 1990, Time merged with film and television producer Warner Communications to form Time Warner, Inc.

Time Warner, Inc., grew throughout the 1990s, notably by acquiring Turner Broadcasting Systems in 1996. By the end of the decade, Time Warner, Inc., would be one of the largest media companies in the world, owning well-known and varied entities including Warner Bros. film, Home Box Office (HBO), Turner Broadcasting System (CNN, TBS, and TNT), *Time* magazine, The Atlanta Braves (Major League Baseball), the Atlanta Hawks (National Basketball Association), the Atlanta Thrashers (National Hockey League), and DC Comics.

In January 2000, Time Warner, Inc., agreed to merge with Internet company AOL in a deal initially valued at more than $250 billion. AOL, formerly America Online, came to prominence in the mid-1990s as one of the first and fastest-growing dial-up Internet providers. In addition to Internet access, AOL was one of the largest content providers, and by 1997 about half of all U.S. homes with Internet access had it through AOL. The AOL Time Warner merger was seen as symbolically important as well, as it was the largest merger between a traditional media company and an Internet-based media company. The excitement would not last long, however, as the merger was poorly timed. The dot-com bubble burst in 2000, driving down share prices of all companies, but especially Internet-based businesses. Questions of accounting irregularities with respect to advertising revenue dogged AOL. In 2002, AOL Time Warner posted a $98.7 billion loss, in what remains the largest real loss in global corporate history.

During the next decade, AOL Time Warner would retrench and focus on its media holdings, especially the cable networks and movie studios. In 2003, it dropped AOL from its name, and over the next few years, most of the former AOL top executives left the company.

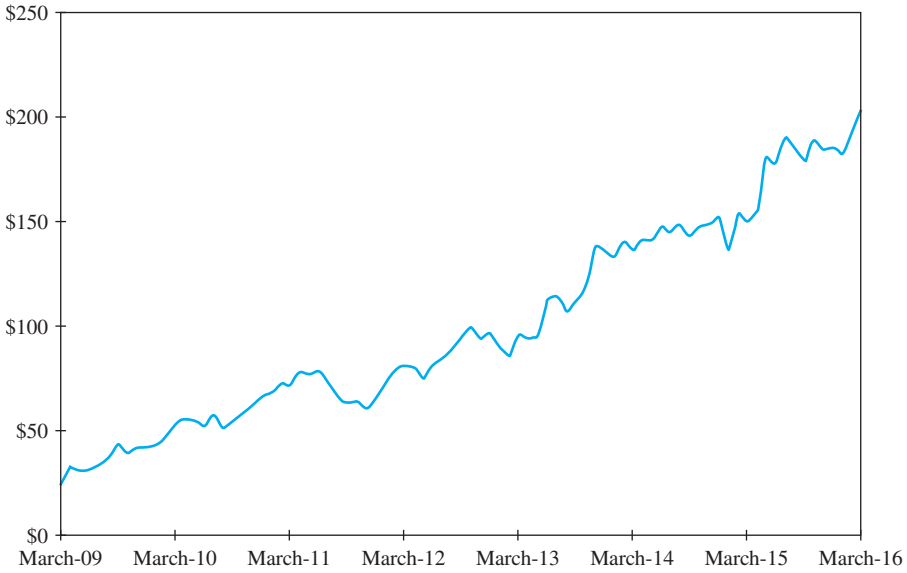
In 2009, Time Warner, Inc., spun off both AOL and Time Warner Cable. Management cited the fact that Time Warner Cable was relying more and more on its Internet and communications business and becoming a multiplatform communications company rather than a media and entertainment business. In March 2009, shareholders of Time Warner, Inc., received separate shares of Time Warner Cable stock and Time Warner Cable was officially separated from the media conglomerate.

Since the spin-off, Time Warner Cable's stock price has done extremely well, posting a sizable return. While it has helped that the overall stock market rallied during that time as well, shareholders generated an annualized return of more than 30 percent from 2009 to 2016, as illustrated in Figure CS–1.

Cable Television History

Cable television in the United States goes back to the late 1940s when inventors used cables to carry broadcast signals in regions where traditional over-the-air signals were blocked by mountains. Modern cable began in the 1970s with the development of cable programming

Figure CS–1
Time Warner Cable's Stock Price, March 2009–2016



networks including HBO (1972), ESPN (1979), and Nickelodeon (1979). In the decade that followed, cable adoption would increase from 16 million households to 53 million households by 1990.

During the 1980s and early 1990s, cable television system operators were largely functioning as monopoly utilities. Cable systems rarely competed over the same geographic areas, and there was little competition from satellite or alternative carriers. As a result, cable had 90 percent of the video subscription industry. The Telecommunications Act of 1996 significantly deregulated the cable industry, allowing for increased ownership between media companies and cable companies.

Consumer growth slowed in the late 1990s and 2000s, as the market reached maturity and competition increased. Satellite companies improved their technology and offerings, leading to increased competition. However, revenue growth and profitability still improved, as cable companies were able to sell increased services. The increased adoption of high-speed Internet, high-definition television, and digital video recorders (DVRs) and increased channel offerings all contributed to increased industry revenue.

Broadband Internet

Residential Internet access only gained widespread adoption in the mid-1990s as consumers subscribed to a service provider and used a dial-up modem to connect to the Internet. Connection speeds were slow and unreliable and, initially, customers had plans that limited the number of minutes that users could spend online. Broadband Internet is a term for access to the Internet through cable, digital subscriber line (DSL), or fiber optic cable that allows multiple signals or types of traffic and that maintains a constant connection to the Internet. As recently as 2001, fewer than 10 million American households were accessing the Internet through a high-speed connection. By the end of 2013, this had grown to over 80 million.

The primary providers for broadband are cable companies and telephone companies. Cable operators collectively have about a 58 percent market share, while telephone companies have the remaining 42 percent.

In 2015, the FCC raised the threshold for download and upload speeds necessary to be considered "broadband." The new minimum download speed is 25 megabits per second (Mbps) and the minimum upload speed is 3 Mbps. The FCC notes that with increasing large data files and multiple services, households need greater speed to take full advantage of Internet access. Under the prior definition, only 6.3 percent of U.S. households didn't have access to broadband service from at least one provider. The new definition increases this to almost 20 percent. Given the increase in video content and other large data, and the changing usage of Internet services, consumers will likely continue to expect faster Internet speeds.

While these levels of Internet speeds are available to most Americans, the adoption rate of high-speed access (by the FCC's new definition) is still less than half of all U.S. households. Still, companies are investing in higher speeds and promoting greater capabilities. Comcast announced a 1 gigabit per second (Gbps) service for which it is currently upgrading its hardware and service. Google Fiber also promotes 1 Gbps speeds, and an important element of competition is likely to continue to be faster speeds.

BUSINESS AND MARKETS

Time Warner Cable operates in the cable television industry in five primary geographic areas: New York, the Carolinas, the Midwest, Southern California, and Texas. The company serves 16 million residential and business customers who subscribe to one or more of its video, high-speed data, and voice services. Its revenue in 2015 was $23.7 billion, generating a profit of more than $1.8 billion. Exhibits 1A and 1B in the Appendix have financial highlights for Time Warner Cable.

Cable television providers generally provide three services: video programming, Internet service, and home telephone. While providers frequently offer bundles of two or three of the services, they are distinct segments with different competitors and market trends.

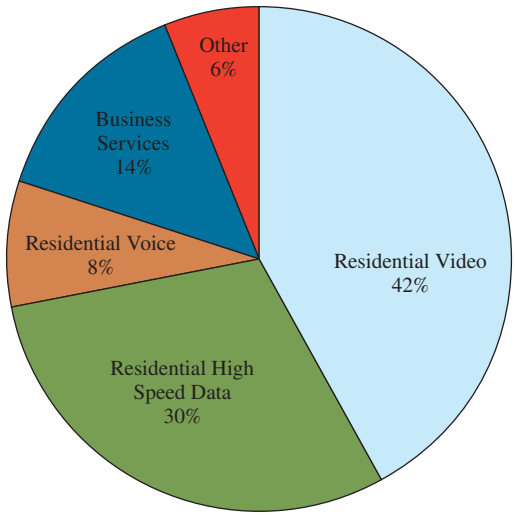
Video Programming

Cable companies' primary business is providing multichannel video services to home consumers. Residential video services make up 41.8 percent of Time Warner's revenue, although this percentage has fallen from 56.1 percent as recently as 2010. Video revenue declined by 5 percent in 2014 and by 1 percent in 2015. Figure CS–2 provides a breakdown of Time Warner's revenue sources. Industry forecasts vary, but the consensus view is that video revenue will continue to decline at a rate of about 1 percent per year for the next five years.

Most cable companies offer more than 300 television channels, and many of them are available in high definition (HDTV). A growing service area for cable is the offering of video on demand. This includes showing network shows on an on-demand basis, as well as movies or other events on a pay-per-view basis. Cable companies are also enhancing revenue by competing in the movie rental market segment, going against online providers such as Netflix, as well as DVD rental businesses like Redbox.

High-definition content and access are increasingly important as 77 percent of households in the United States have at least one HDTV, and about 46 percent have more than one. Fees for HDTV, multiple receivers, and digital video recorders (DVRs) are an important source of revenue for cable companies, and one that has grown dramatically since 2000. These are a major reason that the average monthly revenue per cable subscriber has grown to $76 for video services alone (see Exhibit 2A).

Figure CS–2
Time Warner Revenue Sources, 2015



A noteworthy trend in subscription digital television is the unbundling of channel packages. This trend is being driven largely by consumers who view the large number of channels as excessive, especially as prices continue to increase. The typical consumer watches only 17 channels on a regular basis, while basic cable packages have grown to over 100 channels.

The bundling of channels has been a part of cable television since its inception. In the 1980s, cable offerings were typically a couple dozen channels, and the cable bill was between $20 and $30. Consumers were willing to accept bundled pricing, and cable operators didn't have the easy technology to offer à la carte pricing. Typically, cable companies offered a basic package, along with a small list of premium offerings (e.g., HBO and Showtime Networks). Over time, as the number of channels increased and prices continued to rise, consumer groups began pushing the Federal Communications Commission (FCC) and Congress to mandate unbundled offerings. Proponents of unbundling sought to give consumers more power not to pay for products they weren't using, as well as not to have to pay for cable programming that they deemed offensive. In 2013, Senator John McCain introduced the Television Consumer Freedom Act of 2013, which would have made it more difficult for cable companies to bundle channels. While the bill died in the Senate, the potential for government action still exists.

Cable companies have historically preferred keeping bundled offerings, although over time the number of bundles and tiers has grown. They have resisted any regulatory efforts to mandate à la carte pricing on the grounds that it will stifle the ability of new networks to be launched. Since new channels get added to existing bundles, they have the opportunity to be seen by all of the subscribers and can generate commercial and subscription revenue. If consumers are charged for each channel, few will subscribe to new channels without proven content or brand awareness, creating high barriers to entry.

Networks also prefer bundled offerings since they create a greater subscription base for their channels. Further, through bundled programming, networks can use the leverage of their popular channels to get cable companies and subscribers to take all of their channels. For example, it is widely believed that Disney uses the popularity of its ESPN channel to ensure that their wide varieties of other ESPN properties (e.g., ESPN2 and ESPNews) are included in popular packages.

Competitive pressure is leading some providers to begin offering unbundled or smaller ("skinny") bundles to their consumers. Dish Network offers Sling TV and Verizon TV offers FiOS, both of which offer a small bundle of only the most popular channels at a reduced price. In 2015, ESPN filed suit with several providers claiming that the separation of its channels from basic cable bundles violated the terms of its contracts. As competition in the industry evolves, further unbundling and fragmented offerings are expected to be more common.

Internet Services

Demand for Internet services has grown dramatically and become an important service for cable companies. As noted in Figure CS–2, high-speed data makes up 37 percent of Time Warner Cable's revenue. Further, revenue grew by 11.3 percent per year from 2010 to 2015 (see Exhibit 2B). This reflects both an increase in the number of subscribers (6.0 percent) and an increase in revenue per subscriber (5.4 percent). Exhibit 2C shows the number of subscribers by service.

Time Warner Cable offers six different packages for Internet plans, mainly varying by download speed and price. The "Everyday Low Price" tier offers a download speed of up to 2 Mbps for $15 per month. On the high end, the "Ultimate" tier includes download speeds of 50 Mbps, and access to WiFi hotspots, for $70 per month. The other plans range somewhere in between. In addition to offering these as a stand-alone service, they are also frequently priced as bundles with video programming and home telephone service.

Increasing demand for high-speed data is a positive for cable operators but will also require significant investment on the part of the companies. Online traffic has been growing at a much faster rate than network capacity.

Telephone

Along with video and Internet access, cable companies offer home phone service through their Internet connections. The service is similar to Voice over Internet Protocol (VoIP), but communications are maintained on the companies' private IP networks. Companies typically charge a flat monthly fee for telephone service, including long distance within the United States and to many international destinations. Long distance to other countries is billed on a per-minute rate, but the rates tend to be as low as one cent per minute.

The residential telephone industry is highly competitive, due in part to the shrinking size of the traditional service market. The number of households abandoning home telephone service for strictly wireless plans increased from 20 percent in 2008 to over 40 percent by 2014, and this trend will likely continue as saturation of the wireless industry continues to increase. Not surprisingly, young adults are leading the wireless-only trend with less than a third of young households having residential phone service. In addition, households at or near the poverty line are much more likely to be wireless only.

In spite of declining overall residential telephone service, cable companies are actually increasing the number of customers subscribing to voice services. The number of residential VoIP customers increased from 19.7 million in 2008 to 37.7 million by the end of 2013. By expanding and marketing services to existing video customers, and offering attractive bundles of video, high-speed Internet, and voice services, they have been able to expand market share.

Time Warner Cable serves approximately 6.3 million residential voice subscribers, generating revenue of $1.9 billion in 2015. Average revenue per subscriber is $27 per month (see Exhibit 2A), but this has been declining over the last several years. Comcast's experience has been similar; voice customers are increasing by 3 percent per year, but revenue is decreasing due to greater discounting of bundled services.

COMPETITION

Competition for video programming distribution comes from direct broadcast satellite (DBS) providers, telephone companies, and online video services. In the 1980s and early 1990s, cable had over 90 percent share of the households that subscribed to a service (see Exhibit 3). However, due to improved technology (smaller and more reliable satellite dishes and increased channels), DBS experienced significant growth from late 1990s on. DBS now accounts for more than 34 percent of video subscribers. In addition, growth in competition from telephone companies, primarily Verizon and AT&T, has given them more than an 11 percent share. The result is that cable companies collectively have little more than 50 percent of the video subscription market, a share that has seen a strong downward trend over the last 20 years. Figure CS–3 shows the changes in the number of subscribers for different types of Multichannel Video Programming Distributors (MVPDs).

The result is that consumers have more choices than ever. Virtually every household in the United States has access to two satellite companies. In addition, over 99 percent have access to a cable company. Of those, another 50 million (37 percent of households) have access to a telephone service that provides digital video and online services.

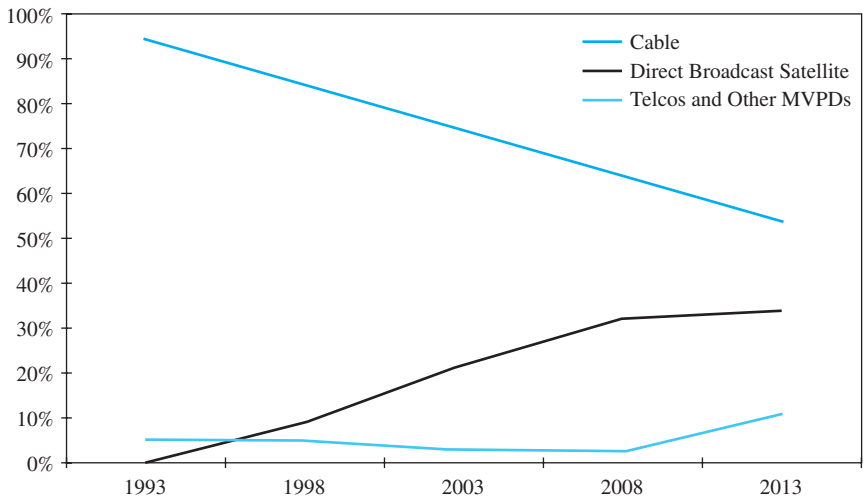
Cable Companies

While cable companies compete in the same industry, one cable company rarely overlaps the geographic footprint of another. Consequently, there is very little direct competition between cable companies. Exhibit 4 provides video revenue and subscriber information for the key industry players.

Comcast

Comcast is the largest cable television operator with 27.7 million customers for its video, Internet, and voice services. Comcast has the most customers for high-speed data (23.3 million), followed by video (22.3 million) and voice (11.5 million). Of the 27.7 million customers, 10.1 million of them use all three services. Headquartered in Philadelphia, Comcast's largest presence is on the East Coast. Other large geographic markets include Florida, Atlanta,

Figure CS–3
MVPD Subscribers by Service Type, 1993–2013



Denver, Northern California, and the Pacific Northwest. Due to its strong presence in highly concentrated areas, Comcast has the largest reach of any cable company, passing by 55.7 million homes and businesses.

In addition to its cable business, Comcast is a media company due to its NBCUniversal division. In December 2009, Comcast announced its intention to purchase majority ownership in media conglomerate NBCUniversal, which was owned by General Electric. Due to the size of the merger, the FCC and the U.S. Department of Justice needed to approve the deal. A number of groups expressed concerns that Comcast would use its ownership in NBCUniversal to prevent or restrict NBC-owned networks from Comcast's competitors. The deal was approved by regulators in 2011 with some conditions regarding the negotiations of NBCUniversal retransmission fees with rival carriers and how the company would deal with online video content. In February 2013, Comcast purchased the remaining interest in NBCUniversal from General Electric to make it a wholly owned subsidiary.

While acquiring NBCUniversal made Comcast a media company, cable operations (including video, high-speed data, and voice) still represent the largest portion of its business, generating revenue of $46.9 billion. The NBCUniversal subsidiary earned revenue of $28.5 billion from cable networks ($9.6 billion), broadcast television ($8.5 billion), films ($7.3 billion), and theme parks ($3.3 billion). NBCUniversal owns 15 cable networks, including USA Network, E!, Syfy, MSNBC, CNBC, and Bravo.

Comcast/Time Warner Cable Proposed Acquisition

In 2014, Comcast announced its intention to acquire Time Warner Cable in a deal that valued Time Warner at $45 billion. The proposed deal was a stock swap, so that shareholders in Time Warner would have received newly issued shares in Comcast. The acquisition would have given the combined company about 33 percent of all paid video customers and 40 percent of the wired broadband market.

Comcast presented the acquisition as an opportunity for the company to increase services, reduce costs, and increase innovation. While the combined company would have been significantly larger, there was little direct competition between Comcast and Time Warner, so the companies argued that competition to consumers would not be diminished by the acquisition. However, critics reacted negatively to the proposed merger on the grounds that the combined entity would have greater leverage in dealing with suppliers and greater control of the domestic broadband market. Further, Comcast was frequently rated as one of the worst companies in the country in terms of customer service. As a result, there was a consumer backlash against the company growing significantly larger.

In April 2015, it was reported that the U.S. Department of Justice announced it would file an antitrust lawsuit opposing the merger due to the reduced competition. While a formal complaint was never made by the government, there was speculation that the decision to oppose the merger was based on concerns that the merged company would have the ability and incentive to inhibit future competition from streaming video. Shortly after the news reports of the government opposition, Comcast withdrew its offer and the acquisition attempt died.

Charter Communications

Charter Communications is a cable company with 6.2 million customer relationships for its services, including high-speed data (5.2 million), video (4.3 million), and telephone service (2.6 million). Revenue for 2015 was $9.7 billion, a 7.1 percent increase over the prior year, although it posted a loss of $271 million. Charter's customers are geographically dispersed, but some of its larger markets are in the South, California, Michigan, Minnesota/Nebraska, and the Pacific Northwest.

After the Comcast/Time Warner merger fell through, Charter looked to put together a deal of its own. In May 2015, Charter announced that it would seek to acquire Time Warner Cable and Bright House Networks, a smaller cable operator, for a total of $67.1 billion.

The deal was facing significant scrutiny from regulators as the merged entity could have a combined 17.8 million high-speed-data customers. Regulators were concerned that a cable company with a large market share could pressure cable networks to keep much of their content away from online video services. In April 2016, the Antitrust Division of the U.S. Department of Justice announced that it was allowing Charter's acquisition of Time Warner Cable and Bright House Networks to proceed with conditions.[2]

Other Cable Players

A number of other smaller cable companies are still competing in these markets in 2016. Cox Communications, Cablevision, and Bright House Networks all have more than a million subscribers each, while about another dozen cable companies exist with less than a million subscribers. Many of these smaller systems are either confined to a small geographic region or comprised of customers gathered when larger firms had to divest customers following a merger.

Satellite

Direct broadcast satellite television competes directly with cable companies for video content. By nature of the technology, virtually any household in the United States has access to satellite television service. In fact, due to limited cable and telephone service areas, about 500,000 (mostly rural) households have access to only satellite services.

AT&T DirecTV

DirecTV is the largest direct broadcast satellite service with 20 million U.S. subscribers, plus another 19 million in Latin and South America. In 2015, AT&T acquired DirecTV in a $49 billion deal, creating a combined firm with 25.4 million video subscribers. Within months of the completed deal, some were questioning AT&T's investment in a video provider when subscription revenue seemed like it was going to decline. AT&T was hoping to use its large retail presence to increase video subscriptions to DirecTV where it currently did not have a video service to provide. In addition, it hoped to take advantage of other DirecTV assets including the NFL Sunday Ticket, an exclusive agreement to show all NFL football games.

One of the benefits of the merger might be to increasingly leverage DirecTV's content to AT&T's mobile customers. However, there are definite complications with this plan. The NFL has a deal with DirecTV to show the Sunday Ticket, but it also has an exclusive deal with Verizon, AT&T's largest competitor, for mobile access to NFL content. As the lines between video, Internet, and wireless content continue to get blurred, complications like this will continue to arise.

AT&T also hopes that its size as the largest multichannel video distributor in the United States will help it lower programming fees charged by cable networks. Being able to take advantage of its size will be critical to returning value to shareholders after the high price paid for DirecTV.

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[2] See www.justice.gov/opa/pr/justice-department-allows-charter-s-acquisition-time-warner-cable-and-bright-house-networks.

Dish Network

Dish Network provides services at a lower cost, generally with fewer channel options than most cable packages. Dish generated $15 billion in revenue in 2015, with a subscriber base of 13.9 million users. In addition, Dish markets broadband services that are bundled with Dish video programming. Broadband services are subcontracted to other carriers.

Dish Network began offering a new service in 2015 known as Sling TV. Sling TV is a service that provides traditional multichannel programming through an Internet connection. Customers do not need a satellite or an existing relationship with Dish to sign up for the service. The base package price for Sling is only $20 per month, with additional channel packages available for $5. While Dish Network has 13.9 million paid video subscribers, it does not disclose how many of those are for satellite television and how many are for Sling TV. Analysts estimate that Sling TV has fewer than 500,000 subscribers after its first nine months of availability.

Sling TV is generating some controversy in the industry, as some are concerned that bypassing traditional cable or satellite services will be bad for the long-term health of the industry. This is not the first time that Dish has created controversy in the industry. Networks were not happy when Dish launched the Hopper DVR, a service designed to allow viewers to easily skip through commercials during playback of recorded content. Networks including Disney (ABC and ESPN) and Fox sued Dish Network over the technology. Some of these lawsuits have been settled, but others are ongoing.

Telephone Providers

Telephone providers have invested significantly to compete for multiple household services. By upgrading their wiring to fiber optic cable, telephone lines can carry digital signals, including digital video and Internet, as well as voice. Due to the technological investment, digital services are only available to 46.4 million households in the United States. In virtually all of these households, customers have their choice among a telephone provider, a cable company, and the two satellite providers. Two telephone companies, Verizon and AT&T, are the largest players in this segment.

Verizon

Verizon is a communications company focused on wireless and wired communications products and services. Wireless service and products make up 69.7 percent of Verizon's business. The remaining portion is divided between FiOS, its fiber optic communications network, and traditional wired home telephone and Internet service. FiOS service is offered in 13 states, and offers video programming, high-speed data, and voice services.

Verizon FiOS promotes "Custom TV" plans in which consumers can choose differing basic packages depending upon their tastes. One of the choices excludes sports channels and instead offers a wide variety of channels at a modest cost. Since sports programming channels tend to be some of the most expensive cable offerings, allowing consumers to opt out of these channels has the potential to increase the value for cable customers. In 2015, ESPN filed a lawsuit against Verizon claiming that the carriage contract mandated that ESPN be carried as part of the basic service, and that the exclusion from the Custom TV plans violated this contract. Resolution of the matter is pending.

AT&T

AT&T is a very large communications company whose largest business is wireless communications. However, it has two services that compete with the cable business: DirecTV and

U-Verse. As mentioned previously, DirecTV is a direct broadcast satellite business acquired by AT&T in 2015. U-verse is a fiber-optic network that provides video, high-speed data, and voice service in 21 states.

Other Companies

A handful of other telephone companies, including Consolidated Communications and Cincinnati Bell, offer competing services in 2016. A notable entrant is Google Fiber, which began offering television and Internet services in 2013. Google is choosing to enter selective markets, mostly certain suburban areas surrounding larger cities, including Kansas City, Austin, and Atlanta. With only 54,000 television subscribers as of January 2016, and availability in only a handful of markets, Google Fiber is not yet a competitive threat.

Online Video Distributors

The popularity of online video content distributors (OVDs) may be the greatest threat to the traditional cable model. Increased Internet download speed has led to considerable growth in the streaming of video since 2011, when Netflix announced its focus on streaming video.

One of the contributing factors to the popularity of online video was the increase in the prevalence of Internet-connected televisions. Currently, the majority of U.S. households have at least one television that is connected to the Internet, either directly (i.e., Smart TVs) or through a device such as a gaming system, Blu-Ray player, or streaming media device (e.g., Google Chromecast, Roku, Apple TV). The number of adults watching online programming through a connected TV at least once a week has increased to over 30 percent and is growing rapidly.

Netflix

Netflix began as a DVD mailing service in the late 1990s, generally competing with video rental stores. In 2011, Netflix shifted focus to its streaming video service, and shortly thereafter began developing its own original content.

The 2011 transition from DVD to online video was not a smooth one for Netflix. It initially announced a plan to spin off the DVD business to a new company that would be known as Qwikster. After significant backlash from its customer base of 24 million at the time, it abandoned the spin-off plan. But Netflix chose to go forward with separating the DVD and online video business models, forcing customers to either choose one of the two plans or pay separately for both. Previously, online video was included with the DVD plan. The transition would cost the company a million subscribers, and the stock price declined by 44 percent. However, this proved to be a short-lived problem, as the company quickly expanded its online content and subscriptions grew quickly.

Netflix streaming video service has 43.4 million paid memberships in the United States. Its content includes movies, TV series, and original programming. Revenue has grown by 20 to 25 percent per year for each of the last three years. Figure CS–4 shows the growth in memberships and revenues over the past three years.

In addition to an increased subscriber base, Netflix is becoming more popular with its subscribers. In 2015, subscribers logged a collective 42.5 billion hours of viewing, which amounts to an average of 1.8 hours per day per subscriber.

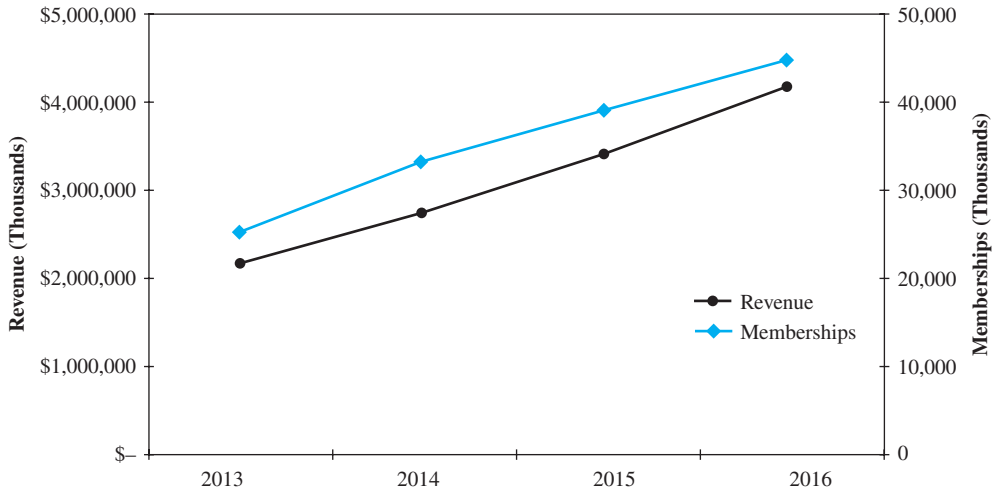


Figure CS–4
Netflix Domestic Streaming Members and Revenue, 2013–2016

Amazon Prime Video

As of 2016, Amazon.com has begun competing more aggressively in providing video content. While best known as an online retailer, Amazon is competing with cable through its Amazon Prime Video service. Amazon Prime members pay $99 per year and get access to free two-day shipping, discounts, and special offers, as well as access to video content through the Amazon Video service. In addition to movies and television series, Amazon is producing original content. While it does not disclose the number of Prime members, analysts estimated this figure to be around 50 million to 55 million in the United States.

Hulu

Hulu is a similar service to Netflix, with the distinction that it is jointly owned by a group of traditional television network companies, including Disney-ABC Television, Fox Broadcasting, and NBCUniversal (a subsidiary of Comcast). This ownership results in a differentiated market strategy where Hulu focuses on showing recent episodes of currently broadcasting television series, as early as the day after they originally air on network or cable television. Hulu carries much less original content and fewer movies than competing streaming services. Pricing for Hulu is currently $7.99 per month, or $11.99 for a commercial-free membership.

The move to original content has been a dramatic and successful one for Netflix, Amazon, and Hulu. At the 2016 Golden Globes, four of the six nominees for Best Series came from either Amazon or Hulu. Meanwhile, Netflix earned the most nominations across all categories of any company or network. Further increasing their critical profile, both Netflix and Amazon are aggressively purchasing distribution rights to well-received films at film festivals such as the Sundance Film Festival. This is part of a growing trend whereby companies seek out exclusive rights to broadcast content, rather than mere replay rights.

Google/YouTube

In late 2015, Google announced the launch of YouTube Red, a subscription version of its YouTube video sharing service. For $10 per month, members can view videos without ads, as

well as download videos. They announced that they would launch more TV-style content from existing YouTube creators.

Some smaller cable and satellite operators also moved to incorporate online video content within their services. In 2015, Dish Network began including Netflix and YouTube through its satellite service. Cablevision packages also include access to Netflix and Hulu services.

In addition to these services, there are plenty of other potential entrants into online video markets. Apple is planning to debut a new service, and dozens of small companies with little brand name are poised to come in with competing content and services.

SUPPLIERS

Cable companies are primarily in the business of reselling video content to consumers. As such, they are highly dependent on the entities that produce the content, and negotiations over pricing and conditions are a key element to the success of their business model.

Cable Networks

Cable providers are facing increasing costs for programming from cable content providers. These effects are strongest in sports programming, where broad sports channels (ESPN, NBCSN), league-run channels (NFL Network, MLB Network), and regional channels (Big Ten Network, Fox Sports Regional Channels) are all increasing in popularity. The channels are spending large sums competing for the broadcast rights of the most popular sporting events and passing the costs along to cable operators.

Cable networks charge programming fees to cable, satellite, and telephone service providers for the rights to carry their networks. These fees total more than $28 billion and account for 38 percent of the revenue of cable networks. The majority of their revenue currently comes from national, regional, and local advertising. While advertising revenue is still steady, the number of consumers either switching to online content or watching recorded television without watching commercials is putting pressure on advertising dollars.

As the number of cable television subscribers begins to decline, cable network revenue will be negatively impacted as well. As a result of limited growth in advertising, higher costs of production, and declining cable subscribers, cable networks are charging higher programming fees to companies that carry their programming.

As a result of this pressure, programming fees have been rising for cable companies. Time Warner's programming fees are rising by an average of 5.5 percent per year. Meanwhile revenue from video is declining. The result is that the gross margin from video has fallen from 60.2 percent in 2010 to 44.4 percent by 2015. Furthermore, the forces generating pressure on margins show little signs of relinquishing.

Broadcast Networks

Traditional broadcast television remains an important player in the video industry. Networks such as ABC, CBS, Fox, and NBC and their local affiliates make up 30 percent of viewed programming. This figure is down from 80 percent of all programming in the late 1980s.

Cable companies are required by the FCC to negotiate with more popular local television stations over retransmission fees. That is, local network affiliates can demand payments in order for cable companies to carry the rights to broadcast their network programming. In the early years of cable, networks were rebroadcast on cable with no fees. This changed in 1992,

as Congress passed a law allowing commercial broadcasters not to allow cable carriers to carry their stations without consent (as well as potential compensation). For years, retransmission fees were either zero or very small. However, over the last decade these fees have skyrocketed.

Total retransmission payments from cable and satellite companies to network affiliates were $200 million in 2006, but had risen to $6.7 billion by 2016. Further, projections by industry analyst SNL Kagan are that these fees will amount to more than $9 billion industry-wide by 2020.

Sports Programming

The popularity of sports in American culture also drives a lot of the economics of the cable industry. As fans want more access to live sporting events on their television, sports leagues are driving up their broadcast rights fees to very high rates. Networks and broadcasters then use the popularity and exclusivity of their programming to demand higher programming and retransmission fees. The National Football League (NFL) and the Olympics provide two examples of this phenomenon.

In 2014, the NFL generated $7.3 billion in revenue from television contracts, up from $3 billion in 2010, an annualized increase of 24.8 percent per year. Driving these payments is the popularity of televised football, as NFL games dominate the TV ratings throughout the season. High ratings lead to high advertising and sponsorship dollars for the networks. As a result, networks are willing to pay for broadcast rights to the games. ESPN pays $1.9 billion per year for the rights to show *Monday Night Football*. CBS, Fox, and NBC all pay large fees for the rights to Sunday games, while CBS also pays to show Thursday night games. Meanwhile, DirecTV pays $1.5 billion per year for NFL Sunday Ticket, which allows the broadcast of all games to its subscribers. Football's continued increasing popularity makes it unlikely that this trend will reverse anytime soon.

Another example of sports programming is the broadcast deal for the Summer and Winter Olympic Games. NBCUniversal has secured the U.S. broadcast rights to the Olympic Games through the 2032 games, paying $1.23 billion for the 2016 games alone. By securing the rights to such a high-profile event, NBC increased its leverage with video providers. The games are generally spread across a number of NBC networks, including NBCSN, MSNBC, CNBC, and Spanish-language station Telemundo. Cable companies that want to provide full coverage of all the Olympic events need to make sure that their cable bundles include all of these channels.

The increased payment for content is making traditional broadcast networks and their cable counterparts more aggressive in demanding retransmission fees from cable and satellite providers.

Carriage Disputes

Carriage disputes are disagreements between cable, satellite, or telephone carriers and a broadcast or cable network over the terms of retransmission. These disputes often result in intense negotiations as well as occasional blackouts when disputes cannot be resolved in a timely manner.

One example is the 2013 dispute between Time Warner and CBS over fees for carrying three premium cable networks: Showtime, The Movie Channel, and The Smithsonian Channel. Without a contract in place, Time Warner stopped carrying the channels, as well as the CBS network, in several cities, beginning on August 2, 2013. The blackout affected about

3 million subscribers and lasted for about six weeks. Customers were upset by the loss of programming, especially due to the popularity of the NFL. CBS is one of the major carriers of NFL football games, and the blackout coincided with the beginning of the 2013 NFL season. During the third quarter of that year, Time Warner Cable lost 300,000 subscribers, about half of which were attributed to the blackout. In addition, the company was forced to issue credits to Showtime subscribers for the lost content during the blackout.

Over-the-Top Content

While the costs of programming content have increased, there also has been a movement by some companies to bypass subscription services and offer content directly to consumers. Known as Over-the-Top (OTT) content, cable channels and content providers are increasingly moving to selling their services directly to consumers through websites and mobile applications.

Besides OVDs such as Netflix and Hulu, in 2015 popular cable channels began offering OTT content. At that time, HBO (which is owned by Time Warner, Inc.) launched its HBO Now service. Consumers can subscribe directly and access all HBO content through the Internet and an enabled device for $15 per month. This was the first major cable network to offer content directly through the Internet without requiring the subscriber to also subscribe to a cable or satellite service. Competing channel Showtime followed suit with its own OTT service, along with a partnership to have it carried (for an extra fee) to Hulu's customers.

Sports leagues are also considering moving in this direction. Major League Baseball (MLB) sells direct access to games through its MLB At-Bat service, although due to agreements with networks, local games are blacked out to consumers. The NFL partnered with the website Yahoo! to broadcast an NFL game played in London, England. To this point, network contracts have limited the sports offerings directly to consumers, but there are concerns that this will change.

MARKET TRENDS AND CONSUMER BEHAVIOR

In addition to the issues outlined, there are a number of market trends that managers need to be aware of when making decisions in the industry. Here are a few of the recent and current trends and technologies that are influencing competition and consumer behavior.

Digital Video Recorders (DVRs)

As of 2016, DVRs are becoming increasingly important to cable operators. Consumers enjoy the ability to pause live television and also to record content and watch it at a later time, a process known as "time-shifting." While time-shifting technology has been available since the widespread adoption of the VCR in the 1980s, the convenience and simplicity of DVRs make it much easier and more common. This service increases the value of cable to consumers, and the fees associated with DVRs provide an additional revenue stream to cable companies.

However, there are drawbacks to increasingly recorded content and time-shifted viewing. First, the move away from watching live shows in real time and toward recorded content on-demand makes more consumers embrace the Netflix and YouTube models of video consumption. Showing current content is the competitive advantage of cable television, and de-emphasizing this will only make online video providers more appealing. Second, cable providers and networks rely in part on advertising dollars from commercials. The use of DVRs allows consumers to skip commercials at a higher rate. In response, networks need to

get creative in embedding more advertising within the programming, or demand higher programming fees from cable carriers. There is evidence that both of these are happening and will continue to increase.

Cutting the Cord

One of the factors intensifying competition in the cable industry is the growing number of households that are canceling subscription video service. These customers are nicknamed "cord-cutters" for their decision to cut service from traditional video services including cable and satellite TV. Increasingly, cord-cutters are relying on video services from the Internet, including Netflix and Hulu.

The first-ever decline in the overall number of households receiving any kind of multichannel video subscription service (including cable, satellite, and telephone) occurred in 2013. The number of subscribers declined from 101.0 million to 100.9 million households. While the reduction was quite small, it signaled a potentially troubling trend in the industry. Currently, some analysts estimate that the percentage of households subscribing to any multichannel video service has fallen to as low as 80 percent from over 88 percent in 2010.

More than a few analysts are predicting a very gloomy outlook for cable operators. If the multichannel video service penetration rate has really fallen by 8 percent over the last few years, there is plenty of evidence to suggest that this trend could continue or even accelerate. After all, channels like HBO and Showtime have been providing OTT packages for less than a year and services like Netflix and Amazon Prime Video are continuing to gain popularity. It is not inconceivable that the size of the entire market for multichannel video could fall to as low as 60 percent of U.S. households.

Cable companies also need to worry about "cord-shavers," consumers who downgrade their video packages to only basic channels. These consumers then tend to supplement their viewing with online video services or OTT packages.

Part of the reason that sports programming is considered so important to cable companies is that sports fans prefer to watch the programming live rather than as a recording. Consequently, sports programming is widely seen as a hedge against both cord-cutting and the skipping of commercials.

Going Mobile

Mobile wireless services have shifted from a luxury to a necessity, and wireless technology companies are investing heavily to facilitate this transition. Mobile devices have gone from being primarily used for voice, e-mail, and web browsing to now including video entertainment, social media, and mobile commerce.

LTE networks deliver download speeds for mobile devices between 5 and 12 Mbps and are available to 98 percent of the population, up from 67 percent in 2012. While fixed and mobile broadband are used in different ways right now, there is likely to be a convergence. As of now, mobile Internet access does not have the speed or capacity to compete with fixed broadband.

REGULATION IN THE CABLE INDUSTRY

U.S. cable companies are subject to a number of laws and regulations that are largely overseen by the Federal Communications Commission (FCC). The following are a few of the significant regulatory areas that impact the operations and strategic decisions of Time Warner and its competitors.

Carriage of Broadcast Television

The FCC mandates that cable companies devote some of their stations to local broadcast television channels that elect to be carried for free. These so-called must-carry channels include smaller local channels as well as community and public access television. These channels are separate from broadcast channels that demand retransmission fees in order to be shown on a cable system.

Cable Pricing Regulation

The FCC regulates and limits the rates that cable companies may charge for basic cable service and equipment in communities that do not have "effective competition." Effective competition is based on the number of competitors and market share that the cable company has. In the case of Time Warner, more than 85 percent of the local markets in which it competes are subject to effective competition and therefore not subject to pricing regulation by the FCC.

Net Neutrality

The FCC is charged with regulating communications including transmissions across the Internet. In a series of regulations, the FCC has adopted "net neutrality" regulations for Internet providers. Some of the provisions of net neutrality are that Internet providers may not block access to lawful content, applications, or services and may not unreasonably discriminate in transmitting lawful network traffic. This includes a ban on prioritizing some Internet traffic over other traffic in exchange for payment.

Net neutrality is a complex set of policy issues that has largely pitted telecommunications companies against Internet content sites and consumer groups. Telecommunications companies argue that allowing services like Netflix the ability to pay for better Internet speed for their customers would allow for more investment in technology and faster service for customers. Netflix, Amazon, and other Internet content sites argue that telecommunication companies will be able to charge high fees that will have to be passed on to consumers. Consumer groups are concerned about high fees, but also that the fees will serve as significant barriers to entry for new companies that would like to provide video content.

In March 2015, the FCC reiterated some of the net neutrality regulations and took the step of reclassifying broadband Internet access as a utility service, subject to increased regulation. Several groups representing telecommunications providers have filed a lawsuit against the FCC challenging the ruling. The litigation is ongoing as of 2016.

Connect America Fund

As part of the American Recovery and Reinvestment Act of 2009, the FCC was directed to create a national broadband plan that would increase high-speed Internet access to Americans. The Connect America plan set the goal of providing download speeds of 100 Mbps to at least 100 million households in the United States. While some of the funding came directly from Internet providers through taxes and fees, the plan also had the benefit of increasing the potential number of customers for cable companies, for all services.

CHALLENGES

The cable television industry faces tremendous competition due to rapid technological change. Video subscription rates are declining, programming fees are increasing, and competitive threats are everywhere. While high-speed data service is a bright spot, customers are

demanding faster speeds and greater access. VoIP telephone service is still growing for cable companies, but increasing competition and a declining demand for traditional residential voice services generate concerns about how long this market will remain profitable.

Andreas is well aware of these challenges but is resilient in the belief that cable companies can continue to provide a valuable service for their customers, while also generating value for their shareholders. He knows that to do this, they will need to continue making the best decisions on a day-to-day basis. After opening his laptop, he begins reading the memos in his inbox.

CASE-BASED EXERCISES

The attachments referred to in the following memos are available online at www.mhhe.com/baye10e. This site also contains additional data that may be useful in your analysis of the case, as well as additional memos that your instructor may choose to assign as problem-solving exercises.

MEMOS

Read the following memos and use the attachments available online at www.mhhe.com/baye10e to provide the information requested.

Memo 1

To: Pricing Manager, Tri-State Region

From: Regional Vice President, Tri-State Region

Re: Revenue from EPIX

We recently added the EPIX Movie Channels as part of a new tier of programming for our digital video subscribers. The EPIX channels are sold as an add-on package for $9.75 per month, but we would like to potentially increase our revenue from our subscriber base. Currently we have about 15,059 subscribers, generating monthly revenue of $146,823.

Some have suggested we should cut price, as customers tend to be fairly price sensitive for add-on packages. However, in this case, if we lower price for our new subscribers, we really need to cut it to all of our existing subscribers as well. I have some concerns that lowering price will be counter-productive.

The marketing department calculated some subscription levels at various price points in this region, and I need you to perform the analysis. Specifically, I want you to estimate the price sensitivity of customers at the current price. Please address the following questions: (1) If we lower the price, do you think this is likely to lead to higher revenue, and (2) how much potential revenue can we generate and how low should we go with our price?

Thanks for your help.

Attachment: Epix.xls

Memo 2

To: Pricing Manager, Austin

From: Vice President, Marketing

Re: Google Fiber

As you are aware, Google has been entering select markets with its Google Fiber service that competes directly with our high-speed data and video services. Even though its market penetration has been moderate, Google has deep pockets and excellent brand awareness. As a result, we are paying close attention to markets that it is entering.

Within the last year, we completed our own fiber upgrade in the area at a cost of a little over $550 million. We are able to provide our high-speed data and video, and have a large number of bundled customers for our products. Unfortunately, many of them have been with us for a while and are no longer under any contract to remain with us. With Google's entry (along with existing competition), we may need to reduce our prices. The Austin service area for our services includes 340,000 households. Currently, in neighborhoods where Google competes, we provide bundled services that average $120 per household per month.

In addition to monthly costs associated with the $550 million (which is being amortized over 15 years at 6.0 percent), agreements with program providers stipulate that we pay them $41.50 per subscriber per month. In addition, we have maintenance, service, and billing costs of $9.20 per subscriber.

I am concerned that increased competition will lead to a price war, and that prices may get to unprofitable levels. If things turn really bad, we may need an exit strategy from this market. How low should we be willing to go with our prices before it makes sense to exit the Austin market?

Memo 3

To: Junior Executive, Strategy Group

From: Vice President, Strategy Group

Re: Strategic Analysis

For our upcoming executive retreat, the Strategy Group has been tasked with competing a strategic analysis of our business and our industry. While there are a number of different approaches that we can take, I would like to rely on Porter's "five forces" framework for our analysis of the industry structure.

Please provide an outline of each of the five forces as it relates to the cable industry and whether conditions in the industry are favorable to long-term profitability.

Memo 4

To: Pricing Manager, Tri-State Region

From: Regional Vice President, Tri-State Region

Re: Revenue from EPIX

As you are aware, we recently added the EPIX Movie Channels as part of a new tier of programming for our digital video subscribers. The EPIX channels are sold as an add-on package for $9.75 per month, but we would like to potentially increase our contribution margin from our subscriber base. Currently we have 15,059 subscribers, generating monthly revenue of $146,823.

In an earlier study, our marketing department generated data on sales quantities at various price levels. In addition, we have included the licensing cost as well as regional expenses.

Please provide a recommendation of the profit-maximizing price, and how much our profits will increase if we adjust price to the recommended level. Also, please note whether this will impact our revenue.

Attachment: Epix.xls

Memo 5

To: Marketing Director, Residential Telephone Services

From: Vice President, Residential Telephone Services

Re: Customer Retention

As you are aware, we are continuing to lose customers of our residential VoIP telephone service. According to our recent marketing research report on the topic, many of our customers are dropping due to the expense of maintaining home phone service while also having wireless plans.

I would like your team to consider whether we can take advantage of selective discounting to maintain higher retention. In practice, when customers call to cancel their service, we would offer them a significant discount (25 to 30 percent) off their current rate in order to retain their business. Customers would need to agree to maintain their service for at least three months in order to get the discounted price.

Please put together a short response that states whether you think this plan would increase our economic profits, and whether there are any risks that we would lose money due to this plan.

Memo 6

To: Director of Marketing, Midwest Region

From: Chief Financial Officer

Re: Economic Planning

I attended a breakfast this morning in which a group of economists presented the economic outlook for the Midwest region for the coming year. According to their forecasts, the likelihood of a recession is as high as 40 percent. It is imperative that we be prepared in case a recession hits the country.

Our research intern pulled some data on household income from the last economic slowdown and we matched it up with the number of subscriptions for our video services. At first glance, it looks like we didn't have too many cancellations. However, in looking a little closer, it appears that a significant number of subscribers downgraded their service to a lower tier.

As you know, our two most popular tiers of television programming are Favored TV for $80 per month and Basic TV for $40 per month. The programming fees that we pay for the Favored TV are $48.50 per subscriber, while programming fees for Basic TV are $18.50. Both sets of customers have maintenance, billing, and service costs of $9.20 per subscriber. Currently, in this region, we have 27,800 Favored TV subscribers and 17,800 Basic TV subscribers.

One member of our quant group ran a regression based on incomes and subscriptions from that two-year period, but I can't quite figure out what it means. Can you use the attached data to calculate the impact on our subscriptions, revenue, and profit in the Midwest region if we were to sustain a recession that led to a 2 percent decline in average household income?

Attachment: Recession.xls

Memo 7

To: Pricing Manager, Central State Region

From: Vice President, Marketing

Re: Strategic Pricing Decision

Our only competitor in the Central State region currently provides bundled services at $79.95. We are currently charging a 10 percent premium over its price, but there are rumors that it is contemplating a 10 percent price increase to bring its price in line with ours. We don't know its cost structure, so we don't know whether its price increase is driven by rising costs or a strategic move to gain margin.

Historically, when we both charge the same price, our market share is about 65 percent. When we charge a 10 percent premium over its price, our market share declines to about 60 percent. It appears that in those instances when it charges a 10 percent higher price than us, our market share is about 70 percent.

Please provide a recommendation regarding whether we should maintain our current price or reduce our price to $79.95. Please factor into your recommendation that we pay programming fees that amount to $49.50 per subscriber. In addition, maintenance, service, and billing costs are about $6.50 per subscriber. At present, there are 110,000 households in the relevant market.

Memo 8

To: Strategic Planning Committee

From: Board of Directors

Re: Potential M&A Target

After a number of years operating solely as a cable company, we are considering expanding our reach back into content and programming. As a result, we are considering an acquisition of Viacom, Inc. Viacom is a media company that focuses on television and film production and distribution, as well as owns a number of well-known television networks. Its properties include Paramount Pictures, MTV, Comedy Central, BET, Nickelodeon, Spike, and VH1.

Please provide your input as to the viability of acquiring Viacom. Please keep this request confidential.

Memo 9

To: Chief Legal Counsel

From: Board of Directors

Re: Potential M&A Targets

Growth seems to be an important goal to provide return to our shareholders. We would like to identify potential merger prospects in order to grow Time Warner Cable's reach and market power. However, a merger with Comcast was challenged by the Department of Justice on the basis that it might have been anti-competitive.

Please put together a brief memo outlining some of the concerns that were raised with the proposed 2015 merger between Comcast and Time Warner. In what ways was the government concerned that competition would be diminished? How might the merger have increased value to our customers and shareholders?

Then, put together a short list of two or three potential targets for merger or acquisition. What advantages would each company bring Time Warner Cable?

Memo 10

To: Director, Content Acquisition

From: Chief Operating Officer

Re: Retransmission Negotiation

We are in continued negotiations with one of the major broadcast network affiliates on the West Coast over retransmission fees and have not been able to reach an agreement. The current contract ends on August 31 of this year. The current retransmission fee is $1 per subscriber per month.

The network affiliate is demanding $1.25 per month and has cited the fact that it has just picked up rights to broadcast the NFL games for the local franchise. We have counter-offered $1.05 per subscriber, but this was immediately rejected.

We currently have 810,000 cable subscribers in the affiliate's market, which makes up about 52 percent of all households in the area. Other households have either cut the cord or are using a competing service (DirecTV, Dish Network, or Verizon). All of our competitors in the market have contracts with the network affiliate through the end of next year.

Based on past experience in other markets, our analysts estimate that losing access to the network affiliate will cost us 3 percent of our customer base within the first week, and another 2 percent if the dispute lasts a month. The network affiliate will lose some revenue as well since half of its viewers will lose access to its programming.

Should we accept the $1.25 monthly fee? What should our negotiating strategy be, and how do you anticipate the affiliate will respond?

Memo 11

To: Vice President, Marketing

From: Chief Operating Officer

Re: Cable Channel Pricing

A number of groups have put pressure on the FCC to mandate that cable companies offer their channels à la carte rather than in bundles. We are opposed to this measure and will continue to strive to provide channels in bundled tiers. However, we want to be prepared in case we need to offer single-channel pricing.

Using existing market research, we were able to calculate an estimated own-price elasticity of demand for a number of our most popular cable channels. Use this information, along with the marginal cost for each channel, to calculate the profit-maximizing price for each of these channels.

Channel	Programming Cost per Subscriber per Month	Estimated Own Price Elasticity of Demand	Subscription Price
ESPN	$6.15	–1.8	
TNT	$1.52	–2.1	
Disney Channel	$1.25	–1.6	
Fox News	$1.05	–1.9	
MSNBC	$0.99	–2.4	
CNN	$0.87	–3.4	

Memo 12

To: Chief Strategy Officer

From: Board of Directors

Re: Market Trends

We are increasingly concerned about Over-the-Top programming. With HBO and Showtime offering their programming directly to consumers and some sports networks (e.g., NFL and MLB) considering the same, we are concerned that we might lose subscribers. We need to know how losing subscribers would affect existing networks and whether it might impact their decision to market directly to consumers.

It would assist us if you would identify whether there are any network effects in the decisions of cable customers to "cut the cord" and networks to provide OTT programming. If more networks sell directly to consumers, how will this affect the demand for our cable television services? Also, will it impact the decision made by other networks. Finally, are there any strategic moves that we should be making to counteract this trend?

Memo 13

To: Strategic Analyst, Metropolitan Area

From: Vice President, Strategy

Re: Competition

A recent survey of the Metro area provides us with some market share data for the region.

Use the attached data to provide some concrete measures of the concentration of our industry.

1. According to Department of Justice guidelines, is the industry heavily concentrated?
2. How has that changed since the 2015 survey?
3. Would a strategic partnership (or merger) with Dish Network create a significant change in concentration in the Metro area?

Your response will help us in developing our strategy.

Attachment: Marketshare.xls

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EXHIBIT 1A

Time Warner Cable Consolidated Statement of Operations

	2015	2014	2013
Revenue:			
Video	9,907	10,002	10,481
High-speed data	7,029	6,428	5,822
Voice	1,931	1,932	2,027
Business Services	3,284	2,838	2,312
Other	1,546	1,612	1,478
Total Revenue	23,697	22,812	22,120
Costs and Expenses:			
Programming and content	5,815	5,294	4,950
Sales and marketing	2,379	2,192	2,048
Technical operations	1,669	1,530	1,500
Customer care	900	839	766
Other operating	4,796	4,729	4,876
Depreciation	3,560	3,236	3,155
Amortization	136	135	126
Merger related costs	203	225	119
Total Costs and Expenses	19,458	18,180	17,540
Operating Income	4,239	4,632	4,580
Interest Expense	1,401	1,419	1,552
Other income	150	35	11
Income Tax provision	1,144	1,217	1,085
Net Income	1,844	2,031	1,954

(In millions)

SOURCE: Time Warner Cable 2015 10K

EXHIBIT 1B

Time Warner Cable Consolidated Balance Sheet

	2015	2014
Assets		
Current Assets:		
Cash and Equivalents	1,170	707
Receivables (Net)	916	949
Other Current Assets	373	383
Total Current Assets	2,459	2,039
Investments	65	64
Property, plant and equipment, net	16,945	15,990
Intangible assets	26,451	26,535
Goodwill	3,139	3,137
Other assets	218	370
Total assets	49,277	48,135
Liabilities and Equity		
Current Liabilities:		
Accounts payable	656	567
Deferred revenue	224	198
Accrued programming expense	985	902
Current maturities of L/T debt	5	1,017
Other current liabilities	2,079	1,813
Total current liabilities	3,949	4,497
Long-term debt	22,497	22,604
Deferred income tax liabilities	12,830	12,291
Other liabilities	1,002	726
TWC shareholders' equity		
Common stock	3	3
Additional paid-in capital	7,481	7,172
Retained earnings	1,925	1,162
Accumulated other loss	(410)	(320)
Total TWC shareholders' equity	8,999	8,017
Total liabilities and equity	49,277	48,135

(In millions)

SOURCE: Time Warner Cable 2015 10K

EXHIBIT 2A

Time Warner Cable—Average Monthly Revenue per Subscriber

	2010	2011	2012	2013	2014	2015	Annualized Growth Rate
Video	70.46	73.18	74.64	74.90	75.85	76.54	1.7%
High-Speed Data	37.00	38.32	39.66	43.92	46.95	48.11	5.4%
Voice	37.08	36.89	35.68	34.40	32.35	27.56	−5.8%
Customer Relationship*	99.77	101.67	103.57	105.28	106.24	106.77	1.4%

SOURCE: Time Warner Cable Annual Reports (2010–2015)

*Customer Relationship is revenue per customer, and is higher due to customers subscribing to multiple services.

EXHIBIT 2B

Time Warner Cable—Revenue by Service

	2010	2011	2012	2013	2014	2015	Annualized Growth Rate
Video	10,577	10,589	10,917	10,481	10,002	9,907	−1.3%
High-Speed Data	4,121	4,476	5,090	5,822	6,428	7,029	11.3%
Voice	1,905	1,979	2,104	2,027	1,932	1,931	0.3%
Business	1,107	1,469	1,901	2,312	2,838	3,284	24.3%
Other*	1,158	1,162	1,374	1,478	1,612	1,546	5.9%
Total Revenue	18,868	19,675	21,386	22,120	22,812	23,697	4.7%

($ in millions)

SOURCE: Time Warner Cable Annual Reports

*Other revenue is primarily Advertising.

EXHIBIT 2C

Time Warner Cable—Subscribers by Service

	2010	2011	2012	2013	2014	2015	Annualized Growth Rate
Residential Video	12,257	11,889	12,030	11,197	10,789	10,821	−2.5%
Residential High-Speed Data	9,469	9,954	10,935	11,089	11,675	12,675	6.0%
Residential Voice	4,385	4,544	5,024	4,806	5,284	6,320	7.6%
Business Subscribers*		486	563	624	687	752	11.5%
Total Customer Relationships**	14,496	14,511	15,237	15,008	15,198	15,881	1.8%

(Subscribers in thousands)

SOURCE: Time Warner Cable Annual Reports

*Business Subscribers not separately reported for 2010.

**Total customer relationships is fewer than the sum of services due to customers with multiple services.

EXHIBIT 3

Multichannel Video Programming Distributer by Type

	1993	1998	2003	2008	2013
Cable	94.9%	85.3%	74.9%	64.9%	54.5%
Direct Broadcast Satellite (DBS)	0.1%	9.4%	21.6%	31.9%	34.2%
Telephone and Other MVPDs	5.0%	5.3%	3.5%	3.2%	11.3%

SOURCE: Federal Communications Commission and author calculations

EXHIBIT 4

Key Industry Players

	2015 Revenue (billions)	Video Subscribers (millions)	Key Business and Notes
Cable Companies			
Time Warner Cable	$23.7	10.8	Time Warner is in a pending deal to be acquired by Charter Communications.
Comcast	$74.5	22.3	In addition to its cable business, Comcast owns NBCUniversal, which includes TV and film production, broadcast and cable networks, and theme parks.
Charter Communications	$9.7	4.3	Charter entered into an agreement to acquire Time Warner Cable and Bright House Networks, a smaller cable company. The deal has yet to go through.
Cox Communications*	$10.4	4.0	Cox is a privately held cable company.
Satellite Providers			
AT&T/DirecTV	$20.3	25.4	AT&T's acquisition of DirecTV has led them to have the highest number of video subscribers. Revenue figure is for Entertainment group, which is comprised primarily of DirecTV and U-Verse.
Dish Network	$15.1	13.9	Dish has a direct broadcast satellite service, as well as an Over-the-Top service providing multichannel content through Internet access.
Phone Companies			
AT&T	$20.3	25.4	Revenue figure is for the Entertainment group, which is comprised primarily of DirecTV and U-Verse.
Verizon	$37.7	5.8	Revenue is for Wireline services, which includes residential telephone, video, and high speed data.
Internet Companies			
Netflix	$6.8	43.4	Netflix streaming video service had 43.4 million paid memberships in the U.S. as of the beginning of 2016. Content includes movies, TV series, and original programming. Revenue growth for Netflix domestic streaming service was between 20% and 25% for each of the last three years.
Amazon**	$107.0	50.0	Amazon does not disclose the number of Prime members; analysts estimated that there were around 50 million U.S. members as of early 2016.
Google/YouTube	***	***	In late 2015, Google announced the launch of YouTube Red, a subscription version of its YouTube video sharing service. For $10 per month, members can view ad-free videos and download videos.
Hulu	$1.5	9.0	Hulu is jointly owned by Disney (ABC and ESPN), Fox Broadcasting, and NBCUniversal television.

SOURCES: Company reports and author calculations

*(Estimated) Cox Communications is a subsidiary of privately held Cox Enterprises.

**Estimated Amazon Prime members

***No available data

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Glossary

A

accounting profits The total amount of money taken in from sales (total revenue, or price times quantity sold) minus the dollar cost of producing goods or services.

adverse selection Situation in which individuals have hidden characteristics and in which a selection process results in a pool of individuals with undesirable characteristics.

affiliated (or correlated) value estimates Auction environment in which bidders do not know their own valuation of the item or the valuations of others. Each bidder uses his or her own information to estimate their valuation, and these value estimates are affiliated: The higher a bidder's value estimate, the more likely it is that other bidders also have high value estimates.

antitrust policy Government policies designed to keep firms from monopolizing their markets.

asymmetric information A situation that exists when some people have better information than others.

average fixed cost (AFC) Fixed costs divided by the number of units of output.

average product (AP) A measure of the output produced per unit of input.

average total cost (ATC) Total cost divided by the number of units of output.

average variable cost (AVC) Variable costs divided by the number of units of output.

B

Bertrand oligopoly An industry in which (1) there are few firms serving many consumers, (2) firms produce identical products at a constant marginal cost, (3) firms compete in price and react optimally to competitors' prices, (4) consumers have perfect information and there are no transaction costs, and (5) barriers to entry exist.

best-response (or reaction) function A function that defines the profit-maximizing level of output for a firm for given output levels of another firm.

block pricing Pricing strategy in which identical products are packaged together in order to enhance profits by forcing customers to make an all-or-none decision to purchase.

brand equity The additional value added to a product because of its brand.

brand myopic A manager or company that rests on a brand's past laurels instead of focusing on emerging industry trends or changes in consumer preferences.

budget line The bundles of goods that exhaust a consumer's income.

budget set The bundles of goods a consumer can afford.

C

change in demand Changes in variables other than the price of a good, such as income or the price of another good, lead to a change in demand. This corresponds to a shift of the entire demand curve.

change in quantity demanded Changes in the price of a good lead to a change in the quantity demanded of that good. This corresponds to a movement along a given demand curve.

change in quantity supplied Changes in the price of a good lead to a change in the quantity supplied of that good. This corresponds to a movement along a given supply curve.

change in supply Changes in variables other than the price of a good, such as input prices or technological advances, lead to a change in supply. This corresponds to a shift of the entire supply curve.

Cobb-Douglas production function A production function that assumes some degree of substitutability among inputs.

commodity bundling The practice of bundling several different products together and selling them at a single "bundle price."

common value Auction environment in which the true value of the item is the same for all bidders, but this common value is unknown. Each bidder uses his or her own (private) information to form an estimate of the item's true common value.

comparative advertising A form of advertising where a firm attempts to increase the demand for its brand by differentiating its product from competing brands.

complements Goods for which an increase (decrease) in the price of one good leads to a decrease (increase) in the demand for the other good.

constant returns to scale Exist when long-run average costs remain constant as output is increased.

consumer equilibrium The equilibrium consumption bundle is the affordable bundle that yields the greatest satisfaction to the consumer.

consumer surplus The value consumers get from a good but do not have to pay for.

contestable market A market in which (1) all firms have access to the same technology, (2) consumers respond quickly to price changes, (3) existing firms cannot respond quickly to entry by lowering their prices, and (4) there are no sunk costs.

contract A formal relationship between a buyer and a seller that obligates the buyer and the seller to exchange at terms specified in a legal document.

cost complementarities Exist when the marginal cost of producing one output is reduced when the output of another product is increased.

cost complementarity When the marginal cost of producing one type of output decreases when the output of another good is increased.

cost minimization Producing output at the lowest possible cost.

Cournot equilibrium A situation in which neither firm has an incentive to change its output, given the other firm's output.

Cournot oligopoly An industry in which (1) there are few firms serving many consumers, (2) firms produce either differentiated or homogeneous products, (3) each firm believes rivals will hold their output constant if it changes its output, and (4) barriers to entry exist.

cross-price elasticity A measure of the responsiveness of the demand for a good to changes in the price of a related good; the percentage change in the quantity demanded of one good divided by the percentage change in the price of a related good.

cross-subsidy Pricing strategy in which profits gained from the sale of one product are used to subsidize sales of a related product.

cubic cost function Costs are a cubic function of output; provides a reasonable approximation to virtually any cost function.

D

Dansby-Willig (DW) performance index Ranks industries according to how much social welfare would improve if the output in an industry were increased by a small amount.

deadweight loss of monopoly The consumer and producer surplus that is lost due to the monopolist charging a price in excess of marginal cost.

decreasing (diminishing) marginal returns Range of input usage over which marginal product declines.

demand function A function that describes how much of a good will be purchased at alternative prices of that good and related goods, alternative income levels, and alternative values of other variables affecting demand.

direct network externality The direct value enjoyed by the user of a network because others also use the network.

diseconomies of scale Exist whenever long-run average costs increase as output increases.

dominant strategy A strategy that results in the highest payoff to a player regardless of the opponent's action.

Dutch auction A descending sequential-bid auction in which the auctioneer begins with a high asking price and gradually reduces the asking price until one bidder announces a willingness to pay that price for the item.

E

economic profits The difference between total revenue and total opportunity cost.

economics The science of making decisions in the presence of scarce resources.

economies of scale Exist whenever long-run average costs decline as output increases.

economies of scope Exist when the total cost of producing two products within the same firm is lower than when the products are produced by separate firms.

elastic demand Demand is elastic if the absolute value of the own price elasticity is greater than 1.

elasticity A measure of the responsiveness of one variable to changes in another variable; the percentage change in one variable that arises due to a given percentage change in another variable.

English auction An ascending sequential-bid auction in which bidders observe the bids of others and decide whether or not to increase the bid. The auction ends when a single bidder remains; this bidder obtains the item and pays the auctioneer the amount of the bid.

extensive-form game A representation of a game that summarizes the players, the information available to them at each stage, the strategies available to them, the sequence of moves, and the payoffs resulting from alternative strategies.

F

finitely repeated game Games in which players do not know when the game will end; and games in which players know when it will end.

firm demand curve The demand curve for an individual firm's product; in a perfectly competitive market, it is simply the market price.

first-price, sealed-bid auction A simultaneous-move auction in which bidders simultaneously submit bids on pieces of paper. The auctioneer awards the item to the high bidder, who pays the amount bid.

fixed costs Costs that do not change with changes in output; include the costs of fixed inputs used in production.

fixed factors of production The inputs a manager cannot adjust in the short run.

four-firm concentration ratio The fraction of total industry sales generated by the four largest firms in the industry.

full economic price The dollar amount paid to a firm under a price ceiling, plus the nonpecuniary price.

G

green marketing A form of niche marketing where firms target products toward consumers who are concerned about environmental issues.

H

Herfindahl-Hirschman index (HHI) The sum of the squared market shares of firms in a given industry multiplied by 10,000.

hidden action Action taken by one party in a relationship that cannot be observed by the other party.

hidden characteristics Things one party to a transaction knows about itself but which are unknown by the other party.

I

income effect The movement from one indifference curve to another that results from the change in real income caused by a price change.

income elasticity A measure of the responsiveness of the demand for a good to changes in consumer income; the percentage change in quantity demanded divided by the percentage change in income.

increasing marginal returns Range of input usage over which marginal product increases.

incremental costs The additional costs that stem from a yes-or-no decision.

incremental revenues The additional revenues that stem from a yes-or-no decision.

independent private values Auction environment in which each bidder knows his own valuation of the item but does not know other bidders' valuations, and in which each bidder's valuation does not depend on other bidders' valuations of the object.

indifference curve A curve that defines the combinations of two goods that give a consumer the same level of satisfaction.

indirect network externality (network complementarities) The indirect value enjoyed by the user of a network because of complementarities between the size of a network and the availability of complementary products or services.

inelastic demand Demand is inelastic if the absolute value of the own price elasticity is less than 1.

inferior good A good for which an increase (decrease) in income leads to a decrease (increase) in the demand for that good.

infinitely repeated game A game that is played over and over again forever and in which players receive payoffs during each play of the game.

isocost line A line that represents the combinations of inputs that will cost the producer the same amount of money.

isoprofit curve A function that defines the combinations of outputs produced by all firms that yield a given firm the same level of profits.

isoquant Defines the combinations of inputs that yield the same level of output.

L

law of demand As the price of a good rises (falls) and all other things remain constant, the quantity demanded of the good falls (rises).

law of diminishing marginal rate of technical substitution A property of a production function stating that as less of one input is used, increasing amounts of another input must be employed to produce the same level of output.

law of diminishing marginal returns States that the marginal product of an additional unit of an input will at some point be lower than the marginal product of the previous unit.

law of supply As the price of a good rises (falls) and other things remain constant, the quantity supplied of the good rises (falls).

learning curve effects When a firm enjoys lower costs due to knowledge gained from its past production decisions.

least squares regression The line that minimizes the sum of squared deviations between the line and the actual data points.

Leontief production function A production function that assumes that inputs are used in fixed proportions.

Lerner index A measure of the difference between price and marginal cost as a fraction of the product's price.

limit pricing Strategy where an incumbent maintains a price below the monopoly level in order to prevent entry.

linear demand function A representation of the demand function in which the demand for a given good is a linear function of prices, income levels, and other variables influencing demand.

linear production function A production function that assumes a perfect linear relationship between all inputs and total output.

linear supply function A representation of the supply function in which the supply of a given good is a linear function of prices and other variables affecting supply.

log-linear demand Demand is log-linear if the logarithm of demand is a linear function of the logarithms of prices, income, and other variables.

long-run average cost curve A curve that defines the minimum average cost of producing alternative levels of output, allowing for optimal selection of both fixed and variable factors of production.

lump-sum tariff A fixed fee that an importing firm must pay the domestic government in order to have the legal right to sell the product in the domestic market.

M

manager A person who directs resources to achieve a stated goal.

managerial economics The study of how to direct scarce resources in the way that most efficiently achieves a managerial goal.

marginal (incremental) cost (MC) The change in total costs arising from a change in the managerial control variable Q.

marginal (incremental) cost (MC) The cost of producing an additional unit of output.

marginal benefit The change in total benefits arising from a change in the managerial control variable Q.

marginal product (MP) The change in total output attributable to the last unit of an input.

marginal rate of substitution (*MRS*) The rate at which a consumer is willing to substitute one good for another good and still maintain the same level of satisfaction.

marginal rate of technical substitution (*MRTS*) The rate at which a producer can substitute between two inputs and maintain the same level of output.

marginal revenue The change in revenue attributable to the last unit of output; for a competitive firm, *MR* is the market price.

market demand curve A curve indicating the total quantity of a good all consumers are willing and able to purchase at each possible price, holding the prices of related goods, income, advertising, and other variables constant.

market power The ability of a firm to set its price above marginal cost.

market rate of substitution The rate at which one good may be traded for another in the market; slope of the budget line.

market structure Factors that affect managerial decisions, including the number of firms competing in a market, the relative size of firms, technological and cost considerations, demand conditions, and the ease with which firms can enter or exit the industry.

market supply curve A curve indicating the total quantity of a good that all producers in a competitive market would produce at each price, holding input prices, technology, and other variables affecting supply constant.

mean (expected value) The sum of the probabilities that different outcomes will occur multiplied by the resulting payoffs.

mixed (randomized) strategy A strategy whereby a player randomizes over two or more available actions in order to keep rivals from being able to predict his or her action.

monopolistic competition A market in which (1) there are many buyers and sellers, (2) each firm produces a differentiated product, and (3) there is free entry and exit.

monopoly A market structure in which a single firm serves an entire market for a good that has no close substitutes.

moral hazard Situation where one party to a contract takes a hidden action that benefits him or her at the expense of another party.

multiproduct cost function A function that defines the cost of producing given levels of two or more types of outputs assuming all inputs are used efficiently.

N

Nash equilibrium A condition describing a set of strategies in which no player can improve her payoff by unilaterally changing her own strategy, given the other players' strategies.

negative externalities Costs borne by parties who are not involved in the production or consumption of a good.

negative marginal returns Range of input usage over which marginal product is negative.

net present value (*NPV*) The present value of the income stream generated by a project minus the current cost of the project.

niche marketing A marketing strategy where goods and services are tailored to meet the needs of a particular segment of the market.

nonexclusionary good A good or service is nonexclusionary if, once provided, no one can be excluded from consuming it.

nonrival good A good is nonrival in consumption if the consumption of the good by one person does not preclude other people from also consuming the good.

normal good A good for which an increase (decrease) in income leads to an increase (decrease) in the demand for that good.

normal-form game A representation of a game indicating the players, their possible strategies, and the payoffs resulting from alternative strategies.

O

oligopoly A market structure in which there are only a few firms, each of which is large relative to the total industry.

one-shot game Game in which the underlying game is played only once.

opportunity cost The explicit cost of a resource plus the implicit cost of giving up its best alternative use.

own price elasticity of demand A measure of the responsiveness of the quantity demanded of a good to a change in the price of that good; the percentage change in quantity demanded divided by the percentage change in the price of the good.

P

peak-load pricing Pricing strategy in which higher prices are charged during peak hours than during off-peak hours.

penetration pricing Charging a low price initially to penetrate a market and gain a critical mass of customers; useful when strong network effects are present.

perfectly competitive market A market in which (1) there are many buyers and sellers, (2) each firm produces a homogeneous product, (3) buyers and sellers have perfect information, (4) there are no transaction costs, and (5) there is free entry and exit.

perfectly elastic demand Demand is perfectly elastic if the own price elasticity is infinite in absolute value. In this case the demand curve is horizontal.

perfectly inelastic demand Demand is perfectly inelastic if the own price elasticity is zero. In this case the demand curve is vertical.

per-unit (or excise) tariff The fee an importing firm must pay to the domestic government on each unit it brings into the country.

predatory pricing Strategy where a firm temporarily prices below its marginal cost to drive competitors out of the market.

present value (*PV*) The amount that would have to be invested today at the prevailing interest rate to generate the given future value.

price ceiling The maximum legal price that can be charged in a market.

price–cost squeeze Tactic used by a vertically integrated firm to squeeze the margins of its competitors.

price discrimination The practice of charging different prices to consumers for the same good or service.

price floor The minimum legal price that can be charged in a market.

price matching A strategy in which a firm advertises a price and a promise to match any lower price offered by a competitor.

producer surplus The amount producers receive in excess of the amount necessary to induce them to produce the good.

production function A function that defines the maximum amount of output that can be produced with a given set of inputs.

profit sharing Mechanism used to enhance workers' efforts that involves tying compensation to the underlying profitability of the firm.

public good A good that is nonrival and nonexclusionary in consumption.

Q

quota A restriction that limits the quantity of imported goods that can legally enter the country.

R

raising rivals' costs Strategy in which a firm gains an advantage over competitors by increasing their costs.

randomized pricing Pricing strategy in which a firm intentionally varies its price in an attempt to "hide" price information from consumers and rivals.

relationship-specific exchange A type of exchange that occurs when the parties to a transaction have made specialized investments.

rent seeking Selfishly motivated efforts to influence another party's decision.

repeated game Game in which the underlying game is played more than once.

reservation price The price at which a consumer is indifferent between purchasing at that price and searching for a lower price.

revenue sharing Mechanism used to enhance workers' efforts that involves linking compensation to the underlying revenues of the firm.

risk averse Preferring a sure amount of $\$M$ to a risky prospect with an expected value of $\$M$.

risk loving Preferring a risky prospect with an expected value of $\$M$ to a sure amount of $\$M$.

risk neutral Indifferent between a risky prospect with an expected value of $\$M$ and a sure amount of $\$M$.

Rothschild index A measure of the sensitivity to price of a product group as a whole relative to the sensitivity of the quantity demanded of a single firm to a change in its price.

S

screening An attempt by an uninformed party to sort individuals according to their characteristics.

second-price, sealed-bid auction A simultaneous-move auction in which bidders simultaneously submit bids. The auctioneer awards the item to the high bidder, who pays the amount bid by the second-highest bidder.

secure strategy A strategy that guarantees the highest payoff given the worst possible scenario.

self-selection device A mechanism in which informed parties are presented with a set of options, and the options

they choose reveal their hidden characteristics to an uninformed party.

sequential-move game Game in which one player makes a move after observing the other player's move.

short-run cost function A function that defines the minimum possible cost of producing each output level when variable factors are employed in the cost-minimizing fashion.

signaling An attempt by an informed party to send an observable indicator of his or her hidden characteristics to an uninformed party.

simultaneous-move game Game in which each player makes decisions without knowledge of the other players' decisions.

specialized investment An expenditure that must be made to allow two parties to exchange but has little or no value in any alternative use.

spot exchange An informal relationship between a buyer and a seller in which neither party is obligated to adhere to specific terms for exchange.

Stackelberg oligopoly An industry in which (1) there are few firms serving many consumers, (2) firms produce either differentiated or homogeneous products, (3) a single firm (the leader) chooses an output before rivals select their outputs, (4) all other firms (the followers) take the leader's output as given and select outputs that maximize profits given the leader's output, and (5) barriers to entry exist.

standard deviation The square root of the variance.

strategy In game theory, a decision rule that describes the actions a player will take at each decision point.

subgame perfect equilibrium A condition describing a set of strategies that constitutes a Nash equilibrium and allows no player to improve his own payoff at any stage of the game by changing strategies.

substitutes Goods for which an increase (decrease) in the price of one good leads to an increase (decrease) in the demand for the other good.

substitution effect The movement along a given indifference curve that results from a change in the relative prices of goods, holding real income constant.

sunk cost A cost that is forever lost after it has been paid.

supply function A function that describes how much of a good will be produced at alternative prices of that good, alternative input prices, and alternative values of other variables affecting supply.

Sweezy oligopoly An industry in which (1) there are few firms serving many consumers, (2) firms produce differentiated products, (3) each firm believes rivals will respond to a price reduction but will not follow a price increase, and (4) barriers to entry exist.

T

***t*-statistic** The ratio of the value of a parameter estimate to the standard error of the parameter estimate.

time value of money The fact that $1 today is worth more than $1 received in the future.

total cost Sum of fixed and variable costs.

total product (TP) The maximum level of output that can be produced with a given amount of inputs.

transaction costs Costs associated with acquiring an input that are in excess of the amount paid to the input supplier.

transfer pricing Pricing strategy in which a firm optimally sets the internal price at which an upstream division sells an input to a downstream division.

trigger strategy A strategy that is contingent on the past play of a game and in which some particular past action "triggers" a different action by a player.

two-part pricing Pricing strategy in which consumers are charged a fixed fee for the right to purchase a product, plus a per-unit charge for each unit purchased.

U

unitary elastic demand Demand is unitary elastic if the absolute value of the own price elasticity is equal to 1.

V

value marginal product The value of the output produced by the last unit of an input.

variable costs Costs that change with changes in output; include the costs of inputs that vary with output.

variable factors of production The inputs a manager can adjust to alter production.

variance The sum of the probabilities that different outcomes will occur multiplied by the squared deviations from the mean of the resulting payoffs.

vertical foreclosure Strategy wherein a vertically integrated firm charges downstream rivals a prohibitive price for an essential input, thus forcing rivals to use more costly substitutes or go out of business.

vertical integration A situation where a firm produces the inputs required to make its final product.

W

winner's curse The "bad news" conveyed to the winner that his or her estimate of the item's value exceeds the estimates of all other bidders.

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EKONOMI TEKNIK



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EKONOMI TEKNIK



UU 28 tahun 2014 tentang Hak Cipta

Fungsi dan sifat hak cipta Pasal 4

Hak Cipta sebagaimana dimaksud dalam Pasal 3 huruf a merupakan hak eksklusif yang terdiri atas hak moral dan hak ekonomi.

Pembatasan Perlindungan Pasal 26

Ketentuan sebagaimana dimaksud dalam Pasal 23, Pasal 24, dan Pasal 25 tidak berlaku terhadap:

a. penggunaan kutipan singkat Ciptaan dan/atau produk Hak Terkait untuk pelaporan peristiwa aktual yang ditujukan hanya untuk keperluan penyediaan informasi aktual;
b. Penggandaan Ciptaan dan/atau produk Hak Terkait hanya untuk kepentingan penelitian ilmu pengetahuan;
c. Penggandaan Ciptaan dan/atau produk Hak Terkait hanya untuk keperluan pengajaran, kecuali pertunjukan dan Fonogram yang telah dilakukan Pengumuman sebagai bahan ajar; dan
d. penggunaan untuk kepentingan pendidikan dan pengembangan ilmu pengetahuan yang memungkinkan suatu Ciptaan dan/atau produk Hak Terkait dapat digunakan tanpa izin Pelaku Pertunjukan, Produser Fonogram, atau Lembaga Penyiaran.

Sanksi Pelanggaran Pasal 113

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Ekonomi Teknik

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Dewasa ini teknologi telah berkembang dengan pesat sehingga dalam praktiknya untuk mewujudkan suatu kebutuhan manusia akan dihadapkan dengan berbagai pilihan/alternatif. Alternatif tersebut bisa dalam bentuk desain, rencana, prosedur, metode, material, waktu, dan lainnya. Karena setiap pilihan alternatif akan berdampak langsung pada pemakaian sumber daya, di mana sumber daya itu sendiri semakin mahal dan sulit, maka seyogyanya pemilihan alternatif harus didasarkan pada prinsip-prinsip efisiensi dan efektivitas dari pemanfaran sumber daya itu sendiri. Prinsip ini akan menjadi lebih penting lagi bila persoalannya berkaitan dengan penerapan kegiatan keteknikan (engineeing), di mana pada umumnya kegiatan teknik akan melibatkan biaya awal (investasi) yang relatif besar dan berdampak langsung pula pada kebutuhan biaya operasional dan perawatan jangka panjangnya.

Buku ini membahas terkait :
Bab 1 Konsep-Konsep Dasar
Bab 2 Nilai Sekarang (Present Worth)
Bab 3 Infinite Analysis Period-Capitalized Cost
Bab 4 Rate of Return Analysis
Bab 5 Sensitivity Analysis
Bab 6 Breakeven Analysis
Bab 7 Payback Period
Bab 8 Menghitung Nilai Investasi Return on Investment (ROI)

Bab 9 Komplikasi Masalah-Masalah Nyata
Bab 10 Analisa Kelayakan Pembangunan Embung

Dalam penyusunan buku ini, penulis mendapatkan informasi dan data dari berbagai sumber seperti buku, jurnal, artikel, laporan ilmiah yang mendukung penyampaian materi secara faktual sehingga buku ini dapat terjamin kesahihan informasi yang disampaikan.

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Medan, Januari 2023

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Bab 1

Konsep-Konsep Dasar

1.1 Pendahuluan

Ilmu pengetahuan dan teknologi telah mengantarkan manusia pada sistem kehidupan modern yang sarat dengan teknologi sebagaimana kita alami dewasa ini. Melalui pengembangan ilmu pengetahuan dan teknologinya, manusia akan dapat memanfaatkan sumber daya alam secara optimal untuk memenuhi berbagai kebutuhannya. Pada awal peradaban manusia hanya memanfaatkan sumber daya alam secara langsung tanpa banyak perbaikan, seperti memanfaatkan gua-gua batu sebagai tempat berteduh, daun-daun dijadikan pakaian, buah-buahan dan umbi-umbian sebagai makanan dan sebagainya. Kemudian manusia mulai mengembangkan berbagai teknologi dan metode dalam rangka pemanfaatan sumber daya alam secara lebih baik dan optimal.

Melalui sentuhan-sentuhan ilmu dan teknologi yang lebih baik, manusia telah mampu merancang dan membangun rumah, gedung, masjid, sekolah, jalan, jembatan, bendungan, irigasi, pembangkit listrik, telepon, berbagai mesin dan peralatan produksi lainnya, mulai dari yang manual, mekanis, otomatis sampai dengan automatical control. Teknologi juga telah berhasil memperbaiki produktivitas lahan-lahan pertanian, mengembangkan berbagai varietas tanaman, peternakan, dan berbagai kelengkapan/asesoris kehidupan lainnya, di

mana hampir tidak ditemukan lagi sisi-sisi kehidupan terkecil dari manusia yang tidak mendapat sentuhan teknologi.

Dewasa ini teknologi telah berkembang dengan pesat sehingga dalam praktiknya untuk mewujudkan suatu kebutuhan manusia akan dihadapkan dengan berbagai pilihan/alternatif. Alternatif tersebut bisa dalam bentuk desain, rencana, prosedur, metode, material, waktu, dan lainnya. Karena setiap pilihan alternatif akan berdampak langsung pada pemakaian sumber daya, di mana sumber daya itu sendiri semakin mahal dan sulit, maka seyogyanya pemilihan alternatif harus didasarkan pada prinsip-prinsip efisiensi dan efektivitas dari pemanfaran sumber daya itu sendiri. Prinsip ini akan menjadi lebih penting lagi bila persoalannya berkaitan dengan penerapan kegiatan keteknikan (engineeing), di mana pada umumnya kegiatan teknik akan melibatkan biaya awal (investasi) yang relatif besar dan berdampak langsung pula pada kebutuhan biaya operasional dan perawatan jangka panjangnya.

Oleh karena itu, seyogyanya setiap rancangan teknik yang akan diterapkan perlu diuji dengan pertanyaan-pertanyaan kritis seperti berikut.

1. Mengapa memilih yang itu, dan mengapa tidak yang lain?
2. Mengapa melakukannya sekarang, bagaimana kalau lain waktu?
3. Mengapa melakukannya dengan cara ini, mengapa tidak dengan cara lain?

Pertanyaan pertama dapat diturunkan lagi menjadi pertanyaan yang lebih spesifik, seperti: Haruskah kegiatan yang diusulkan itu dilaksanakan; Perlukah kegiatan yang ada diperluas, dikurangi atau ditinggalkan; Haruskah standar yang ada atau prosedur operasi diperbaiki?

Pertanyaan Mengapa melakukannya sekarang? Dapat dilengkapi dengan pertanyaan: Haruskah dibangun dengan ukuran atau kapasitas itu sekarang atau perlu dibangun sesuai dengan perkembangan kabutuhan/permintaan; Apakah biaya mencukupi sekarang; Apakah tidak akan mengganggu kondisi bisnis yang lainnya jika dibangun sekarang; dan sebagainya.

Pertanyaan-pertanyaan di atas merupakan bagian dari keputusan-keputusan teknik yang tidak dapat diabaikan dalam rangka membuktikan bahwa desain/rancangan yang dibuat merupakan rancangan yang baik dan menguntungkan untuk dilaksanakan/direalisasikan. Konsep pikir ini akan lebih penting lagi jika desain teknik tersebut ditujukan pada kegiatan-kegiatan profit

oriented (Perusahaan Bisnis) seperti perusahaan manufaktur, pertanian, manufaktur, real estate, dan sebagainya).

Untuk menjawab pertanyaan-pertanyaan tersebut dibutuhkan suatu kriteria dan indikator penilaian yang tepat dan relevan sehingga jawaban yang dihasilkan objektif dan rasional. Untuk pertanyaan yang bersifat teknis pada dasarnya perlu dijawab dengan kriteria dan indikator teknis melalui suatu evaluasi teknis, namun pada akhirnya keputusan-keputusan teknis dapat dikonversikan menjadi kriteria-kriteria ekonomis melalui indikator-indikator *cashflow* yang diakibatkan oleh aspek biaya dan manfaat yang terkandung dari setiap alternatif teknis yang diusulkan tersebut.

Dengan demikian, Ekonomi teknik pada dasarnya adalah suatu ilmu pengetahuan yang menjelaskan bagaimana metode menilai suatu desain teknis direncanakan juga layak ekonomis/menguntungkan untuk direalisasikan sebagaimana yang terkandung dalam tujuan pembahasan buku ini.

1.2 Konsep Ekonomi

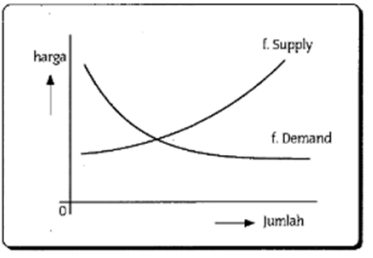
Menyadari kebutuhan manusia yang tidak terbatas, sedangkan di lain pihak kemampuan alam dalam menyediakan kebutuhan manusia tersebut terbatas, melahirkan suatu kondisi kelangkaan (Scarcity) (White et al., 2020). Suatu barang/jasa dikatakan langka jika jumlah yang diinginkan lebih besar dari yang dapat disediakan, maka terjadi perebutan. Dengan demikian, untuk mendapatkan barang/jasa yang langka tersebut individu/perusahaan bersedia membayar dengan harga tertentu, maka barang/jasa yang demikian disebut dengan barang (objek) ekonomi. Sementara itu, proses terjadinya transaksi pemindahan kepemilikan barang dari satu pihak ke pihak lain disebut dengan transaksi ekonomi. Dengan demikian, tran-saksi ekonomi akan terjadi sekurang-kurangnya bila ada dua pihak yaitu pihak penyedia barang (penjual) dan pihak pemakai (pembeli). Penjual mungkin hanya sebagai supplier (pedagang) dan mungkin juga sebagai produsen (membuat langsung) barang tersebut. Begitu pula dengan pembeli, mungkin hanya sebagai pedagang yangakan menjual kembali barang yang baru dibelinya tersebut atau pemakai (konsumen) langsung dari barang yang dibelinya.

Orang/kelompok/perusahaan yang secara simultan melakukan kegiatan transaksi ekonomi disebut dengan pelaku ekonomi (economic entity).

Sementara itu, kegiatannya disebut dengan kegiatan ekonomi. Dengan demikian, kegiatan ekonomi adalah suatu konsep aktivitas yang berorientasi pada proses untuk mendapatkan keuntungan ekonomis (profi) dengan adanya perbedaan nilai manfaat (value) dari suatu objek akibat dari adanya perbedaan waktu, tempat, sifat atau kepemilikan terhadap objek tersebut.

Nilai ekonomi dari suatu objek akan sangat tergantung dari ekni kebutuhan dan ketersediaan (supply and demand). Di mana jika suplay banyak demand kecil maka harganya jadi turun dan sebaliknya jika supply sedikit permintaan banyak harga naik, untuk jelasnya lihat grafik supply demand (Gambar 1.1). Oleh karena itu setiap pelaku ekonomi perlu memahami dan mengetahui kondisi supply demand tersebut secara baik dan memanfaatkan situasi itu sebagai peluang dalam mendapatkan keuntungan ekonomisnya secara optimal.

Para Pedagang pada umumnya akan mendapatkan keuntungan dengan memanfaatkan adanya perbedaan (fluktuasi) harga yang terjadi akibat perubahan kepemilikan, perubahan tempat, atau perubahan waktu. Berbeda dengan produsen, pada umumnya produsen mendapatkan keuntungan akibat adanya perubahan sifat maupun bentuk objek melalui suatu kegiatan proses produksi.Oleh karena itu, pengertian kegiatan ekonorni bagi produsen adalah



Gambar 1.1: Grafik Fungsi Supply-Demand

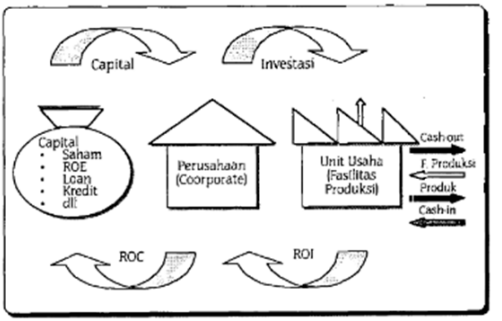
kegiatan memperbaiki nilai ekonomis suatu benda melalui kegiatan proses produksi (Gambar1.2).



Gambar. 1.2: Kegiatan Proses Produksi

1.2.1 Kegiatan Ekonomi dari Pandangan Sistem Produksi

Kegiatan ekonomi sebuah perusahaan adalah usaha untuk memperoleh keuntungan pada setiap siklus kegiatan usaha. Siklus kegiatan usaha dapat digambarkan sebagai berikut (lihat Gambar 1.3).



Gambar 1.3: Siklus Kegiatan Ekonomi Perusahaan Berdasarkan Sifat Perputaran Uang Memperbaiki Nilai Ekonomis

Perusahaan (corporate) hanyalah sebuah teknik formal dari kegiatan usaha, perusahaan memerlukan modal (capital) yang akan ditanamkan sebagai investasi pada setiap unit aktivitas usaha (fasilitas produksi). Aktivitas usaha berada pada unit usaha apakah dalam bentuk usaha produksi atau jasa yang tentu saja memerlukan sejumlah sarana, prasarana produksi, bahan baku, tenaga kerja dan lainnya yang disebut juga dengan teknik produksi. Faktor produksi menghasilkan *cash-out* dan selanjutnya teknik produksi dijalankan sedemikian rupa menghasilkan produk. Produk yang dijual memberikan cash-in pada unit produksi. Siklus ini dijalankan secara simultan, di mana pada tahap awal kemungkinan cash-in < < cash-out, namun dalam jangka teknik kondisinya akan berbalik sehingga dihasilkan selisih positif (profit). Profit inilah yang dikembalikan pada perusahaan secara teknik dalam bentuk *Return On Investment* (ROI). Pada tahap berikutnya ROI dipakai oleh perusahaan untuk mengembalikan modal dalam bentuk *Return On Capital* (ROC). Jika ROI > > ROC, perusahaan akan mendapat keuntungan. Namun, jika kejadian sebaliknya, perusahaan akan merugi. Oleh karena itu, perusahaan perlu selalu menjaga kondisi di atas.

Usaha-usaha yang dapat dilakukan oleh perusahaan jika kondisi di atas terusik antara lain:

1. Memperbaiki ROC Financial Management;
2. Memperbaiki ROI I meningkatkan produktivitas fasilitas produksi penambahan investasi baru Revitalisasi, rekapitali-sasi, reinvestasi, dan sebagainya) agar didapatkan ROI gabungan yang lebih baik;
3. Investasi baru dapat dilakukan dalam rangka: intensifikasi, diversifikasi, buka usaha baru, dan sebagainya.
4. Menutup perusahaan (likuidasi) jika peluang perbaikan usaha tidak memungkinkan lagi.

1.3 Ekonomi Teknik dan Perancangan Teknik Manufaktur

Aktivitas teknik adalah suatu konsep kegiatan manusia yang berorientasi pada proses perbaikan/perubahan sifat maupun bentuk dari benda-benda alam dalam rangka mendapatkan manfaat yang lebih baik dari sebelumnya. Bagaimana manusia mengubah sifat dan fungsi batu-batuan menjadi bangunan, mengubah pasir besi menjadi besi dan baja, mengubah kayu menjadi teknik atau menjadi kertas, dan sebagainya, yang semuanya merupakan hasil perancangan teknik yang dilakukan secara berkesinambungan.

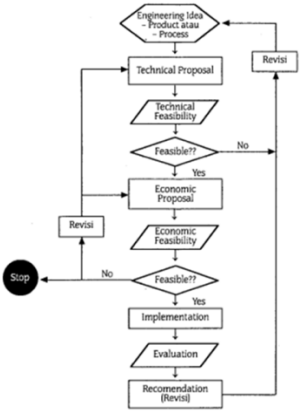
Ketika keputusan manajemen sedang dipertimbangkan mengenai investasi dalam produksi maju dan proyek sistem manufaktur, dampak potensial pada daya saing perusahaan mungkin signifikan. Namun bagaimana jika analisis ekonomi proyek tersebut belum dilakukan dengan baik? Tidak hanya pembuat keputusan yang cacat (mungkin tanpa disadari), tetapi kelangsungan hidup jangka panjang dari perusahaan itu sendiri dapat terancam (R. Parsaei and Mital, 1992).

Suatu aktivitas teknik akan selalu berawal dengan munculnya ide-ide rancangan teknik yang ingin diterapkan dalam rangka mengatasi keterbatasan-keterbatasan sumber daya alam guna memenuhi berbagai kebutuhan manusia. Manusia ingin mereka hidup dengan aman dan nyaman tanpa banyak mendapat gangguan lingkungan, maka dirancang bangunan sedemikian rupa.

Manusia ingin dapat bergerak dan berpindah tempat dari suatu daerah ke daerah lain, maka manusia merancang kendaraan. Manusia membutuhkan berbagai peralatan untuk dapat meringankan berbagai tugas pekerjaannya, maka dirancang peralatan untuk tujuan tersebut.

Pada awalnya para perancang teknik masih lebih banyak memfokuskan rancangannya pada aspek-aspek teknis saja, yaitu bagaimana rancangannya tersebut dapat dilaksanakan secara teknis, tanpa begitu memerhatikan aspek efisiensi pemakaian sumber daya. Hal itu dimungkinkan karena sumber daya yang dibutuhkan masih teknik banyak (murah). Namun, dengan semakin terbatasnya sumber daya alam dan semakin mahalnya biaya yang harus dikeluarkan untuk mendapat sumber-sumber daya alam tersebut, semua perancang teknik (engineer) dituntut untuk dapat menghasilkan rancangan-rancangan yang lebih efektif dan efisien.Tuntutan tersebut akan lebih nyata lagi jika hasil rancangan tersebut ditujukan sebagai bagian dari kegiatan ekonomi perusahaan,di mana semakin tingginya tingkat kompetisi usaha, menuntut setiap pengusaha dapat menghasilkan produk yang berkualitas baik dengan harga yang kompetitif, artinya setiap produk yang dibuat harus dikerjakan secara efektif dan efisien.

Dalam rangka menjamin dihasilkannya produk-produk *engineering* yang efektif dan efisien serta kompetitif tersebut, maka proses rancangannya perlu dilakukan secara baik, sistematis, dan terukur. Adapun prosedur rancangan yang baik dan sistematis tersebut dapat dijelaskan dengan *flow-chart* berikut (Gambar 1.4.)



Gambar 1.4: Siklus Kegiatan Teknologi yang Berorientasi Ekonomis

Diawali dengan munculnya ide/konsep teknik, mungkin berupa ide baru ataupun penyempurnaan dari ide atau rancangan yang ada yang mencakup tentang produk ataupun proses pengerjaan produk. Ide-ide tersebut tentu perlu dilahirkan secara sistematis dan tertulis melalui penjelasan-penjelasan, gambar-gambar, spesifikasi-spesifikasi, dan penjelasan teknis lainnya yang disebut dengan proposal teknis. Selanjutnya proposal teknis tersebut perlu dievaluasi kelayakan teknisnya sebelum dilaksanakan/direalisasikan.Artinya apakah rancangan tersebut memungkinkan secara teknis untuk direalisasikan, apakah sudah tersedia teknologinya beserta tenaga ahlinya. Jika belum memungkinkan, ada baiknya rancangan tersebut diperbaiki kembali atau dihentikan saja.

Jika secara teknologi dan teknis tidak ada masalah/layak, dilanjutkan dengan penyusunan proposal ekonomis untuk mengetahui seberapa besar biaya yang diperlukan untuk merealisasikan rancangan tersebut, apakah rancangan tersebut sudah ekonomis atau belum serta dari mana sumber-sumber dana yang diperlukan diperoleh, seberapa besar beban untuk memperoleh sumber-sumber biaya tersebut, dan sebagainya. Kalau rancangan ini bertujuan sebagai kegiatan usaha bisnis, tentu perlu dikaitkan dengan seberapa kompetitif produk tersebut dengan produk pesaingnya sehingga rancangan ini menjadi layak direalisasikan.

Jika proposal ekonomis tidak layak, kemungkinan proposal diperbaiki kembali atau dihentikan saja. Namun, jika proposal ekonomis terbukti layak, barulah rencana teknik tersebut dapat dilaksanakan/direalisasikan.

Untuk melakukan evaluasi ekonomis terhadap rancangan teknik di atas dibutuhkan pengetahuan pendukung ekonomi teknik (Economic Engineering). Oleh karena itu, Ekonomi Teknik adalah suatu ilmu pengetahuan yang berorientasi pada pengung kapan dan perhitungan nilai-nilai ekonomis yang terkandung dalam suatu rencana kegiatan teknik (engineering).

Karena penerapan kegiatan teknik pada umumnya memerlukan investasi yang teknik besar dan berdampak jangka Panjang terhadap aktivitas pengikutnya, penerapan aktivitas teknik tersebut menuntut adanya keputusan-keputusan strategis yang memerlukan pertimbangan-pertimbangan teknik maupun ekonomis yang baik dan rasional. Oleh karena itu, llmu Ekonomi Teknik sering juga dianggap sebagai sarana pendukung keputusan (Decision Mahing Support).

1.3.1 Pengambilan Keputusan

Keputusan yang baik dan rasional pada dasarnya memerlukan prosedur dan proses yang sistematis serta terukur dengan tahapan proses sebagai berikut:

1. Mengidentifikasi atau memahami persoalan dengan baik;
2. Merumuskan tujuan penyelesaian masalah;
3. Mengumpulkan data-data yang relevan;
4. Klarifikasi, klasifikasi, dan validasi kebenaran data yang terkumpul;
5. Identifikasi atau pelajari teknik pemecahan masalah yang mungkin;
6. Menetapkan kriteria pengukuran teknik;
7. Menyusun atau menyiapkan model keputusan;
8. Melakukan evaluasi dan analisis terhadap semua teknik yang disediakan;
9. Mengambil keputusan sesuai dengan tujuan;
10. Menerapkan atau mengimplemenrasikan keputusan yang telah diambil.

Dalam menyiapkan teknik perlu diperhatikan persyaratan berikut:

1. Jumlah teknik yang ideal 2-10 alternatif, jika teknik banyak perlu dilakukan seleksi bertingkat;
2. Memenuhi sifat mutually exclusiye (tidak ada teknik yang teknik tindih);
3. Memenuhi sifat axhausive (semua kemungkinan teknik yang tersedia telah terwakili).
    a. Efisiensi, Efektivitas, dan Optimalisasi

       Memahami konsep efisiensi, efektivitas, dan optimalisasi dengan baik sangat dibutuhkan dalam melakukan analisis dari suatu rancangan teknik, karena pemahaman konsep yang salah tidak akan memberikan hasil analisis yang tajam dan bermanfaat.

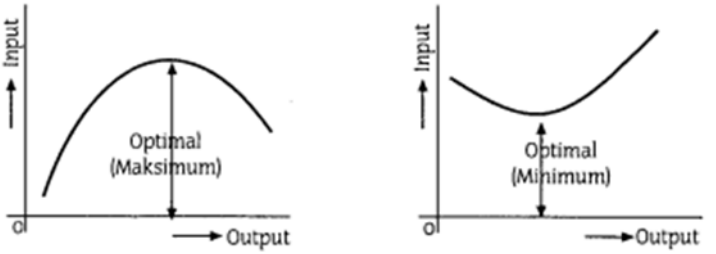
       Adapun pengertian dari masing-masing konsep tersebut adalah sebagai berikut.

       1) Efektivitas adalah ukuran tingkat keberhasilan dalam mencapai suatu tujuan. Semakin sempurna atau baik

pencapaian tujuan, artinya semakin efektif proses tersebut dilakukan.

2) Efisiensi adalah ukuran tingkat penghematan pemakaian sumber daya (input) dalam suatu proses, di mana semakin hemat memakai sumber daya, maka akan semakin efisien proses tersebut dilakukan.
3) Produktivitas adalah suatu ukuran yang menjelaskan seberapa besar rasio antara tingkat pencapaian tujuan dengan pemakaian sumber daya.
4)
$$\text{Produktifitas} = \frac{Efektivitas}{Efisiensi} = \frac{Output}{Input}$$
5) Optimal adalah suatu nilai yang terbesar ataupun terkecil akibat adanya hubungan yang tidak linear antara dua variable yang berpengaruh. Contohnya teknik dalam semua Teknik-teknik akan menghasilkan hubungan Output – Input tidak selalu linear sehingga akan menghasilkan kondisi optimal (lihat Grafik 1.5). Kondisi yang optimal ini selalu menjadi tujuan diperbaikinya teknik produksi secara terus-menerus dengan berbagai teknik tinjauan.

Suatu rancangan teknik yang baik seharusnya memerhatikan prinsip-prinsip efesiensi, efektivitas, dan produktivitas rancangannya dengan mencari kondisi-kondisi yang oprimal dari setiap teknik yang berpengaruh terhadap rancangan tersebut.



Gambar 1.5.a: Kondisi Optimal Maksimum **Gambar 1.5.b:** Kondisi Optimal Minimum

b. Cash Flow

Cash flow adalah tata aliran uang masuk dan keluar per periode waktu pada suatu perusahaan. Bidang ekonomi teknik menggunakan teknik matematika dan ekonomi untuk menganalisis situasi secara sistematis yang menimbulkan tindakan alternatif. langkah awal dalam masalah ekonomi teknik adalah menyelesaikan suatu situasi atau setiap jalur alternatif dalam situasi tertentu, menjadi konsekuensi atau faktor yang menguntungkan dan tidak menguntungkan (G. Newnan, G. Eschenbach and P. Lavelle, 2004).

Cash flow terdiri dari:

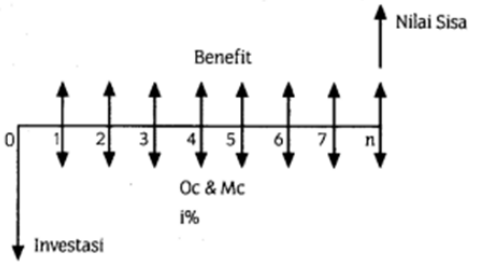
1) *cash-in* (uang masuk), umumnya berasal dari penjualan produk atau manfaat terukur (benefit);
2) *cash-out* (uang keluar), merupakan kumulatif dari biaya-biaya (cost) yang dikeluarkan.

Cash flow yang dibicarakan dalam ekonomi Teknik-teknik adalah cash flow investasi yang bersifat estimasi/prediktif. Karena kegiatan evaluasi investasi pada umumnya dilakukan sebelum investasi tersebut dilaksanakan, jadi perlu dilakukan estimasi atau perkiraan terhadap *cash flow* yang akan terjadi apabila rencana investasi tersebut dilaksanakan.

Dalam suatu investasi secara umum, *cash flow* akan terdiri dari empat komponen utama, yaitu:

1) Investasi;
2) Operational cost;
3) I cost;
4) Benefit/manfaat.

Secara umum bentuk grafis dari *cash flow* suatu investasi sebut diperlihatkan pada Gambar 1.6 berikut.



Gambar 1.6: Contoh Cash Flow

Jika *cash flow* tersebut sudah mqrupakan perkiraan uang yang akan masuk dan keluar akibat suatu investasi selama umurnya, perlu diketahui apakah investasi tersebut akan menguntungkan atau tidak. Artinya, apakah jumlah uang yang bakal masuk lebih besar dari jumlah uang yang akan keluar? Jika ya, artinya investasi akan menguntungkan (layak ekonomis), dan sebaliknya.

Jika besaran uang yang akan masuk dan keluar tidak berada pada waktu yang sama, sesuai dengan konsep "time value of money" (nilai uang akan berubah teknik waktu), maka diperlukan metode perhitungan tersendiri yang disebut ekuivalensi nilai uang.

Ekonomi teknik pada dasarnya adalah pengetahuan yang membicarakan tentang tatacara dan metode dalam melakukan evaluasi terhadap suatu rencana investasi. Maka, sebelum investasi tersebut dilaksanakan/diimplementasikan, seyogyanya rencana tersebut telah teruji kelayakan ekonomisnya di samping kelayakan teknis.

1.3.2 Proses Pengambilan Keputusan

Pengambilan keputusan yang masuk akal dan rasional merupakan proses yang yang tidak mudah. Ada delapan langkah pengambil keputusan (rational decision making proses):

1. Kenali Permasalahan
2. Artikan atau defenisikan Tujuan
3. Kelola dan pilih Data yang sesuai
4. Identifikasi alternative yang feasible
5. Pilih dan tentukan kriteria untuk pertimbangan teknik terbaik
6. Simulasi dan modelkan korelasi kriteria, data dan teknik
7. Ramalkan hasil dari semua teknik
8. 8. Pilih dan Eksekusit eknik yang realistis dan terbaik

Prinsip-prinsip pengambilan keputusan

1. Pakai standart ukuran yang umum (contoh: nilai waktu uang, nyatakan segala sesuatu dalam bentuk moneter ($ atau Rp)
2. Estimasi hanya perbedaannya
   a. Sederhanakan teknik yang dievaluasi dengan mengesampingkan biaya-biaya umum
   b. Biaya yang lampau (Sunk cost)boleh diabaikan
3. Evaluasi keputusan yang dapat dipisah secara terpisah contoh: keputusan finansial dan investasi)
4. Ambil sudut pandang teknik (teknik swasta atau teknik-teknik) Gunakan perencanaan ke depan yang umum (bandingkan teknik dengan bingkai waktu yang sama)

Contoh Kasus:

Sebuah mesin bubut dengan produk baut biaya Rp.40 untuk material dan Rp. 15 untuk tenaga kerja. Jumlah orderan barang sebanyak 6 juta buah baut. Setelah separo pesanan telah selesai dikerjakan, salesman mesin menawarkan penambahan suatu alat pada mesin bubut yang akan mengurangi biaya, sehingga biaya ke material menjadi Rp. 34 dan Rp.10 untuk tenaga kerja, tapi biaya penambahan alat tersebut Rp 100.000. dengan biaya lain sebesar 250%

dari biaya tenaga kerja. Mana yang akan dipilih, melanjutkan dengan mesin yang lama atau menambah alat pada mesin??

Solution:

Alternatif I: melanjutkan dengan tanpa penambahan alat:

Biaya material 3.000.000 x 0.40 = 1.200.000

Direct labor cost 3.000.000 x 0.15 = 450.000

Biaya lainya 2.50 x direct labor cost = 1.125.000

Cost for remaining 3.000.000 pieces = 2.775.000

Alternatif II: melanjutkan dengan penambahan alat:

Additional tooling cost = 100.000

Biaya material 3.000.000x 0.34 = 1.020.000

Direct labor cost 3.000.000x 0.10 = 300.000

Biaya lainnya 2.50 x direct labor cost = 750.000

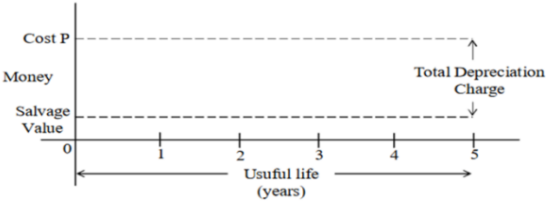
Cost for remaining 3.000.000 pieces = 2.070.000

Maka pilihan adalah akan tetap melanjutkan denganmenambah alat. Yaitu Alternatif II

Depresiasi

Depresiasi adalah penyusutan nilai secara fisik "decrease in value" barang seiring bertambahnya waktu dan penggunaan berdasarkan umur ekonomis actual asset hingga usia rencana tertentu (useful life) dengan mempunyai nilai buku (book value/salvage value). Penurunan atau penyusutan nilai harga pasar, penurunan nilai pakai/kemanfaatan, penurunan alokasi cost fungsi waktu, kemanfaatan dan usia.

Secara umum gambarannya:



Apakah semua barang dapat didepresiasi?? Tidak

Dapat didepresiasi jika memenuhi ketentuan antara lain:

1. Harus aplikasikan dalam bisnis atau untuk menambah penghasilan pendapatan
2. Umur harus ekn di prediksi hingga kapan efektif.
3. Sesuatu yang sedapat mungkin dipakai sampai aus, rusak, diperbaiki, menjadi tidak dipakai
4. Bukan merupakan barang inventori, stok dalam perdagangan atau barang investasi

Barang: berwujud (tangible) dan tak berwujud (intangible)

Barang berwujud:

1. Barang pribadi (personal property), seperti kenderaan, mesin, perabotan barang dan alat alat.
2. Barang riil (real property), seperti: bangunan, tanah. Note: tanah tidak terdepresiasi karenan umur efektifnya tidak ekn ditentukan.

Barang tak berwujud: seperti penghargaann dari HKI antara lain Paten sederhanan, Paten biasa, Hak Cipta.Note: kita tidak membahas depresiasi atas barang tak berwujud karena proyek-proyek teknik hampir tidak pernah melibatkan kelompok barang ini.

Metode Depresiasi:

1. Metode Garis Lurus (Straight Line Method)
2. Metode Keseimbangan Menurun (Declining Balance Method/Double Declining Balance)
3. Metode Jumlah Angka Tahun (Sum of the Year Digits Method)
4. Metode Unit Produksi (Unit of Production Method)

Pemahaman terhadap beberapa defenisi:

1. Cost: biaya orisinal asset
2. Nilai Buku (Book Value-BV): suatu nilai barang yang sudah tidak terlalu bermanfaat dari segi pasarnya

3. Nilai Pasar (Market Value): Nilai barang yang menjadi kesepakatan penjual dan pembeli
4. Umur Efektif (Useful Life): harapan (estimasi) jangka waktu penggunaan barang
5. Nilai Sisa (Salvage Value/Residual Value): estimasi nilai barang pada akhir umur efektifnya

Metode Garis Lurus (Straight Line Method)

Metode Garis Lurus mengasumsikan jumlah yang tetap depresiasi tiap tahunnya.

$$Depreasi\ per\ Tahun = \frac{Cost - Residual\ Value}{Useful\ Life, th}$$

Contoh kasus:

Sebuah mesin las otomatic beli dengan harga: Rp.41 jt. Estimasi umur max 5 th, dan setelah 5 th barang dapat dijual lagi dengan harga Rp. 1 jt. Tabelkan depresisi tahunannya:

Penyelesaian:

$$Depresiasi\ Tahunan \quad \frac{81.000.000 - 1.000.000}{5} = 16.000.000$$

Tahun	Depresiasi	BV (jt)
0		81.000.000
1	16.000.000	65.000.000
2	16.000.000	49.000.000
3	16.000.000	33.000.000
4	16.000.000	17.000.000
5	16.000.000	1.000.000

Metode Keseimbangan Menurun (Declining Balance Method/Double Declining Balance Method).Metode ini mengasumsikan depresiasi biaya tahunan adalah merupakan persentase tetap dari BV

DDB Depresiasi = Aset BV x prosentase penurunan

Contoh kasus:

Sebuah mesin CNC Mini dibeli dengan harga Rp. 41 juta. Diperkirakan efektif beroperasi selama 5 th. Depresiasi DDB dengan Rate 40%, tabelkan depresiasi tahunannya.

Penyelesaian:

Tahun	**Cost**	**Depresiasi Tahunan**			**Akumulasi**	
		DDB rate	**BV**	**Depresiation Expense**	**Depresiasi**	**BV**
0	91.000.000					91.000.000
1		0.40x	91.000.000	36400000	36400000	54.600.000
2		0.40x	54.600.000	21840000	36.400.000	32.760.000
3		0.40x	32.760.000	13104000	58.240.000	19.656.000
4		0.40x	19.656.000	7862400	71.344.000	11.793.600
5		0.40x	11.793.600	4717440	79.206.400	7.076.160
					91.000.000	

Bab 2

Nilai Sekarang (Present Worth)

2.1 Pengertian Nilai Sekarang (Present Worth)

Pada pelaksanaannya, seluruh investasi akan memerlukan Analisa mengenai seluruh fakta-fakta yang akan terjadi dan memengaruhi nilai investasi dengan mengubahnya menjadi nilai angka yang kemudian digabungkan dengan nilai investasi, sehingga dapat dicari nilai ekivalensi dari seluruh cashflow yang ada. Metode ini disebut dengan Present *Worth Analysis* atau Analisis Nilai Sekarang.

Asumsi *Present* yaitu menjelaskan waktu awal perhitungan bertepatan dengan saat evaluasi dilakukan atau pada periode tahun ke-nol (0) dalam perhitungan cash flow investasi. Untuk memperoleh *Presnt Worth* (PW) sebagai fungsi dari i% dari serangkaian aliran kas masuk (in cashflow) dan aliran kas keluar (out cashflow), yang berada pada periode di depan titik sekarang perlu didiskon (dikalikan faktor bunga) ke masa sekarang dengan menggunakan suatu tingkat bunga selama periode penelaahan.

Metode ini banyak digunakan oleh para pelaku usaha untuk menjamin keputusan mereka dalam berinvestasi selalu memberikan hasil yang positif,

walaupun dalam pelaksanaannya banyak sekali fakta-fakta mengenai nilai investasi yang perlu dicari pembuktiannya.

2.2 Rumusan umum Nilai Sekarang (Present Worth)

Secara umum, Analisa Nilai Sekarang (Present Worth Analysis) mempunyai rumus yang dapat digunakan pada berbagai persoalan. Akan tetapi memerlukan penyesuaian dengan fakta-fakta yang berlaku pada masing-masing soal.

Berikut adalah rumus umumnya :

$$PW(i\%) = F_0(1+i)^0 + F_1(1+i)^{-1} + F_2(1+i)^{-2} + \ldots + F_k(1+i)^{-k} + \ldots + F_n 1+i)^{-n}$$

$$= \sum_{k=1}^{n} F_k (1+i)^{-k}$$

di mana :

i = tingkat bunga efektif per tahun (per periode pemajemukan)

k = indeks periode pemajemukan ($0 \leq k \leq n$)

Fk = arus kas pada periode di depan

n = periode penelahaan

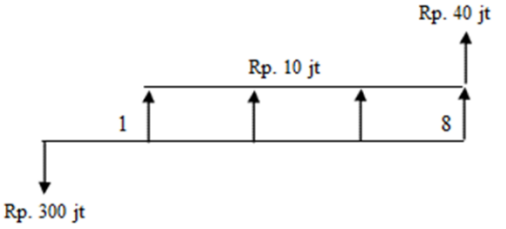
Kriteria pengambilan keputusan (decision making criterion) yang digunakan pada analisis Present Worth adalah sebagai berikut :

No	Kondisi	Kriteria
1	Seluruh alternatif memiliki biaya yang sama	*Maximixe* PW
2	Seluruh alternatif memiliki benefit yang sama	*Minimize* PW
3	Tidak satupun alternatif memiliki biaya maupun manfaat yang sama	*Maximize* PW *Benefit*-PW *Cost (Net Present Worth)*

Contoh soal 1 :

Sebuah perusahaan mempertimbangkan mesin baru seharga Rp. 300jt dengan penghematan yang akan didapat sebesar Rp. 10jt selama 8 tahun. Pada akhir masa pakai menghasilkan nilai jual sebesar Rp. 40jt. Apakah pembelian mesin tersebut menguntungkan, jika tingkat suku bunga 12% ?

Penyelesaian :



PW = Rp. 40jt (P/F,12%,8) + Rp. 10jt (P/A,12%,8) – Rp. 300jt

PW = Rp. 40jt (0,40388) + Rp. 10jt (4,96764) – Rp. 300jt

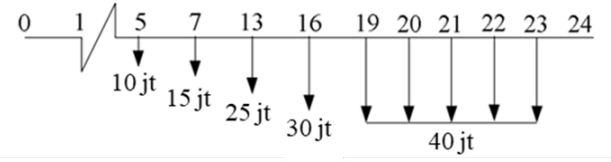
PW = Rp.-227.990.443

Dari hasil perhitungan tersebut diatas, maka investasi tersebut tidak layak dilakukan.

Contoh soal 2 :

Sebuah keluarga muda baru memperoleh kebahagiaan dengan lahirnya anak pertama mereka. Mereka sedang merencanakan berapa banyak biaya pendidikan yang harus disediakan untuk anak pertamanya tersebut, di mana mereka mengharapkan dapat menyekolahkannya sampai dengan perguruan tinggi. Mereka mengestimasi biaya yang dibutuhkan anaknya masuk ke setiap jenjang pendidikan. Pada usia 5 tahun akan masuk pendidikan di TK dengan biaya Rp.10 Juta, usia 7 tahun masuk SD dengan biaya Rp.15 Juta, usia 13 Tahun masuk SLTP dengan biaya Rp.25 juta, usia 16 tahun masuk SMU dengan biaya Rp.30 juta, dan pada usia 19 tahun masuk Perguruan Tinggi dengan biaya 40 Juta per tahun selama 5 tahun. Hitung jumlah biaya pendidikan yang didepositokan sekarang sehingga rencana pendidikan anak tersebut berjalan ? (Suku Bunga Deposito 10%/tahun)

Penyelesaian :



PW Total = PWTK + PWSD + PWSLTP + PWSMU + PWPT

= Rp. 10jt (P/F,10%,5) + Rp. 15jt (P/F,10%,7) + Rp. 25jt (P/F,10%,13) + Rp. 30jt (P/F,10%,16) + Rp. 40jt (P/A,10%,5) (P/F,10%,18)

= Rp. 54.949.321,41

Dari hasil perhitungan tersebut diatas, maka investasi awal pada tahun sekarang harus mempunyai dana sebesar Rp. 54.949.321,41

2.3 Jenis-jenis Analisa Alternatif pada Analisa Nilai Sekarang (Present Worth Analysis)

Dalam beberapa kasus, juga sering dijumpai hal hal berbeda dengan kondisi diatas dalam pengambilan keputusan terhadap beberapa alternatif :

1. Penentuan alternatif yang memiliki masa fungsi/masa pelayanan yang sama dengan periode analisis.
   Contoh soal :
   Sebuah perusahaan yang sedang membangun gedung baru sebagai pusat kegiatan operasionalnya, sedang mempertimbangkan usulan dalam penggunaan elevator dengan merk “ABC” dan “XYZ” Kedua jenis elevator memiliki masa pelayanan (service life) 25 tahun, tanpa nilai sisa pada akhir masa pelayanannya. Biaya Investasi elevator ABC $ 150.000 dengan biaya operational dan maintenance (Annual O & M Cost) $ 25.000 per tahun. Sedangkan elevator XYZ

membutuhkan investasi $ 200.000 dengan biaya operasional dan maintenance $15.000 per tahun. Elevator jenis manakah yang harus dipilih jika diketahui Div. Properti 4% per tahun.

Penyelesaian :



PW(4%) Elevator ABC = $ 150.000 + $ 25.000 (P/A,4%,25)
= $ 150.000 + $ 25.000 (15,6221)
= $ 540.551,99



PW(4%) Elevator XYZ = $ 200.000 + 15.000 (P/A,4%,25)
= $ 200.000 + 15.000 (15,6221)
= $ 434.331,19

Karena kasus di atas termasuk kondisi perbandingan biaya, maka kriterianya adalah minimasi biaya. Oleh karena itu, Elevator XYZ adalah yang terpilih sebagai investasi terbaik.

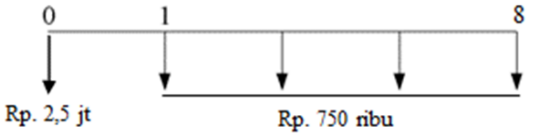
2. Penentuan alternatif yang memiliki masa fungsi/masa pelayanan yang berbeda dengan periode analisis

Contoh soal :

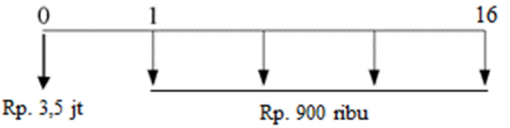
Sebuah perusahaan sedang mempertimbangkan untuk pembelian mesin baru dalam rangka peningkatan kapasitas produksi. Terdapat 2 alternatif mesin yang akan di beli dengan merk A dan B. Mesin dengan merk A mempunyai usia pakai 8 tahun dengan harga beli Rp. 2,5 juta dan biaya perawatan per tahun mencapai Rp. 750 ribu, sedangkan mesin Merk B mempunyai usia pakai 16 tahun dengan harga beli Rp. 3,5 juta dan biaya perawatan per tahun mencapai Rp.

900 ribu. Mesin manakah yang harus dipilih, jika tingkat suku bunga 15%/tahun ?

Penyelesaian :



PW(15%) Mesin A = Rp. 2,5jt + Rp. 750 ribu (P/A,15%,8)
= Rp. 2,5jt + Rp. 750 ribu (4,7716)
= Rp. 5.865.491,13



PW(15%) Mesin B = Rp. 3,5jt + Rp. 900 ribu (P/A,15%,16)
= Rp. 3,5jt + Rp. 900 ribu (4,7716)
= Rp. 8.858.811,38

Berdasarkan hasil perhitungan diatas, maka mesin A. Karena memiliki nilai investasi lebih kecil.

3. Penentuan alternatif yang memiliki masa fungsi/masa pelayanan yang permanent/abadi (>50 tahun), misalnya proyek-proyek pemerintah (public utility-infrastructure/gov. projects)

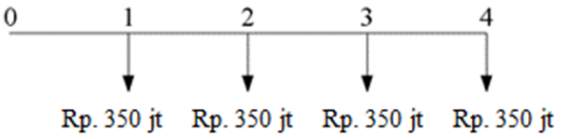
   Contoh soal 1 :

   Sebuah instansi Lembaga pemerintahan sedang berencana untuk menerapkan sebuah Sistem Pelayanan Pelanggan (Customer Service System). 2 alternatif sistem yang menjadi ususlan adalah Sistem Pelayanan Semi Terintegrasi (Semi Intergrated-Customer Service System) dan Sistem Pelayanan Terintegrasi Penuh (Fully Integrated-Customer Service System) untuk mengganti sistem lama yang masih manual. Sistem Manual menghabiskan biaya *Overall Annual Maintenance* (OAM) Rp. 350 Juta per tahun, *Semi Integrated* CSS membutuhkan biaya awal Rp. 400 Juta dan mampu menghemat biaya OAM Rp. 100 juta per tahun, sedangkan *Fully Integrated* CSS

membutuhkan *initial costs* Rp. 500 Juta dengan penghematan biaya OAM Rp. 150 juta pada tahun pertama, Rp.175 juta pada tahun kedua, Rp. 200 juta pada tahun ketiga, dan Rp.225 juta pada tahun keempat. Jika tingkat suku bunga 10%/tahun dan periode analisis 4 tahun sistem manakah yang sebaiknya dipilih. Penyelesaian :

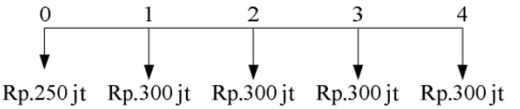
Penyelesaian :

a. Manual CSS



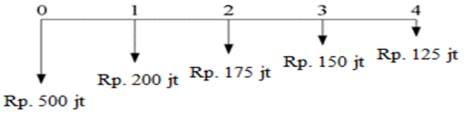
PW(10%) = 350 juta (P/A,10%,4)
= 350 juta (3,1699)
= Rp. 1.109.452.906,22

b. Semi Integrated CSS



PW (10%) = 400 juta + 250 (P/A,10%,4)
= 400 juta + 250 (3,1699)
= Rp. 1.192.466.361,58

c. Fully Integrated CSS



PW (10%) = 500 juta + {200jt (P/A,10%,4) – 25jt (P/G/10%,4)}
= 500 juta + {200jt (3,1699) – 25jt (4,3781)}
= Rp. 1.024.520.183,04

Kriteria : Minimize Cost ☐ Pilih alternatif Semi Integrated CSS

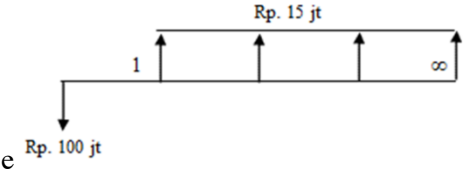
Contoh soal 2 :

Sebuah perusahaan jasa konsultasi investasi menawarkan 3 pilihan investasi, yaitu pilihan 1 mempunyai nilai investasi sebanyak Rp. 100jt dan waktu investasi tak terhingga, dengan keuntungan pertahun Rp. 15jt. Kemudian pilihan 2 mempunyai nilai investasi sebanyak Rp. 150jt dan waktu investasi 14 tahun dengan keuntungan pertahun Rp. 25jt. Sedangkan pilihan 3 mempunyai nilai investasi sebanyak Rp. 200jt dan waktu investasi 9 tahun dengan keuntungan pertahun Rp. 50jt. Pilihan manakah yang harus dipilih, jika suku bunga per tahun adalah 10% ?

Penyelesaian :

Untuk persoalan diatas perlu diselesaikan dengan Analisa Nilai Tahunan (Annual Worth Analysis) seperti berikut ini

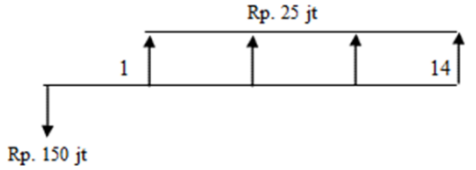
Pilihan 1



e

AW 1 = Rp. 15jt – Rp. 100jt (A/P, 10%, ∞)
= Rp. 15jt – Rp. 100jt (0,10)
= Rp. 5jt

Pilihan 2



AW 1 = Rp. 25jt – Rp. 150jt (A/P, 10%, 14)
= Rp. 25jt – Rp. 150jt (0,10)
= Rp. 4.638.066,51

Pilihan 3



AW 1 = Rp. 50jt – Rp. 200jt (A/P, 10%, 9)
= Rp. 50jt – Rp. 200jt (0,10)
= Rp. 15.271.892,19

Bab 3

Infinite Analysis Period-Capitalized Cost

3.1 Kriteria Ekonomi

Penentuan kriteria ekonomi mengandung ketentuan bahwa dalam membandingkan arus kas, pertama-tama kita harus menggunakan acuan waktu yang sama. Kita dapat memilih untuk memindahkan semuanya ke masa sekarang, yang menghasilkan analisis nilai sekarang (present worth analysis); memindahkannya ke masa depan kemudian memberi kita analisis nilai masa depan (future worth analysis); atau ke rangkaian setara arus kas yang sama secara berkala, memberi kita analisis arus kas tahunan (annual cash flow analysis).

Masing-masing metode ini, dengan analisis tingkat pengembaliannya, akan selalu menghasilkan rekomendasi yang sama untuk memilih alternatif terbaik di antara sekumpulan alternatif. Namun, beberapa masalah dapat diselesaikan secara lebih alami dengan satu metode dibandingkan dengan metode yang lain. Salah satu metode yang lazim dipakai adalah dengan analisis nilai sekarang (present worth analysis). Dalam beberapa literatur, istilah tersebut sering dipakai bersama istilah lain yang sejenis, yakni *Present Worth* (PW), *Present Value* (PV), *Net Present Worth* (NPW), dan *Net Present Value* (NPV) sebagai

sinonim. Penggunaan istilah net dalam dua istilah di atas berfungsi untuk memberi penekanan bahwa biaya dan manfaat dipertimbangkan dalam pembahasan.

Terdapat setidaknya tiga kasus periode-analisis (Newnan et al., 2018):

1. Umur rencana atau usia manfaat masing-masing alternatif sama dengan periode analisis (useful lives equal to the analysis period).
2. Umur rencana atau usia manfaat masing-masing alternatif berbeda dengan periode analisis (The alternatives have useful lives different from the analysis period). Dalam analisis jenis ini, periode analisis harus disebutkan secara spesifik.
3. Keadaan di mana periode analisis dianggap tidak berhingga (There is an infinite analysis period) ($n=\infty$).

Bahasan dalam bab ini berfokus pada asumsi periode tak terbatas. Keadaan terakhir adalah keadaan yang membutuhkan analisis dengan periode tak terbatas. Dalam keadaan tersebut, analisis nilai sekarang atas biaya akan memiliki periode tak terbatas sehingga kita harus menganggap biaya sebagai modal atau *capitalized cost* yakni jumlah uang di masa sekarang (the present sum of money) sehingga bisa dipakai dengan jangka waktu tak berhingga atau dianggap bernilai abadi (perpetual).

Dalam berbagai kegiatan pembangunan atau proyek, kerangka waktu menjadi suatu ukuran utama dalam analisis. Waktu atau umur proyek dapat diasumsikan tak berhingga ketika kita membayangkan bahwa proyek diharapkan akan berumur selamanya. Secara sederhana, kita tidak menginginkan proyek, pabrik, infrastruktur, atau fasilitas yang dibuat akan berakhir dalam beberapa tahun atau bahkan dalam puluhan tahun. Banyak perencana merencanakan karya mereka berusia awet atau bersifat perpetual, tak akan rusak atau hancur. Dalam proyek-proyek infrastruktur besar di mana penghancuran atau penggantian bangunan utama tidak diharapkan terjadi dalam waktu singkat, seperti pada bendungan besar, bandara, pelabuhan atau bahkan jalan maka analisis ekonominya dapat menggunakan periode analisis tak berhingga.

3.2 Jenis-jenis Biaya

Jenis-jenis biaya yang dipertimbangkan dalam analisis ekonomi teknik antara lain dapat dilihat berdasarkan waktu, tetap atau tidak tetapnya, dan kepada siapa biaya tersebut akan berpengaruh. Dalam literatur mengenai ekonomi sumber daya air, Kuiper mengelompokkan biaya menjadi dua kelompok, yaitu biaya modal (capital cost) dan biaya tahunan (annual cost) (Kuiper, 1971). Biaya modal adalah jumlah seluruh pengeluaran yang diperlukan sejak dicetuskannya sebuah proyek pada tahap pra-studi, studi kelayakan, desain, pengawasan dan konstruksi, hingga proyek selesai terbangun. Biaya ini meliputi biaya langsung (direct cost) termasuk biaya pembebasan lahan, biaya konstruksi yang semuanya ditanggung oleh pemilik pekerjaan (bowheer atau owner), dan biaya tak langsung (indirect cost) termasuk biaya desain rekayasa, biaya tak terduga (contigency cost), dan bunga (interest) dalam hal biaya konstruksi dianggap sebagai pinjaman, meski menggunakan dana sendiri dari pemilik pekerjaan. Biaya langsung ini termasuk devisa, pajak, upah, biaya-biaya untuk pinjaman luar negeri sekiranya proyek menggunakan dana pinjaman asing (Adler, 1980)

Biaya tahunan (annual cost) adalah biaya yang dikeluarkan setelah proyek selesai hingga umur rencana proyek berakhir. Umur rencana ditentukan pada saat desain dengan mempertimbangkan antara lain integritas bangunan proyek, acuan periode ulang yang akan dilayani oleh proyek, misalnya periode ulang banjir untuk infrastruktur drainase, periode ulang kegempaan. Biaya tahunan meliputi bunga (interest), depresiasi dan amortisasi, serta biaya operasi dan pemeliharaan. Depresiasi adalah besarnya penyusutan nilai suatu barang akibat pemakaian, kerusakan, atau keusangan barang yang dimaksud. Amortisasi adalah besarnya pengembalian atau pembayaran dalam periode tertentu (misalnya per tahun). Amortisasi berkaitan dengan pembayaran utang yang diambil untuk mendanai proyek atau penyediaan barang.

Penjelasan tentang jenis-jenis biaya (types of costs) dianggap penting sebelum membahas inti dari bab ini yakni infinite analysis period-capitalized cost. Penjelasan bab ini akan membahas biaya modal (capital cost) sebagai acuan. Analisis ini mengandaikan bahwa biaya-biaya yang dikeluarkan akan dikapitalkan atau dianggap sebagai modal.

Secara ringkas, capitalized cost adalah jumlah dalam acuan saat ini atas uang yang dikeluarkan di masa depan, dengan tingkat suku bunga tertentu, untuk

menghitung besarnya dana yang dibutuhkan untuk menyediakan barang atau jasa dalam periode yang tidak terbatas. Agar hal ini tercapai, jumlah uang atau pengeluaran yang dimaksud tidak boleh berkurang.

3.3. Infinite Analysis Period

Ada dua terminologi yang digabungkan dalam konteks ini, yaitu infinite analysis period dan capitalized cost. Keduanya digabungkan mengingat terdapat irisan pengertian dari kedua istilah tersebut. Pengertian infinite analysis period atau periode analisis tak hingga dapat dipahami dengan kerangka waktu. Periode atau jangka waktu menjadi cakupan analisis yang tidak dibatasi waktu.

Terdapat kesulitan dalam analisis dengan infinite analysis period. Salah satu kesulitan dalam memecahkan masalah adalah kebanyakan masalah cenderung sangat rumit sehingga beberapa asumsi penyederhanaan diperlukan untuk membuat masalah tersebut dapat dikelola. Triknya tentu saja adalah menyelesaikan masalah yang disederhanakan dan tetap puas bahwa solusinya dapat diterapkan pada masalah sebenarnya.

Dalam analisis proyek pemerintah, suatu jenis layanan atau prasarana harus dijaga agar berfungsi dalam jangka waktu yang tak terbatas. Kebutuhan akan prasarana seperti jalan, bendungan, jaringan pipa, dan sebagainya dianggap sebagai kebutuhan permanen. Dalam hal ini, analisis untuk nilai sekarang dari biaya-biaya harus menggunakan infinite analysis period yang kita sebut juga sebagai *capitalized costs*.

Untuk proyek swasta, asumsi usia tak terhingga jarang diambil. Namun, asumsi yang serupa sering diambil, misalnya pada sarana dengan peralatan motor listrik, sistem HVAC mekanis, dan peralatan berat, sepanjang peralatan tersebut tetap beroperasi, dan dengan asumsi bahwa usia sarananya lebih panjang dari usia peralatan sehinga peralatannya bisa dianalisa sebagai sesuatu yang memiliki usia tak terbatas.

Salah satu kesulitan dalam memecahkan masalah adalah kebanyakan masalah cenderung sangat rumit sehingga beberapa asumsi penyederhanaan diperlukan untuk membuat masalah tersebut dapat dikelola. Triknya tentu saja adalah menyelesaikan masalah yang disederhanakan dan tetap puas bahwa solusinya dapat diterapkan pada masalah sebenarnya.

3.4. Capitalized Cost

Sebagaimana telah disinggung sebelumnya, *capital cost* dapat berupa biaya yang murni biaya modal atau biaya yang dianggap sebagai modal yang di akhir umur rencana umumnya akan kembali sebagai keuntungan dalam bentuk nilai sisa (salvage value). Nilai sisa ini hanya ada dalam penyediaan barang yang berusia panjang, misalnya tanah. Mengingat tanah dianggap memiliki usia tak berhingga, sangat beralasan jika analisis ekonomi proyek yang menyediakan tanah sebagai modal awal dianalisis dengan periode analisis tak berhingga (Newnan et al., 2018).

Analisis ini seseungguhnya merupakan bagian dari teknik perhitungan nilai sekarang (present worth analysis) yang dibahas di bab sebelumnya. Teknik nilai sekarang (present worth techniques) memberi penyelesaian masalah biaya dan manfaat dari alternatif saat ini dari alternatif saat ini. Dengan demikian, kita harus mempertimbangkan periode waktu yang dicakup oleh analisis, atau disebut juga sebagai periode analisis (analysis period), horizon perencanaan (planning horizon) atau umur rencana proyek (project life).

Proyek publik, seperti jembatan, bendungan, jalan tol, jalan kereta api, pembangkit listrik tenaga air, dan sarana pembangkitan listrik lain, tergolong dalam sarana yang memiliki usia manfaat yang sangat panjang. Oleh karena itu, cakrawala perencanaannya dianggap tak terbatas atau perpetual.

Selain itu, hibah permanen atau dana abadi untuk organisasi amal dan perguruan tinggi juga dianggap memiliki usia manfaat yang tak terbatas. Dengan demikian, analisis ekonomi kelayakan kegiatan semacam ini dievaluasi dengan nilai sekarang untuk arus kasnya.

Arus kas untuk perhitungan tersebut dapat dikategorikan dalam dua jenis, yaitu berulang dan tidak berulang. Sebagai contoh pada proyek jembatan, arus kas bisa dibagi atas berulang (recurring) dan tidak berulang (non-recurring). Pengecatan kembali bisa diklasifikasikan sebagai recurring, sedang investasi awal untuk struktur utama, dapat dianggap sebagai non-recurring.

Periode analisis berbeda-beda pada masing-masing industri. Industri teknologi yang bersifat *volatile* memiliki periode analisis yang singkat relatif singkat, bahkan dengan kecepatan perkembangan bidang telekomunikasi dan komputasi, periode analisis 5 tahun mungkin terasa cukup lama. Industri dengan teknologi yang lebih stabil memiliki periode yang lebih lama (10-20

tahun). Periode analisis pemerintah bisa sampai 50 tahun. Dalam hal penyediaan infratsruktur publik, terutama dengan tingkat kesulitan penyediaan yang tinggi seperti pelabuhan samudera atau bendungan, umur rencana bisa mencapai 100 tahun. Pengadaan aset semacam tanah ataupun timbunan, termasuk reklamasi, dapat dianalisis sebagai *capitalized worth* dengan periode analisis tak berhingga.

Pada dasarnya, nilai sekarang yang setara dengan rangkaian arus kas yang panjangnya tak terhingga disebut nilai kapitalisasi (capitalized worth) karena dalam sebagian besar aplikasi, nilai yang dikapitalisasi dihitung untuk investasi yang memiliki hanya sedikit pengembalian positif, itu pun jika ada. Nilai yang dikapitalisasi lebih umum disebut sebagai biaya yang dikapitalisasi (capitalized costs) atas suatu usaha.

Metode nilai yang dikapitalisasi (capitalized costs) hanya dapat diterapkan jika kuat alasan untuk meyakini bahwa serangkaian arus kas akan menerus tanpa batas waktu hingga ke masa depan. Karena tidak menggunakan horizon perencanaan yang sama dengan PW, FW, dan AW, tidak ada alasan untuk berasumsi bahwa hasilnya akan sama dengan yang akan terjadi jika menggunakan horizon perencanaan terbatas. Namun, jika dihitung dalam batas hubungan matematis, asumsi penyamaan tersebut tidak boleh dibuat secara gegabah.

3.5 Prosedur Perhitungan Capitalized Cost

Prosedur untuk menentukan *capitalized cost* (CC) untuk arus kas yang tak terbatas adalah sebagai berikut (Badiru dan Omitaomu, 2007):

1. Gambarkan diagram arus kas yang menunjukkan semua arus kas tidak berulang (satu kali) dan setidaknya dua siklus dari semua arus kas berulang (periodik). Penggambaran diagram arus kas dalam hal ini dianggap lebih penting dalam perhitungan CC dibandingkan dalam perhitungan lain karena membantu memisahkan jumlah tidak berulang dan berulang. Pada langkah terakhir, nilai sekarang dari

semua arus kas komponen telah diperoleh; total biaya yang dikapitalisasi (CC) diapatkan hanya dengan menjumlahkannya.

2. Tentukan nilai sekarang dari jumlah semua arus kas tidak berulang (interval terbatas) menggunakan rumus ekonomi teknik reguler (P/F, P/A, P/G, dll). Hasil yang didapatkan adalah nilai CC-nya
3. Tentukan nilai A (Anuitas) melalui satu siklus dari jumlah semua cash flow berulang. (nilai yang sama terdapat di semua siklus hidup berikutnya) Tambahkan ini ke semua jumlah seragam lainnya (A) yang terjadi pada tahun pertama sampai tak terhingga. Hasilnya adalah total nilai seragam tahunan setara (Annual Worth/AW). Konversikan semua jumlah berulang (non-tahunan) menjadi nilai tahunan selama satu siklus hidup dan tambahkan semua nilai A bersama-sama
4. Bagilah AW yang diperoleh pada langkah 3 dengan suku bunga i untuk mendapatkan PW dari jumlah tahunan yang juga nilai CC.
5. Tambahkan nilai CC yang diperoleh pada langkah 2 dan 4. Tambahkan bersama semua PW untuk mendapatkan *capitalized cost*.

Rumus untuk menghitung CC diturunkan dari relasi PW P/A (P/A, i %, n), di mana n = ∞ periode waktu. Ambil persamaan untuk P menggunakan faktor P/A dan bagi pembilang dan penyebutnya dengan (1 + i)n untuk mendapatkan

$$P = A\left[\frac{1-\frac{1}{(1+i)^n}}{1}\right] \qquad (3.1)$$

Saat n mendekati ∞, suku yang di dalam kurung menjadi 1/i. Kemudian kita mengganti simbol P dan PW dengan CC sebagai pengingat bahwa ini adalah kesetaraan untuk biaya yang dikapitalisasi. Karena nilai A juga dapat disebut AW untuk nilai tahunan, rumus biaya yang dikapitalisasi disederhanakan menjadi

$$CC = \frac{A}{i} \text{ atau } CC = \frac{AW}{i}\text{i} \qquad (3.2)$$

Penyelesaian untuk A atau AW, jumlah uang baru yang dihasilkan setiap tahun dengan kapitalisasi sejumlah CC adalah

$$A = C \times i \qquad (3.3)$$

Dengan mempertimbangkan nilai sekarang,

$$P = A/i \qquad (3.4)$$

Ini sama dengan perhitungan A/P(i) untuk jumlah periode waktu yang tak terhingga. Persamaan (4.3) dapat dijelaskan dengan mempertimbangkan nilai waktu dari uang. Jika $20.000 diinvestasikan sekarang (yang merupakan kapitalisasi) pada 10% per tahun, jumlah maksimum uang yang dapat ditarik pada akhir setiap tahun untuk waktu *infinite* adalah $2000, yang merupakan akumulasi bunga setiap tahun. Yang disisakan $20.000 pokok untuk mendapatkan bunga sehingga $2.000 lainnya akan diakumulasikan pada tahun berikutnya. Arus kas (biaya, pendapatan, dan tabungan) dalam perhitungan biaya yang dikapitalisasi biasanya terdiri dari dua jenis: berulang, disebut juga periodik, dan tidak berulang. Biaya operasi tahunan sebesar $50.000 dan biaya pengerjaan ulang diperkirakan sebesar $40.000 setiap 12 tahun adalah contoh arus kas berulang. Contoh arus kas tidak berulang adalah jumlah investasi awal di tahun 0 dan perkiraan arus kas satu kali di masa depan, misalnya, $500.000 dalam biaya 2 tahun kemudian.

Contoh kasus 3.1

Tentukan biaya yang dikapitalisasi pada bunga 15% dari suatu struktur bangunan dengan biaya awal sebesar Rp. 200.000.000 dan biaya operasi dan pemeliharaan tahunan sebesar Rp. 40.000.000.

P = Rp. 200.000.000 + Rp. 40.000.000 (P/A,15%,n = ∞)

= Rp. 200.000.000+ Rp. 40.000.000 (1/0,15)

= Rp. 200.000.000+ Rp. 266.666.667

=Rp. 466.666.667

Contoh kasus 3.2

Kota A memiliki jaringan pipa yang perlu diperbaiki. Setelah diperbaiki, pipa membutuhkan perbaikan lagi setiap 50 tahun. Setiap kali perbaikan membutuhkan biaya Rp. 8 Milyar. Bunga adalah 7%.

Pertama kita harus memnetukan anuitas. Hal ini dapat dilakukan dengan menggunakan rumus dana pelunasan (sinking funds formula) (A/F, n, i):

A =8.000.000.000(A/P,50,0,07)

Sekarang kita dapat menemukan biaya yang dikapitalisasi:

P =598.400.000

Perhatikan bahwa kami juga memiliki perbaikan awal sebesar Rp. 8 M sehingga total biaya kapitalisasi sebenarnya adalah Rp. 8,598. M.

Contoh Kasus 3.3

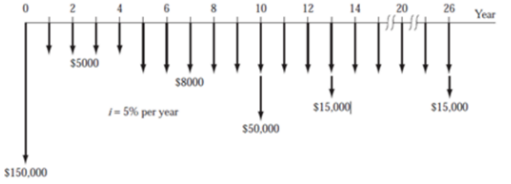
Otoritas Transportasi Kota A baru saja menerapkan sistem perangkat lunak baru untuk menagih dan melacak biaya tol. Pimpinan ingin mengetahui total biaya ekuivalen dari semua biaya masa depan yang dikeluarkan untuk membeli sistem perangkat lunak. Jika sistem baru akan digunakan untuk waktu yang tidak terbatas, tentukan ekuivalensi biaya untuk:

1. sekarang, nilai CC,
2. untuk setiap tahun selanjutnya, nilai AW.

Sistem ini memiliki biaya pemasangan sebesar $150.000 dan biaya tambahan sebesar $50.000 setelah 10 tahun. Biaya kontrak pemeliharaan perangkat lunak tahunan adalah $5000 untuk 4 tahun pertama dan $8000 setelahnya. Selain itu, diperkirakan akan ada biaya peningkatan besar berulang sebesar $15.000 setiap 13 tahun. Asumsikan bahwa i = 5% per tahun untuk dana daerah.

1. Prosedur lima langkah untuk menemukan CC dapatg diterapkan.
   a. Gambarkan diagram arus kas untuk dua siklus Gambar (3.1).
   b. Tentukan nilai sekarang dari biaya tidak berulang $150.000 sekarang dan $50.000 pada tahun ke-10 untuk i = 5%. Beri label CC1 untuk hal tersebut

$$CC_1 = -150{,}000 - 50{,}000(P/F\,, 5\%, 10) = \$ - 180{,}995$$



   c. Konversikan biaya berulang $15.000 menjadi nilai A selama siklus pertama 13 tahun, dan tentukan biaya kapitalisasi CC2 sebesar 5% per tahun menggunakan Persamaan (3-2).

$$A = -150{,}000(A/F\,, 5\%, 13) = \$ - 847$$

$$CC_2 = -780/0.05 = \$ - 16{,}940$$

d. Ada beberapa cara untuk mengonversi seri biaya pemeliharaan perangkat lunak tahunan menjadi nilai A dan CC. Metode langsungnya adalah, pertama, pertimbangkan $–5000 sebuah serangkaian nilai A dengan kapitalisasi biaya sebesar

$$CC_2 = -5000/0.05 = \$ - 100{,}000$$

Kedua, konversi rangkaian biaya pemeliharaan bertahap sebesar $–3000 menjadi biaya kapitalisasi CC4 pada tahun ke-4, dan tentukan nilai sekarang pada tahun ke-0.

$$CC_4 = (-3000/0.05)\,(P/F\,, 5\%, 4) = \$ - 49{,}362$$

e. Total biaya CCT yang dikapitalisasi untuk Otoritas Transportasi Kota A adalah jumlah dari empat nilai CC komponen.

$$CC_T = (-180{,}695 - 16{,}940\ - 100{,}000 - 49{,}362\ = \$ - 346{,}997$$

2. Persamaan (3-3) menentukan nilai AW selamanya.

$$AW = P \times i = CC_T\ \times i = \$ - 346{,}997(0.05) = 17.350$$

Dengan pengertian yang tepat, ini berarti pejabat Kota A telah berkomitmen setara dengan $17.350 selamanya untuk mengoperasikan dan memelihara perangkat lunak manajemen tol.

3.6 Investasi sebagai Capitalized Cost

Dalam literatur ekonomi, modal didefinisikan sebagai sumber daya manusia yang digunakan dalam produksi barang atau penyediaan jasa. Investasi adalah penciptaan modal. Investasi adalah aliran (yaitu, untuk periode waktu tertentu), sedangkan modal adalah persediaan (yaitu, pada suatu titik waktu). Investasi pelabuhan adalah penciptaan modal pelabuhan yang digunakan dalam penyediaan layanan pelabuhan. Investasi pelabuhan dapat berupa penambahan terminal pelabuhan serta akses jalan pelabuhan, misalnya saluran air dan jalan raya. Investasi dapat dilakukan pada modal tidak bergerak pelabuhan seperti dermaga, apron, dan gerbang interchange dan modal bergerak seperti derek. Investasi pelabuhan dapat mencakup investasi dalam (1) akses laut pelabuhan seperti pengerukan pelabuhannya dan penyediaan alat bantu navigasi; (2) akses jalan raya seperti trotoar dan lampu lalu lintas; dan (3) akses relnya seperti pembangunan rel kereta api (Talley, 2017).

Bab 4

Rate of Return Analysis

4.1 Pengertian Rate of Return (Laju Pengembalian)

Rate of Return atau disebut juga dengan Laju Pengembalian adalah tingkat bunga yang menjadikan selisih pengeluaran dan pemasukan menjadi nol. *Rate of Return* (RoR) ini pada studi-studi terhadap proposal proyek digunakan sebagai alat untuk menentukan alternatif-alternatif proyek. Dengan melihat angka RoR ini maka pihak pemodal dapat menyimpulkan apakah proyek tertentu memberi keuntungan atau tidak (Kodoatie, 2005).

Analisis terhadap Laju Pengembalian (Rate of Return) terkadang bukan hanya terkait dengan keuntungan yang akan diperoleh dari sebuah proyek, melainkan juga dapat digunakan untuk pengambilan keputusan terkait terbatasnya sumberdaya. Sumberdaya yang dimaksud meliputi manusia, material, uang, mesin dan kesempatan. Analisis RoR setidaknya bisa membantu untuk mendapatkan pilihan terbaik secara ekonomi, baik ketika membandingkan berbagai alternatif rancangan, membuat keputusan investasi modal, maupun mengevaluasi kesempatan finansial (Pattiapon, 2021)

4.2 Perhitungan Rate of Return (RoR)

Dalam analisis *Rate of Return* (RoR) dikenal istilah IRR atau *Internal Rate of Return*. IRR yang dimaksud adalah hasil perhitungan RoR yang tidak dipengaruhi oleh suku bunga komersil. (Kodoatie, 2005) menyatakan bahwa apabila hasil perhitungan *Rate of Return* lebih besar daripada suku bunga komersil maka proyek atau investasi tersebut menguntungkan, tetapi bila lebih kecil maka dianggap rugi.

Sebagaimana diketahui bahwa RoR merupakan tingkat bunga yang menyebabkan terjadinya keseimbangan antara semua pengeluaran dan semua pemasukan pada suatu periode tertentu, maka bisa dikatakan bahwa RoR merupakan tingkat penghasilan yang mengakibatkan nilai *Net Present Worth* (NPW) sebuah proyek sama dengan nol.

$$\mathbf{NPW} = \sum_{t=0}^{N} F_t\,(1+i)^{-t} = 0 \quad (4.1)$$

Di mana:

NPW = Net Present Worth

Ft = aliran kas pada periode t

N = umur proyek atau periode studi dari proyek tersebut

i* = nilai RoR dari proyek atau investasi tersebut

karena Ft pada persamaan (4.1) bisa bernilai positif maupun negatif maka persamaan RoR dapat juga dinyatakan:

$$\mathbf{NPW = PWR - PWE = 0} \quad (4.2)$$

Atau

$$\sum_{t=0}^{N} R_t\left(\frac{P}{F}, i\%, t\right) - \sum_{t=0}^{N} E_t\left(\frac{P}{F}, i\%, t\right) = 0 \quad (4.3)$$

Di mana:

PWR = nilai present worth dari semua pemasukan (aliran kas positif)

PWE = nilai present worth dari semua pegeluaran (aliran kas negatif)

Rt = penerimaan netto yang terjadi pada period ke-t

Et = pengeluaran netto yang terjadi pada period ke-t, termasuk investasi awal (P)

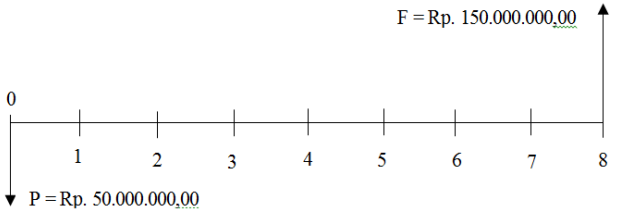
Di samping menggunakan nilai dari present worth, perhitungan RoR juga bisa dilaksanakan dengan deret seragam (annual worth) sehingga akan berlaku hubungan:

$$\textbf{EUAR-EUAC = 0} \qquad (4.4)$$

Di mana EUAR atau *Equivalent Uniform Annual Revenue* merupakan deret seragam yang menyatakan pendapatan (aliran kas masuk) per tahun dan EUAC atau *Equivalent Uniform Annual Cos*t adalah deret seragam yang menyatakan pengeluaran (aliran kas keluar) per tahun (Pujawan, 2019)

Contoh soal

Sebuah investasi bernilai Rp. 50.000.000,00 dengan perkiraan pendapatan pada tahun ke-8 sebesar Rp. 150.000.000,00. Tentukan besarnya *Rate of Return* (RoR) dari aliran kas tersebut.



Gambar 4.1: Diagram Aliran Kas untuk Contoh 4.1

Solusi

NPW $= \text{PWR} - \text{PWE} = 0$

$= \text{Rp. } 150.000.000{,}00\ (\text{P/F,i\%,8}) - \text{Rp. } 50.000.000 = 0$

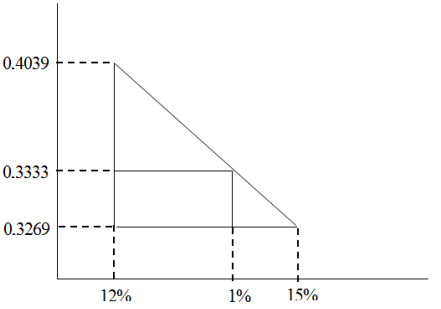
$$(\text{P/F, i\%, 8}) = \frac{50}{150} = 0{,}333$$

Persamaan di atas menunjukkan bahwa nilai i harus dicari hingga (P/F, i%, 8) = 0,333. Nilai i bisa diperoleh dengan melakukan pendekatan beberapa nilai i melalui tabel bunga.

Bila dimasukkan i = 12% maka diperoleh: (P/F, 12%, 8) = 0,4039

Bila dimasukkan i = 15% maka diperoleh: (P/F, 15%, 8) = 0,3269

Hasil di atas menunjukkan bahwa (P/F, i%, 8) = 0,333 akan dapat diperoleh pada nilai i adalah antara 12% dan 15%. Selanjutnya bisa dilakukan interpolasi, sebagaimana ilustrasi pada gambar 4.2 berikut:



Gambar 4.2: Ilustrasi perbandingan segitiga untuk interpolasi linier

Dalam bentuk persamaan diperoleh hasil:

$$\frac{15-i}{15-12} = \frac{0{,}3269-0{,}3333}{0{,}3269-0{,}4039}$$

$$\frac{15-i}{3} = \frac{-0{,}064}{-0{,}077}$$

$$15 - i = 0{,}2494$$

$$i = 15 - 0{,}2494$$

$$i = 14{,}751\%$$

Jadi Rate of Return (RoR) dari aliran kas adalah 14,751%

4.3 Analisis Internal Rate of Return (RoR)

Dalam melakukan evaluasi sebuah investasi, metode *Internal Rate of Return* (IRR) digunakan dengan cara mencari suku bunga di saat NPV (Net Present Value). Informasi yang dihasilkan oleh metode IRR ini berkaitan dengan kemampuan cash *flow* dalam pengembalian investasi yang dijelaskan dalam bentuk persentase per periode waktu. Termasuk menjelaskan seberapa kemampuan cash flow dalam mengembalikan modal dan seberapa besar kewajiban yang harus dipenuhi. Kemampuan pengembalian disebut dengan

Internal Rate of Return (IRR), sedangkan besarnya kewajiban disebut dengan *Minimum Activate Rate of Return* (MARR). Sebuah investasi dikatakan layak/menguntungkan secara ekonomi apabila IRR ≥ MARR (Giatman, 2011).

MARR umumnya ditentukan secara subjektif melalui suatu pertimbangan-pertimbangan tertentu dari investasi, yaitu:

1. Suku bunga investasi (i)
2. Biaya lain yang harus dikeluarkan untuk investasi (Cc)
3. Faktor risiko investasi (α)

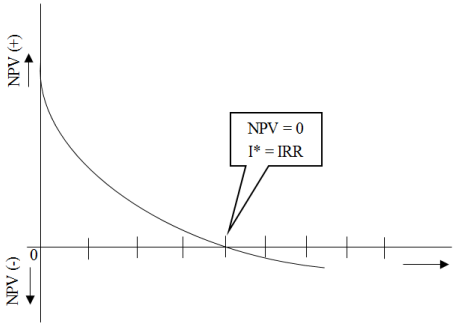
Jadi MARR = $i+Cc+\alpha$

Jika Cc dan α tidak ada atau nol, maka MRR = i, sehingga MARR ≥ i untuk dikatakan layak.

Faktor risiko dipengaruhi oleh sifat risiko dari usaha, tingkat persaingan usaha sejenis, dan gaya pimpinan. Dalam gaya manajemen dikenal 3 kategori utama tipe pimpinan, yaitu:

1. Optimistic
2. Most Likely
3. Pesimistic

Besarnya nilai MARR biasanya ditentukan secara subyektif dengan memperhatikan faktor-faktor tersebut, sedangkan IRR ditentukan berdasarkan estimasi *cash flow* investasi. Suatu *cash flow* investasi dihitung nilai NPV-nya pada tingkat suku bunga berubah/variabel, dan pada umumnya akan menghasilkan grafik NPV seperti pada gambar 4.3 berikut.



Gambar 4.3: Grafik NPV dengan nilai IRR tunggal

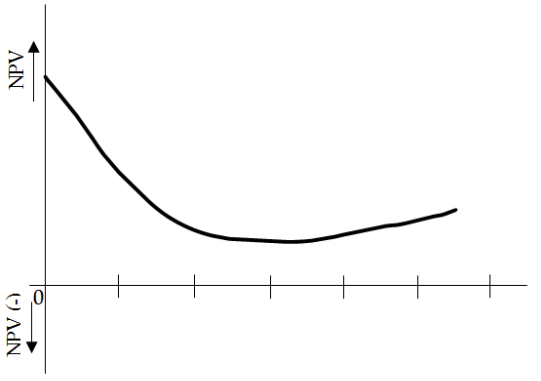
Gambar 4.3 di atas menunjukkan bahwa jika *cash flow* suatu investasi dicari nilai NPV-nya pada suku bunga (i) = 0%, pada umumnya akan menghasilkan nilai NPV maksimum. Jika suku bunga diperbesar, nilai NPV akan cenderung menurun sampai pada i tertentu, NPV akan mencapai nilai negatif. Saat NPV sama dengan nol (NPV = 0), nilai i = i* atau i = IRR.

Hal lain yang perlu diketahui:

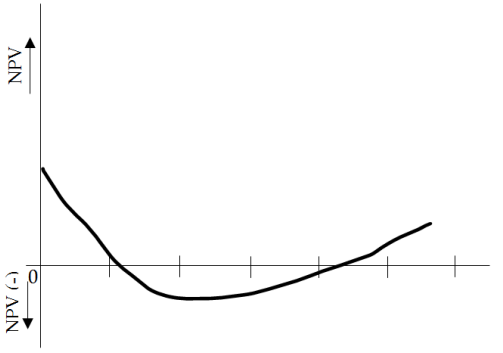
1. Tidak semua *cash flow* akan menghasilkan IRR
2. Jika menghasilkan IRR ada kalanya dapat ditemukan lebih dari satu.

Cash flow tanpa *Internal Rate of Return* (IRR) biasanya dicirikan dengan terlalu besarnya rasio antara aspek benefit dengan aspek *cost* seperti pada gambar 4.4. Sedangkan *cash flow* dengan banyak IRR dicirikan oleh net cash flow yang bergantian antara positif dan negatif, seperti ditunjukkan pada gambar 4.5.

Meski ada beberapa kemungkinan terkait nilai IRR, namun tulisan ini hanya dibatasi pada persoalan *cash flow* yang menghasilkan satu IRR. Untuk memperoleh nilai IRR dilakukan dengan mencari besarnya NPV dengan memberikan nilai i variabel, berubah-ubah, sedemikian rupa, sehingga diperoleh suatu nilai i saat NPV mendekati nol, yaitu NPV (+) dan NPV (-).



Gambar 4.4: Grafik NPV tanpa IRR

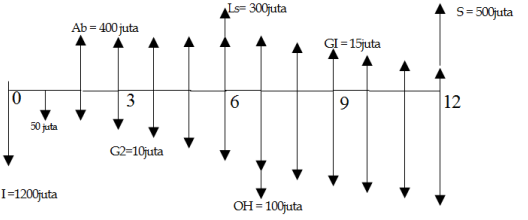


Gambar 4.5: Grafik NPV dengan IRR lebih dari satu

Contoh soal

Sebuah perusahaan akan mengembangkan usahanya dengan merencanakan investasi baru dengan nilai 1200 juta rupiah. Perkiraan pendapatan mulai tahun ke-2 sampai tahun ke-7 sebesar 400 juta. Setelah itu menurun sebesar 15 juta rupiah/tahun. Biaya operasional dikeluarkan mulai tahun ke-1 sebesar 50 juta rupiah dan selanjutnya naik gradient 10 juta rupiah. Usia investasi diprediksi dengan nilai sisa 500 juta rupiah. Ada pendapatan lumpsum pada tahun ke-6 sebesar 300 juta rupiah dan biaya *over houl* pada tahun ke-7 sebesar 100 juta rupiah.

Pertanyaan: Evaluasilah rencana tersebut dengan metode IRR, jika MARR = 15%/tahun



Solusi

IRR akan diperoleh saat NPV = 0, sehingga perlu dicari NPV dengan i yang berbeda untuk mendapatkan NPV mendekati nol.

NPV $= \sum_{i=0}^{n} CF_t(FBP)$

Di mana CF = Cash Flow investasi

FPB = Faktor bunga present

i* = i yang akan dicari

NPV =-I + Ab(P/A,i*,11)(P/F,i*,1) - G1(P/G,i*,6)(P/F,i*,6) + LS(P/F,i*,6) + S(P/F,i*,n) - AC(P/A,i*,n) - G2(P/G,i*,n) - OH(P/F,i*,7)

NPV = -1200 + 400(P/A,i*,11)(P/F,i*,1) - 15(P/G,i*,6)(P/F,i*,6) + 300(P/F,i*,6) + 500(P/F,i*,12) - 50(P/A,i*,12) - 10(P/G,i*,12) - 100(P/F,i*,7)

Jika i = 15%

NPV = -1200 + 400(P/A,i*,11)(P/F,i*,1) - 15(P/G,i*,6)(P/F,i*,6) + 300(P/F,i*,6) + 500(P/f,i*,12) - 50(P/A,i*,12) - 10(P/G,i*,12) - 100(P/F,i*,7)

= -1200 + 400(P/A,15,11)(P/F,15,1) - 15(P/G,15,6)(P/F,15,6) + 300(P/F,15,6) + 500(P/F,15,12) - 50(P/A,15,12) - 10(P/G,15,12) - 100(P/F,15,7)

= -1200 + 400(5.234)(0.8696) - 15(7.937)(0.4323) + 300(0.4323) + 500(0.1869) - 50(5.421) - 10(21.185) - 100(0.3759)

= + 271,744 juta

Jika i = 18%

NPV = -1200 + 400(P/A,i*,11)(P/F,i*,1) – 15(P/G,i*,6)(P/F,i*,6) + 300(P/F,i*,6) + 500(P/f,i*,12) – 50(P/A,i*,12) – 10(P/G,i*,12)-100(P/F,i*,7)

= -1200+400(P/A,18,11)(P/F,18,1) – 15(P/G,18,6)(P/F,18,6) + 300(P/F,18,6) + 500(P/F,18,12) – 50(P/A,18,12) – 10(P/G,18,12) - 100(P/F,18,7)

= -1200 + 400(4.656)(0.8475) – 15(7.083)(0.3704) + 300(0.3704) + 500(0.1372) – 50(4.793) – 10(17.481) – 100(0.3139)

= 72,90 juta

Jika i = 20%

NPV = -1200 + 400(P/A,i*,11)(P/F,i*,1) – 15(P/G,i*,6)(P/F,i*,6) + 300(P/F,i*,6) + 500(P/f,i*,12) – 50(P/A,i*,12) – 10(P/G,i*,12) - 100(P/F,i*,7)

= -1200 + 400(P/A,20,11)(P/F,20,1) – 15(P/G,20,6)(P/F,20,6) + 300(P/F,20,6) + 500(P/F,20,12) – 50(P/A,20,12) – 10(P/G,20,12)-100(P/F,20,7)

= -1200 + 400(4.327)(0.8333) – 15(6.581)(0.3349) + 300(0.3349) + 500(0.1125) – 50(4.439) – 10(15.467) – 100(0.2791)

= - 38,744 juta

Nilai NPV = 0 berada antara i = 18% dengan i = 20%, selanjutnya dengan metode interpolasi akan diperoleh IRR, yaitu:

IRR = $iNPV_{-}+\frac{NPV_{+}}{|NPV_{+}+NPV_{-}|}(iNPV_{-}+iNPV_{+})$

IRR = $18\%+\frac{72{,}90}{72{,}90+38744}(20\%-18\%)$

IRR = 19,306 %

Karena IRR = 19,306% > MARR = 15%, maka rencana investasi tersebut direkomendasikan layak secara ekonomis untuk dilaksanakan.

Bab 5

Sensitivity Analysis

5.1 Pendahuluan

Sensivity Analysis adalah ilmu yang memepelajari tentang bagaimana ketidakpastian dalam model atau system matematika dapat di bagi ke berbagai sumber ketidakpastian dalam inputnya. Atau bisa juga disebut penelitian tentang kemungkinan perubahan dan kesalahan potensial dan pengaruh terhadap kesimpulan yang di tarik dari model *sensitivy analysis*, *sensitivy analysis* bisa dilakukan dengan mudah karena mudah di mengerti. Ini mungkin teknik yang paling berguna dan paling banyak digunakan untuk peneliti yang ingin mendukung pengambilan keputusan.

Kegiatan investasi membutuhkan pemahaman yang mendalam terkait dengan kelayakan suatu rencana bidang usaha dapat dilaksanakan sesuai dengan beberapa aspek yang memengaruhi keberlangsungan kegiatan bidang usaha tersebut, di antaranya yaitu aspek operasional dan keuntungan. Agar seorang investor dapat memperkirakan apakah keberlangsungan dari suatu usaha dapat bertahan jika terjadi perubahan dari beberapa aspek tersebut, maka perlu dilakukan suatu analisis yang dapat mengetahui sejauh mana kemungkinan suatu usaha dapat bertahan jika terjadi perubahan dan seberapa besar perubahan yang dapat terjadi masih memungkinkan suatu usaha dapat bertahan, oleh sebab itu maka perlu dilakukan suatu *Sensitivity Analysis*. Sesuai dengan kondisi teraktual saat ini, banyak bidang usaha yang mengalami

kebangkrutan selama masa Pandemi Covid-19 ini, maka sebagai seorang pelaku bisnis baik investor ataupun pemilik suatu usaha/manajer, perlu melakukan suatu kajian analisis terhadap usaha, seperti keakuratan data, discount rate yang digunakan, agar dapat mengambil keputusan lebih awal terhadap perubahan aspek bisnis yang akan memperkecil kerugian atau bahkan dapat mengalihkan jenis usaha yang akan menyelamatkan nilai investasi.

5.2 Sensitivity Analysis

Analisa kelayakan suatu proyek sangat penting sebelum suatu proyek dilaksakan, ada beberapa metode yang digunakan untuk menganalisa suatu proyek, dalam hal ini akan dijelaskan analisa kelayakan suatu proyek dengan metode sensitivity analysis Yang dimaksud dengan Sensitivity Analysis atau analisa sensitivitas adalah suatu analisa yang tujuanya melihat apa yang akan terjadi terhadap hasil analisa proyek jika ada suatu kesalahan atau perubahan dalam dasar-dasar perhitungan benefit maupun *cost*.

Dengan demikian tujuan utama daripada *Sensitivity analysis*:

1. Untuk memperbaiki cara pelaksanaan proyek yang sedang dilaksanakan.
2. Untuk memperbaiki design daripada proyek, sehingga dapat meningkatkan Net Present Value.
3. Untuk mengurangi risiko kerugihan dengan menunjukkan beberapa tindakan pencegahan yang harus diambil.

Dalam *sensitivity analysis* setiap kemungkinan itu harus dicoba, yang berarti bahwa tiap kali harus diadakan analisa kembali. Ini perlu sekali, karena analisa proyek didasarkan pada proyeksi yang mengandung banyak ketidak pastian tentang apa yang akan terjadi di waktu yang akan datang.

Ada 3 hal yang perlu diperhatikan, antara lain:

1. Terdapatnya cost overrun, misalnya kenaikan dalam biaya konstruksi,
2. perubahan dalam perbandingan harga terhadap tingkat harga umum, misalnya penurunan harga hasil produksi,
3. Mundurnya waktu/jadwal implementasi.

Untuk mengoptimalkan kegunaan *sensitivity analysis*, perlu dilakukan secara sistematis. Mengoptimalkan kinerja dapat mengikuti Langkah-langkah sebagai berikut:

1. Identifikasi variabel sensitive yang memengaruhi keputusan proyek.
2. Perhitungan efek dari perubahan.
3. Pertimbangan variabel dalam kombinasi yang bisa diubah secara simultan.

5.2.1 Net Present Value (NPV)

Net Present Value (NPV) adalah nilai saat ini yang diperoleh dari manfaat operasi pada suatu proyek, merupakan selisih antara *Present Value* dari pada benefit dan *prensent value* daripada biaya (Kadariah, dkk. 1978), yang dirumuskan sebagai:

$$\sum_{i=1}^{n} \frac{B_t - C_t}{(1+i)^1}$$

Di mana:

Bt = Benefit kotor pada suatu proyek pada tahun ke t

Ct = Biaya kotor pada suatu proyek pada tahun ke t

N = umur ekonomis proyek

i = social opportunity Cost of Capital/Social Discount Rate (tingkat bunga)

atau bisa juga dirumuskan:

$NPV = PV_{benefit} - PV_{Cost}$,

Keterangan:

$PV_{benefit}$ = Peresent Value dari benefit, yakni nilai sekarang dari keuntungan operasi suatu proyek pada beberapa tahun yang akan datang.

PV_{Cost} = Peresent Value dari Cost, yakni nilai sekarang dari biaya operasi suatu proyek pada beberapa tahun yang akan datang.

Indikator keberhasilan suatu proyek berdasarkan nilai NPV (Net Present Value) adalah (Kadariah, dkk. 1978):

NPV > 0, bisa disimpulkan 90 %-100 % proyek berhasil/layak.

NPV = 0, berarti proyek tersebut mengembalikan persis sebesar cost yang dikeluarkan.

NPV < 0, proyek supaya ditolak, artinya ada penggunaan lain atau alternatif lain yang lebih menguntungkan/layak.

5.2.2 Internal Rate of Return (IRR)

IRR (Internal Rate of Return) adalah nilai *discount rate* i yang membuat NPV pada suatu proyek sama dengan nol (Kadariah, dkk. 1978) yaitu:.

$$\sum_{i=1}^{n} \frac{B_t - C_t}{(1 + \text{IRR})^1} = 0$$

Atau $PV_{benefit} = PV_{Cost}$

Di mana:

Bt = Benefit kotor pada suatu proyek pada tahun ke t

Ct = Biaya kotor pada suatu proyek pada tahun ke t

N = umur ekonomis proyek

i = social opportunity Cost of Capital/SocialDiscount Rate (tingkat bunga)

IRR dapat juga diartikan sebagai tingkat keuntungan dari investasi bersih dalam suatu proyek, Indikator keberhasilan suatu proyek berdasarkan nilai IRR (Kadariah, dkk. 1978) adalah:

IRR > i, bisa disimpulkan proyek berhasil/layak.

IRR = i, berarti proyek tersebut mengembalikan persis sebesar cost yang dikeluarkan.

IRR < i, proyek tersebut tidak layak.

5.2.3 Benefit Cost Ratio (B/C)

Benefit *Cost Ratio* (B/C) adalah perbandingan nilai semua manfaat terhadap nilai semua biaya (Ferianto Raharjo. 2007), dengan rumus sebagai berikut:

$$\text{B/C} = \frac{\text{PV benefit}}{\text{PV Cost}}$$

Indikator keberhasilan suatu proyek berdasarkan nilai IRR adalah (Kada riah, dkk.,1978):

B/C > 1, bisa disimpulkan proyek berhasil/layak.

B/C = 0, berarti proyek tersebut mengembalikan persis sebesar cost yang dikeluarkan.

B/C < 1, proyek tersebut tidak layak.

Adapun indikator keberhasilannya/kelayakannya ditentukan dengan nilai NPV (Net Present Value), IRR (internal Rate of Return) dan B/C (Benefit Cost Ratio) pada suatu proyek.

5.2.4 Metode Langsung

Dalam metode langsung yang ditetapkan pada analisis sensitivitas ini Anda akan mengganti angka yang berbeda menjadi asumsi dalam model. Misalnya, asumsi pertumbuhan pendapatan Anda 20% dari tahun ke tahun, maka rumus pendapatan adalah:

(Pendapatan tahun lalu) x (1+20%)

Dengan menggunakan metode langsung, kami mengganti angka yang berbeda untuk menggantikan tingkat pertumbuhan untuk melihat jumlah pendapatan yang di hasilkan.

5.2.5 Metode Tidak langsung

Dalam metode tidak langsung, Anda akan memasukkan perubahan persen ke dalam rumus alih-alih mengubah nilai asumsi secara langsung, Misalnya, jika asumsi pertumbuhan pendapatan Anda adalah 20% dari tahun ke tahun dan kita tahu bahwa rumus pendapan adalah:

(Pendapatan tahun lalu) x (1+20%)

Alih-alih mengubah 20% ke angka lain, kami mengubah rumus menjadi:

(Pendapatan tahun lalu) x (1+20%+X))

Di mana: X adalah nilai di area analisis sensitivitas model.

5.3 Perbedaan Sensitivity Analysis dan Scenario Analysis

Sensitivity Analysis dapat memprediksi hasil dari suatu peristiwa yang diberikan rentang variabel tertentu, dan seorang analis dapat menggunakan informasi ini untuk memahami bagaimana perubahan dalam satu variabel memengaruhi variabel atau hasil lainnya. Sensitivity Analysis dapat mengisolasi variabel tertentu dan menunjukkan kisaran hasil.

Namun, *Scenario Analysis* menentukan apa yang akan menjadikan situasi tertentu, seperti perubahan peraturan industri atau kehancuran pasar saham. Seorang analis dapat menggunakan khusus untuk *scenario* tertentu untuk mengubah variabel dalam model, memberikan pengalaman tentang hasil untuk situasi kehidupan nyata tertentu.

5.4 Manfaat dan Kelebihan Sensitivity Analysis

5.4.1 Manfaat Sensitivity Analysis

Ada beberapa manfaat menggunakan *sensitivity analysis*. Penting untuk diingat bahwa *sensitivity analysis* menggunakan serangkaian hasil berdasarkan asumsi dan variabel yang kemudian, berdasarkandata historis.

Berikut ini manfaat dari analisis sensitivitas, baik secara umum dan lebih khususnya adalah dalam dunia finansial.

1. Memberikan simulasi sensitivitas terhadap segala ketidakpastian dalam input variabel sebuah model.
2. Membantu proses pengambilan keputusan dengan memberikan gambaran menyeluruh tentang situasi tertentu, termasuk risiko yang bisa muncul dan keuntungan yang mungkin didapatkan.
3. Memberikan prediksi tentang hasil dari sebuah pengambilan keputusan jika situasi yang ada di lapangan berbeda dengan apa yang sudah diprediksikan sebelumnya.

4. Membantu menilai tingkat risiko strategi. Dalam dunia bisnis hal ini penting agar perusahaan tahu apakah strategi yang mereka ambil dapat memberikan keuntungan.
5. Membantu para pemegang saham dan direksi perusahaan untuk megambil keputusan yang tepat dan penuh pertimbangan.
6. Membantu menemukan kesalahan-kesalahan yang ada pada sebuah model situasi.

5.4.2 Kelebihan Sensitivity Analysis

Jika sebuah perusahaan melakukan analisis sensitivitas, mereka bisa mendapatkan keuntungan seperti berikut.

1. Analisis sensitivitas dapat meningkatkan kredibilitas segala jenis model finansial dengan menguji coba model tersebut ke dalam berbagai macam kemungkinan.
2. Analisis sensitivitas secara finansial membuat para analis lebih fleksibel terhadap berbagai batasan untuk menguji sensitivitas variabel dependen terhadap variabel independen.

5.5 Kegunaan dan manfaat What if Analysis

5.5.1 Kegunaan what if analysis

Ada beberapa kegunaan untuk *what if analysis* di banyak karir dan industri. *What if analysis* juga merupakan model dengan ruang untuk kesalahan dan mungkin tidak sepenuhnya akurat, tetapi merupakan alat yang berharga dan banyak digunakan.

Berbagai situasi memerlukan penggunaan *sensitivity analysis* untuk meramalkan, memprediksi, mengidentifikasi area perbaikan atau membuat penyesuaian.

Berikut ada beberapa aplikasi umum dari *sensitivity analysis*:

1. Memahami bagaimana variabel input berhubungan dengan variabel output.
2. Membuat Hipotesis untuk menguji skenario tertentu.
3. Membuat rekomendasi.
4. Mengkomunikasikan data dan hasil.
5. Mengidentifikasi titik imbas, nilai kritis, dan perubahan strategi yang optimal.
6. Pengujian kelayakan untuk solusi ideal.
7. Memperkirakan kebutuhan untuk variabel outputdan input.
8. Mengukur parameter.
9. Membuat asumsi untuk memungkinkan pengambilan keputusan.
10. Menilai jumlah risiko untuk skenario atau strategi.
11. Mengidentifikasi variabel sensitif.
12. Mengembangkan rekomendasi.

5.5.2 Manfaat utama menggunakan what if analysis

Berikut ini manfaat utama menggunakan what if analysis secara umum dan lebih khususnya adalah:

1. Pengambilan keputusan yang lebih baik: Sensitity analysis memberi keputusan berbagai hasil untuk membantu mereka membuat keputusan bisnis yang lebih baik.
2. Predisi yang lebih handal: ini memberikan studi mendalam tentang variabel yang membuat prediksi dan model lebih andal.
3. Menyoroti area untuk perbaikan: Sensitvity analysis membantu pengambilan keputusan mengidentifikasi di mana harus melakukan perbaikan di masa depan.
4. Memberikan tingkat kredibilitas yang lebih tinggi: Sensivity analysis menambahkan kredibilitas pada model keuangan dengan mengujinya di berbagai kemungkinan.

Contoh *sensitivity analysis*

Berikut adalah dua contoh hipotesis ketika *what-if analysis* dapat digunakan:

Contoh 1:

Arief Menjual tas ransel di mall, Dia tahu sebelum kembali ke sekolah akan di mulai pada bulan Agustus, dan dia ingin menentukan apakah peningkatan pelanggan di mall akan meningkatkan pendapatan penjualannya dan, jika ya, berapa banyak.

Harga rata-rata tas ransel yang dijual Arief adalah Rp. 40.000. Bulan lalu, sebelum kembali ke sekolah, dia menjual 250 tas ransel, menghasilkan penjualan sebesar Rp.10.000.000. Setelah menggunakan program perangkat lunak spreadsheet, Arief menemukan bahwa ketika pelanggan di mall meningkat sebesar 20%, ada peningkatan 14% dalam penjualannya.

Pada saat ini Arief sudah mengetahui informasi penjualan pada bulan lalu, dia dapat menggunakannya untuk memprediksi berapa banyak pendapatan penjualannya akan meningkat atau menurun. Jika pelanggan meningkat menjadi 40%, penjualannya harus meningkat sebesar 28%. Jika pelanggan menurun 10%, maka penjualannya juga menurun sebesar 7%.

Contoh 2:

Aisyah adalah seorang manajer penjualan dan ingin lebih memahami bagaimana peningkatan pembeli pada hari libur memengaruhi total penjualan untuk departemennya.Menggunakan data dari penjualan liburan tahun lalu, Aisyah mengetahui bahwa total penjualan hari libur merupakan fungsi dari volume transaksi dan harga. Dia menentukan bahwa ketika pembeli libur akan meningkat 10%, maka penjualanpun akan meningkat sebesar 5%.

Aisyah dapat membangun model keuangan dan menggunakan laporan what-if analysis untuk mengetahui informasi ini. Berdasarkan hal ini, Aisyah nemahami bahwa jika peningkatan pembeli pada saat liburan meningkat sebesar 50%, total penjualan harus juga meningkat sebesar 25%.

5.6 Pendekatan Sensitivity Analysis

Sensitivity analysis merupakan ide sederhana yang dapaat dilakukan dengan mengubah model dan mengamati perilakunya. Dalam prakteknya ada banyak cara yang berbeda untuk mengubah dan mengamati model. Bagian ini mencakup apa yang harus bervariasi, apa yang harus diperhatikan dan desain eksperimen dari sensitivity analysis.

5.6.1 Variasi dalam Sensitivity Analysis

Seseorang mungkin memilih untuk memvariasikan salah satu atau semua hal berikut:

1. Kontribusi kegiatan terhadap tujuan.
2. Tujuannya (misalnya, meminimalkan risiko kegagalan dan bukan memaksimalkan keuntungan).
3. Batas Kendala (misalnya, ketersediaan sumber daya maksimum).
4. Jumlah kendala (misalnya, menambahkan atau menghapus batasan yang dirancang untuk mengungkapkan preferensi pribadi pembuat keputusan atau terhadap aktivitas tertentu).
5. Jumlah aktivitas (misalnya menambahkan atau menghapus aktivitas).
6. Parameter teknik. Umumnya, pendekatannya adalah untuk memvariasikan nilai parameter numerik melalui beberapa tingkatan. Dalam kasus lain, ada ketidakpastian tentang situasi dengan hanya dua kemungkinan hasil yaitu akan terjadi atau tidak situasi tersebut.

Contohnya meliputi:

1. Bagaimana jika pemerintah mengizinkan teknologi tertentu untuk alasan lingkungan?
2. Dalam masalah rute terpendek, bagaimana jika jalan bebas hambatan bary dibangun di antara dua pusat utama?
3. Bagaimana jika masukan atauy ramuan baru dengan sifat unik tersedia?

Seringkali pertanyaan jenis diatas memerlukan beberapa perubahan struktur pada model. Begitu pertubahan ini dilakukan, keluaran dari model yang

direvisi dapat dibandingkan dengan solusi asli, atau model yang di revisi dapat digunakan dalam sensitivity analysis parameter yang tidak pasti untuk menyelidiki implikasi yang lebih luas dari perubahan tersebut (Kadariah & Gray, 1978).

5.6.2 Sensitivity Analysis yang harus diperhatikan

Apapun barang yang dipilih oleh pemodel bervariasi, ada banyak aspek yang berbeda dari keluaran model yang harus dibayar perhatiannya:

1. Nilai fungsi objektif untuk strategi optimal.
2. Nilai fungsi objectifuntuk strategi suboptimal (misal strategi yang optimal untuk skenario lain, atau strategi khusus yang disarankan oleh pembuat keputusan).
3. Perbedaan nilai fungsi objektif antara dua strategi (misal antara strategi optimal dan strategi tertentu yang disarankan oleh pengambil keputusan).
4. Nilai variabel keputusan.
5. Dalam model optimasi, nilai biaya bayangan atau harga bayangan.
6. Peringkat variabel keputusan, biaya bayangan, dan lain-lain.

5.6.3 Desain Eksperimental

Desain eksperimental adalah kombinasi parameter yang akan bervariasi dan tingkat di mana hal tersebut akan ditetapkan. Pemodel harus memutuskan apakah akan bervariasi parameter satu per satu, meninggalkan yang lain pada nilai standar atau dasar, atau apakah akan memeriksa kombinasi perubahan. Isu penting dalam keputusan ini adalah kemungkinan kombinasi-kombinasi yang relatif kecil. Jika dua parameter cenderung berkorelasi positif (misalnya harga dua keluaran serupa), kemungkinan keduanya akan mengambil nilai yang relatif tinggi pada saat yang sama layak dipertimbangkan. Sebaliknya jika dua parameter berkorelasi negatif, pemodel harus memeriksa nilai tinggi satu kombinasi dengan nilai rendah yang lain. Jika tidak ada hubungan sistematis antara parameter, mungkin masuk akal untuk mengabaikan risiko rendah sehingga kedua akan berbeda secara substansial dari nilai dasarnya pada saat bersamaan, terutama jika tidak diperkirakan akan sangat bervariasi (Raharjo, 2020).

Dalam memilih tingkat parameter yang akan digunakan dalam sensitivity analysis, pendekatan yang umum dan biasanya dengan interval ukuran yang sama antara tingkat. Tingkat yang dipilih untuk setiap parameter harus mencakup kisaran kemungkinan hasil untuk variabel tersebut, atau setidaknya rentang kemungkinan besar. Apa yang dimaksud dengan kemungkinan besar adalah pilihan subyektif dari modeller, namun satu kemungkinan pendekatannya adalah memilih tingkat maksimum dan minimum sehingga probabilitas nilai aktual berada di luar kisaran yang dipilih adalah 10 persen. Jika kombinasi perubahan pada dua atau lebih parameter sedang dianalisis, pendekatan potensial adalah menggunakan rancangan eksperimentaal faktorial lengkap di mana model dipecahkan untuk semua kemungkinan kombinasi parameter. Meskipun ini memberikan banyak informasi, jika ada sejumlah parameter untuk dianalisis, jumlah solusi model yang harus didapat bisa sangant besar. Untuk melakukan sensitivity analysis faktorial lengakap untuk delapan paramater masing-masing dengan lima tingakatan memerlukan solusi 390.625. Jika ini memerlukan waktu satu menit untuk diproses, tugas tugas tersebut akan memakan waktu sembilan bulan, setelah ini volume output yang dihasilkan akan terlalu besar untuk digunakan secara efektif. Dalam prakteknya seseorang harus berkompromi dengan mengurangi jumlah variabel dan/atau jumlah tingkat yang termasuk dalam faktorial lengkap. Sensitivity Analysis awal pada parameter individu sangat membantu dalam menentukan parameter yang paling penting untuk dimasukkan dalam percobaab faktorial yang lengkap.

Bab 6

Breakeven Analysis

6.1 Pendahuluan

Setiap investasi baik yang dilakukan pemerintah maupun swasta pasti dilakukan dengan tujuan untuk mendapatkan keuntungan. Setiap investor tentu menginginkan modal yang telah ditanam dalam usahanya dapat segera kembali. Dan bahkan selain kembali pokok (modal) setiap investor juga pasti berharap mendapat tambahan dari pokok yaitu keuntungan.

Dengan tingginya harapan dari setiap investor atas berkembangnya modal yang telah ditanam tersebut, maka pihak pengelola harus mampu membuat perencanaan secara matang untuk mendapatkan keuntungan maksimal. Perencanaan, pengelolaan disertai pengawasan dan pengendalian kegiatan usaha akan mewujudkan ketercapaian harapan setiap investor dengan lebih terukur.

Perencanaan adalah kegiatan memperkirakan apa yang akan terjadi yang terkait dengan kegiatan usaha yang dikelola di masa yang akan datang disertai persiapan berbagai langkah teknis yang akan diambil perusahaan untuk mencapai tujuan yang telah disepakati. Perencanaan menduduki peran yang sangat krusial bagi suatu perusahaan dalam menjalankan kegiatan operasionalnya. Mengingat keuntungan (laba) adalah tujuan setiap usaha, maka kegiatan perencanaan lebih ditekankan pada penentuan laba yang

diinginkan. Oleh karena itu keberhasilan pengelolaan biasanya dinilai berdasarkan tingkat perolehan keuntungan yang dicapai. Untuk itu setiap manajemen harus mampu membuat perencanaan sekaligus mencapai keuntungan yang maksimal. Salah satu kegiatan perencanaan yang populer dilakukan adalah analisis titik impas (breakeven point analysis atau BEP analysis) atau biasa juga disebut dengan analisis impas (breakeven analysis). Dalam buku ini penggunaan istilah breakeven selanjutnya akan digunakan secara bersama-sama dengan istilah "analisis impas" atau "analisis titik impas".

Secara luas analisis breakeven dikenal sebagai analisis biaya-volume-laba atau *Cost-Volume-Profit* (CVP) analysis. Sejak diperkenalkan pada abad ke-19 Masehi, konsep titik impas ini telah banyak digunakan, dipertajam, disesuaikan dan bahkan dimodifikasi untuk mengurangi keterbatasannya sekaligus meningkatkan kemampu-terapannya dalam dunia bisnis. Analisis ini diyakini merupakan salah satu cara terbaik dalam mendalami hubungan antara biaya, volume dan laba (Cafferky, 2010).

Titik impas erat kaitannya dengan batas keamanan (margin of safety). Batas keamanan ini memberikan informasi tentang seberapa jauh penurunan realisasi penjualan dibolehkan terjadi agar perusahaan tidak mengalami kerugian. Agar perusahaan tidak merugi, besar penurunan realisasi penjualan dari penjualan maksimum rencana haruslah sebesar nilai batas keamanannya (Entar Sutisman and Ak, 2022). Sedangkan contribution margin dapat digunakan oleh pihak manajemen untuk mengetahui apakah volume yang tersedia cukup atau tidak untuk menutupi biaya tetap perusahaan yang kemudian akan menjadi laba (Choiriyah, AR and Hidayat, 2016).

6.2 Pengertian dan Manfaat Analisis Impas

6.2.1 Pengertian Analisis Impas

Titik impas (Break Even Point/BEP) adalah suatu kondisi di mana dalam operasional perusahaan berada pada titik tidak mengalami kerugian tapi juga belum mendapatkan keuntungan (Maruta, 2018). Dengan bahasa yang berbeda dapat dikatakan bahwa antara biaya dan pendapatan berada pada kondisi yang

sama sehingga labanya adalah sama dengan nol. Titik impas dapat diartikan sebagai titik pulang pokok di mana jumlah pemasukan sama dengan biaya total (Entar Sutisman and Ak, 2022). Analisis ini sangat berguna untuk mengambil keputusan dari beberapa alternatif yang sensitif terhadap faktor tunggal yang sulit didekati atau diprediksi (diperkirakan besarannya). Secara umum, analisis impas merupakan suatu proses memvariasikan parameter masalah dan menentukan nilai parameter apa yang menyebabkan ukuran kinerja mencapai nilai ambang atau "titik impas"(Fraser and Jewkes, 2012).

Analisis titik impas ini mempelajari hubungan antara volume penjualan dan profitabilitasnya (Maruta, 2018). Teknik ini mempelajari suatu metode untuk menentukan titik tertentu di mana seluruh biaya tertutup oleh besarnya pemasukan sekaligus memberi gambaran adanya keuntungan atau kerugian jika pemasukan terlampaui atau di bawah titik yang dimaksud.

Analisis impas ini merupakan alat yang sederhana namun kuat dalam menilai risiko suatu proyek. Pada banyak pekerjaan engineering seringkali dihadapkan pada beberapa pilihan alternatif proyek. Pilihan terbaik dari beberapa alternatif proyek dapat diperoleh dari hasil pengujian sensitivitas proyek terhadap perubahan setiap parameter yang bekerja misalnya tingkat suku bunga, tingkat produksi, atau kombinasi berbagai parameter lainnya. Analisis titik impas dapat digunakan untuk menilai beberapa proyek alternatif untuk menjawab pertanyaan seperti "Pada kisaran suku bunga berapakah proyek A merupakan pilihan terbaik?" atau "untuk pertimbangan apa dua pilihan proyek tidak lagi menarik", dan sebagainya. Analisis dilakukan dengan memvariasikan satu parameter dalam dua atau lebih proyek lalu memperhatikan kapan kinerjanya memenuhi ambang batas atau melampaui titik impas. Parameter itu dapat dari komponen biaya, pendapatan, penghematan, suku bunga atau yang lain (Fraser and Jewkes, 2012).

6.2.2 Manfaat Analisis Impas

Analisis impas telah sangat luas dikenal dengan penyebutan analisis *Break Even Point* (BEP). Analisis BEP merupakan salah satu perangkat analisis keuangan yang sangat popular digunakan dalam perencanaan laba (profit planning) perusahaan. Analisis BEP dan perencanaan laba memiliki keterkaitan yang sangat erat mengingat keduanya menganalisis biaya, harga jual unit seerta volume penjualan, yang pada ujungnya meengarah pada perolehan lab aitu sendiri. Selain itu analisis BEP dapat digunakan sebagai

tolok ukur dalan usaha menaikkan perolehan laba atau mengetahui seberapa jauh penurunan laba yang dibolehkan agar tidak terjadi kerugian.

Beberapa manfaat yang dapat diperoleh dari pengaplikasian analisis BEP, di antaranya adalah sebagai berikut:

1. Sebagai alat perencanaan untuk menentukan berapa tingkat keuntungan yang ingin dicapai dalam periode waktu tertentu
2. Memberikan gambaran perolehan laba pada berbagai tingkat volume penjualan
3. Mengetahui keseluruhan laba perusahaan.
4. Sebagai bahan pertimbangan dalam menentukan harga jual produk per unit
5. Mengetahui berapa tingkat penjualan minimal per minggu, per bulan, per catur-wulan, dan sebagainya.
6. Membuat kebijakan perubahan harga
7. Menganalisis Safety Margin
8. Membantu manajemen membuat keputusan berikut:
   a. Apakah akan merubah kapasitas produksi
   b. Akankah merubah komposisi produk
   c. Apakah akan menjual melalui internet
   d. Dan sebagainya

Manfaat analisis impas sangatlah banyak tergantung kebutuhan dan interpretasi ke arah mana diinginkan. Namun secara umum manfaat utama dari analisis ini adalah mengetahui titik kembali modal (pulang pokok) sehingga pihak manajemen dapat mengetahui harus memperoleh pamasukan berapa atau menjual berapa unit untuk menutup keseluruhan biaya agar perusahaan tidak merugi.

6.3 Asumsi dalam Analisis Impas

Menjadi sangat penting untuk memahami beberapa asumsi yang mendasari interpretasi dari analisis CVP/BEP/titik impas, karena kesalahan memahami asumsi dapat membuat kesalahan serius yang dapat mengarahkan pada hasil

simpulan yang juga salah. Untuk itu seorang Analis harus memahami adanya beberapa asumsi penting berikut (Drury, 2006):

1. Semua variabel lainnya tetap konstan.
   Semua variabel yang lain selain variabel yang sedang dianalisis dianggap tetap. Dengan kalimat lain dapat juga diartikan bahwa pemasukan hanya semata-mata dipengaruhi oleh volume penjualan, meskipun sebenarnya variabel lain seperti efisiensi, tingkat harga, dapat sangat berpengaruh pada biaya maupun pemasukan. Jika saja perubahan pada beberapa komponen tersebut benar-benar terjadi secara signifikan maka hasil analisis CVP yang dilakukan menjadi tidak benar.
2. Hanya untuk satu produk tunggal atau penjualan campuran yang tetap. Dalam asumsi ini perusahaan diasumsikan hanya menjual satu jenis produk. Jika produk yang dijual beragam maka analisis ini harus mempertahankan pada penjualan produk campuran tersebut.
3. Biaya total (total cost) dan pemasukan total (total revenue) adalah fungsi linier dari output.
4. Tidak ada perubahan biaya tetap secara tiba-tiba, dan keuntungan dihitung berdasarkan biaya variabel.
5. Analisis dapat diaplikasikan hanya pada rentang nilai relevan.
6. Biaya dapat dipisahkan secara akurat ke dalam komponen biaya tetap dan biaya variabel.
7. Analisis ini hanya dapat diaplikasikan untuk rentang waktu yang singkat.

6.4 Komponen dalam Analisis Impas

Melakukan analisis titik impas tentu tidak terlepas dari pemahaman tentang arus kas yang berkaitan dengan hubungan antara pendapatan dan biaya dalam suatu proyek. Pengertian yang paling mendasar dari konsep titik impas untuk suatu proyek adalah kondisi di mana total pendapatan sama dengan total biaya. Biaya total dalam analisis ini adalah biaya keseluruhan yang merupakan

gabungan antara biaya tetap dan biaya variabel. Bagian selanjutnya dari buku ini akan menjelaskan komponen dan data apa saja yang diperlukan dalam perhitungan analisis impas.

Berikut ini beberapa komponen analisis yang harus diketahui dalam analisis impas, di antaranya adalah:

1. Biaya tetap (fixed cost)
   Adalah biaya yang tetap yang pasti dikeluarkan oleh perusahaan dalam menjalankan usahanya tanpa melihat berapa banyak jumlah unit yang diproduksi. Biaya ini juga diistilahkan dengan biaya overhead. Berapapun jumlah unit yang diproduksi, tidak akan memengaruhi besaran biaya tetap. Atau dapat dikatakan bahwa biaya tetap ini bukan fungsi dari jumlah unit yang diproduksi, dan besarnya relatif konstan.
   Biaya yang masuk kelompok ini adalah biaya administrasi, tagihan rutin bulanan seperti listrik, air dan biaya komunikasi, gaji dan upah karyawan, biaya sewa maupun depresiasi dari bangunan dan peralatan, biaya operasional, biaya perbaikan dan pemeliharaan, termasuk juga biaya iklan, pajak dan asuransi.
2. Biaya Variabel (Variable Cost)
   Biaya variabel ini sangat erat terkait dengan volume (banyak unit) yang diproduksi. Makin banyak produk yang dihasilkan (dijual) makin besar pula biaya variabel. Biaya yang masuk kelompok ini adalah biaya tenaga kerja serta bahan baku untuk produksi, bahan bakar, biaya tambahan dari kontraktor (rekanan) independen, biaya yang terkait dengan bahan tak langsung misalnya pemakaian gas, listrik, pemeliharaan alat dan sebagainya.
3. Harga per Unit.
   Adalah nilai jual atau harga jual per unit produk yang dihasilkan
4. Biaya Variabel per Unit
   Adalah jumlah biaya variabel dibagi jumlah unit yang diproduksi atau dapat dikatakan sebagai biaya rata-rata per unit produk.

5. Marjin Kontribusi per Unit
   Adalah selisih antara harga jual per unit produk terhadap biaya variabel per unitnya, atau, harga jual produk per unit dikurangi biaya variabel per unit.
6. Rasio Margin Kontribusi
   Adalah perbandingan antara margin kontribusi terhadap penjualan. Atau besarnya margin kontribusi dibagi penjualan.

6.5 Perhitungan Titik Impas

Perhitungan titik impas dapat dilakukan melalui beberapa metode dari yang analitis hingga grafis. Berikut ini beberapa Teknik yang dapat gunakan untuk mendapat nilai titik impas (Cafferky, 2010):

1. Metode Biaya Total (Total Cost Method)
   Metode ini menggunakan konsep dasar dari kondisi breakeven, yaitu di titik ketika total pemasukan telah sama dengan biaya total dalam suatu periode tertentu, maka disebut impas karena titik impas telah tercapai. Sehingga dapat dikatakan impas terjadi ketika total pemasukan telah sama jumlah biaya tetap dan biaya variabel.

   Biaya Total= Pemasukan Total = Impas

   Atau

   (Biaya Tetap+Biaya Variabel)= Total Pemasukan = Impas

   (Biaya Tetap+Biaya Variabel)= (Jumlah Penjualan x Harga Jual) = Impas

   Persamaan umum perhitungannya sebagai berikut:

   $$px=a+bx$$

   Dari persamaan di atas, maka titik impas diperoleh dengan persamaan berikut:

   $$BEP\ (Unit) = \frac{a}{p-b}$$

   atau

$$BEP\ (Rupiah) = \frac{a}{1 - \left[\frac{bx}{px}\right]}$$

Di mana:
p = harga jual produk per unit
x = jumlah unit produk yang dijual atau diproduksi
a = biaya tetap total
b = biaya variabel untuk setiaap produk

2. Metode Marjin Kontribusi (Contribution Margin Method)
   Metode ini dapat menghasilkan jumlah unit minimal yang harus diproduksi dan terjual agar impas. Untuk melakukan analisis impas menggunakan metode Marjin Kontribusi, seseorang harus mengetahui terlebih dahulu harga jual per unit, biaya variabel per unit dan biaya tetap per unit untuk satu periode waktu tertentu. Biasanya periode waktunya diambil satu tahun atau kurang. Contribution Margin (CM) atau Marjin Kontribusi sendiri dapat diartikan sebagai selisih antara pemasukan dan biaya variabel. Atau dapat disajikan dalam persamaan berikut:
   Margin Kontribusi per Unit = Harga Jual per Unit – Biaya Variabel per Unit
   Dalam analisis impas menggunakan metode Marjin Kontribusi, dikenal nilai Contribution Margin Ratio (CM Ratio) yang merupakan nilai rasio marjin kontribusi dalam satuan %, atau, perbandingan antara marjin kontribusi per unit dengan harga jual per unit.
   Nilai CM Ratio dapat disajikan dalam bentuk persamaan sebagai berikut:
   $CM\ Ratio = \frac{Marjin\ Kontribusi\ per\ Unit}{Harga\ Jual\ per\ Unit}$ atau $CM\ ratio = \frac{Total\ marjin\ Kontribusi}{Total\ Pemasukan}$
   Atau dapat juga menggunakan persamaan berikut:

$$CM\ Ratio = 1 - \frac{Biaya\ Variabel\ per\ Unit}{Harga\ Jual\ per\ Unit}$$

   Metode Marjin Kontribusi ini menyajikan nilai titik impas yang diperoleh dari persamaan berikut:

$$Titik\ Impas\ (Unit) = \frac{Total\ Biaya\ Tetap}{Marjin\ Kontribusi\ per\ Unit}$$

$$Titik\ Impas\ (Rupiah) = \frac{Total\ Biaya\ Tetap}{CM\ Ratio}$$

3. Metode Target Laba (Target Profit Method)

   Mengetahui titik impas adalah informasi yang yang sangat berguna mengingat tujuan dari setiap investasi adalah mengetahui kapan pulang modal dan mendapat keuntungan. Manajemen dapat memberikan sejumlah laba yang diinginkan dalam periode tertentu (bulanan, catur wulanan atau tahunan). Target laba yang diinginkan ini kemudian ditambahkan ke dalam formulasi perhitungan titik impas untuk mendapatkan berapa unit penjualan minimum yang harus dicapai.

   Berdasarkan target laba yang diinginkan tersebut, untuk mendapatkan jumlah unit yang harus dijual dapat dicari dengan persamaan berikut (Cafferky, 2010):

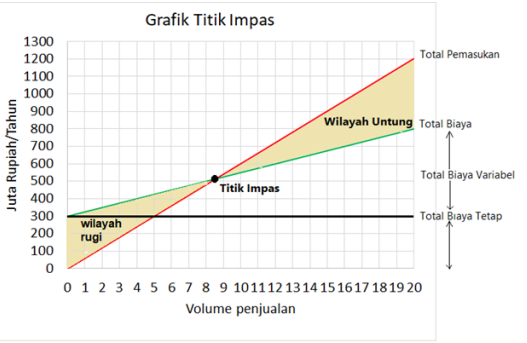
$$Penjualan\ (Unit) = \frac{Biaya\ Tetap + Laba\ yang\ diinginkan}{Margin\ Kontribusi\ per\ Unit}$$

$$Penjualan\ (Unit) = \frac{Biaya\ Tetap}{Margin\ Kontribusi\ per\ Unit - Laba\ yang\ diinginkan}$$

   Dengan persamaan tersebut di atas dapat diketahui berapa jumlah penjualan minimum unit untuk mendatangkan pemasukan sejumlah total biaya sehingga tercapai kondisi impas.

4. Metode grafis

   Analisis titik impas dapat juga disajikan dalam bentuk grafis yang disebut grafik impas. Metode ini melakukan perhitungan seluruh komponen analisis impas dan menyajikannya dalam grafik hubungan komponen tersebut terhadap volume penjualan. Dari grafik tersebut akan didapatkan titik perpotongan antara pemasukan total dan biaya total, dan titik potong tersebut disebut sebagai titik impas, seperti diilustrasikan pada Gambar 6.1. di bawah ini.



Gambar 6.1: Grafik Titik Impas

Dalam grafik tersebut terlihat besaran biaya tetap besarnya adalah konstan tidak terpengaruh oleh volume penjualan. Sedangkan biaya variabel dan pemasukan besarnya mengikuti volume penjualan. Semakin tinggi volume penjualan semakin tinggi biaya variabel dan pemasukannya. Perpotongan antara garis biaya total dan pemasukan total terjadi pada volume penjualan 8,5unit dengan nilai Rp. 510 Juta.

5. Menggunakan Aplikasi Kalkulator Analisis BEP
   Jodinesa and Sutopo (2018), menyebutkan bahwa terdapat bentuk aplikasi yang dapat digunakan untuk menganalisis per satu jenis produk namun tidak dapat digunakan untuk membandingkan antara produk sejenis atau antar produk secara keseluruhan. Karena aplikasi hanya berfungsi sebagai kalkulator maka pengaruh perubahan atau fluktuasi biaya terhadap perencanaan laba tidak dapat ditampilkan.

6.6 Kekurangan Metode Analisis Impas

Meskipun analisis titik impas ini banyak diterapkan, namun pada dasarnya metode ini memiliki beberapa kekurangan.

1. Memerlukan nilai asumsi
   Analisis titik impas memerlukan banyak asumsi khususnya mengenai hubungan antara biaya dengan pendapatan. Padahal nilai asumsi tidak

selalu tepat (sama) dengan kenyataan yang terjadi di masa yang akan datang.

2. Asumsi linieritas
   Penggunaan asumsi linieritas menjadi salah satu kelemahan dalam analisis titik impas. Pada umumnya harga jual per unit dan biaya variabel per unit tidaklah berdiri sendiri melainkan dipengaruhi oleh volume penjualan secara keseluruhan. Harga jual per unit produk dapat saja lebih murah pada volume produksi (atau volume penjualan) yang lebih besar. Dari sudut yang lain dapat dikatakan tingkat penjualan yang mampu melewati titik tertentu pada umumnya dicapai dengan cara menurunkan biaya per unit. Hal ini membuat grafik garis pemasukan (revenue) tidaklah linier melainkan akan berbentuk lengkung. Dari sisi biaya variabel untuk operasional (operating variable cost), juga dapat saja tidak linier yang diakibatkan oleh volume produksi yang tinggi dapat menyebabkan penurunan efisiensi tenaga kerja atau peningkatan besarnya upah lembur.
3. Pengelompokan biaya
   Adanya kebutuhan untuk pengelompokan komponen biaya ke dalam komponen biaya tetap dan biaya variabel juga menjadi kekurangan dari analisis ini. Karena relatif sulit untuk memisahkan secara akurat kedua jenis biaya tersebut, selain juga adanya biaya yang semi variabel. Biaya semi variabel ini relatif tetap hingga titik tertentu dan menjadi fluktuatif setelah melewati titik tersebut.
4. Jangka waktu penerapan yang terbatas
   Analisis titik impas ini hanya direkomendasikan untuk digunakan dalam pembuatan proyeksi operasi dalam jangka waktu terbatas, umumnya setahun atau kurang. Hal ini berakibat pada pengeluaran investasi (cost) yang besar namun berdampak lama (misalnya biaya iklan), akan mengakibatkan pemasukan yang harus dicapai dari penjualan juga menjadi lebih besar, jika menggunakan metode titik impas.

5. Hanya untuk penjualan produk tunggal
   Merupakan kelemahan analisis impas berikutnya yang mana analisis hanya mendasarkan pada satu produk saja yang dijual. Jika produk yang dijual lebih dari satu, maka kombinasi penjualannya harus tetap (konstan). Hal ini menambah kekurangan dari penerapan metode ini mengingat pada saat ini banyak perusahaan yang justru harus memperbanyak varian produknya untuk meningkatkan daya saingnya di dunia bisnis global.

Bab 7

Payback Period

7.1 Pendahuluan Payback Period

Dalam ekonomi teknik penggunaan rumus atau teknik penerapannya bisa di temukan dalam bidang pemerintahan, lingkungan bisnis oleh pelaku usaha. Penerapannya untuk kepentingan proyek, *tool* atau alat analisis ekonomi teknik yang bisa di gunakan untuk kepentingan pribadi dalam memilih dan membuat keputusan seperti pembelian mobil, pembelian motor, pembelian rumah, pembelian tanah dan lain lain.

Pemilihan sebuah alternatif dalam ekonomi teknik pada beberapa pilihan tertentu memiliki kriteria yang di sebut ukuran nilai. Salah satu ukuran nilai yang digunakan adalah jangka waktu pengembalian modal pokok atau biasa disebut *payback period*. *Payback Period* adalah metode yang sering digunakan dalam mempertimbangkan tentang risiko untuk dapat mengetahui tingkat waktu dalam menutup kembali modal yang diinvestasikan (Eka Nurus Sakinah, I Nyoman Dita Pahang Putra and Anna Rumintang, 2021).

Payback period merupakan salah satu ukuran nilai yang menggambarkan fakta bahwa uang ternyata bisa menghasillkan uang lagi karena pengaruh waktu. Hal ini biasa di sebut konsep nilai waktu dari uang. Nilai waktu dari uang menjelaskan perubahan jumlah uang atas waktu untuk penggunaan dana yang di investasikan, di miliki atau di pinjamkan (Ai Nurhayati, 2022).

7.2 Definisi Payback Period

Kegiatan investasi kegiatan jangka panjang serta memerlukan biaya besar terhadap keberlansungan usaha. Oleh sebab itu, pemikiran rasional sangat diperlukan dalam kegiatan ini. Salah satu metode yang umum dipakai dalam mengevaluasi kelayakan investasi adalah metode *payback period* (PP).

Payback period adalah kegiatan pengembalian modal yang dikeluarkan oleh para investor dalam suatu jangka waktu. Dunia bisnis menyebutnya dengan pengembalian modal. *Payback Period* menunjukkan terjadinya arus penerimaan atau *cash in flows* secara kumulatif sama dengan jumlah investasi dalam bentuk *present value*. Untuk mengetahui berapa lama usaha/proyek yang dikerjakan baru dapat mengembalikan investasi, maka hasil analisis *payback period* perlu ditampilkan

Semakin cepat dalam pengembalian biaya investasi proyek, maka semakin baik proyek tersebut karena semakin lancar perputaran modal. Di pihak lain, dengan adanya perkembangan teknologi yang begitu cepat akhir-akhir ini, semakin cepat pengembalian biaya (Wati, 2016)

Payback period adalah jangka waktu yang dibutuhkan agar initial investment dapat kembali. Dalam perhitungan *payback period* ini menggunakan *proceed* sebagai aliran kas masuk. Sebelum dimulai perhitungan *payback period* terhadap investasi, perlu ditetapkan terlebih dahulu umur ekonomi. yang digunakan sebagai pendamping dengan *payback period* dari investasi yang dilaksanakan (Ediwodjojo and Ginting, 2018)

Periode pengembalian (payback period) merupakan jangka waktu yang dibutuhkan untuk mengembalikan nilai investasi melalui penerimaan-penerimaan yang dihasilkan oleh proyek (Nurusi, Lengga Sari Munthe and Yuli Sari, 2022)

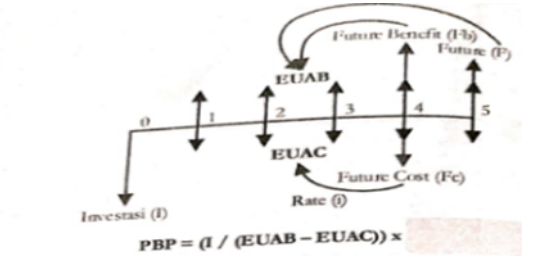
Analisa pembayaran kembali dalam arti sebuah periode di mana titik impas sudah terlewati, investor sudah mulai merasakan keuntungan dari hasil invetasinya. Periode di mana jumlah waktu yang di butuhkan untuk pemodal bisa mendapatkan kembali modal awalnya (Ai Nurhayati, 2022)

Kelebihan dari metode payback period merupakan cara yang gampang dalam penggunaan dan perhitungannya, sehingga sangat bermanfaat buat memilih investasi yang mana akan memiliki masa pengembalian tiap periode tercepat, masa pengembalian investasi bisa dipakai buat indera prediksi risiko

ketidakpastian dalam masa mendatang, dan masa pengembalian tercepat mempunyai risiko lebih minim dibandingkan menggunakan masa pengembalian yang relatif lebih lama. (Supadi and Setiyono, 2022)

Para investor dan pebisnis lebih sering menggunakan cara *payback* periode dalam menentukan atau mengambil keputusan investasi, apakah perusahaan tersebut layak untuk diinvestasikan ataupun tidak

Metode *payback periode* mempunyai kekurangan yaitu mengabaikan nilai uang terhadap waktu (Muhammad Faisal Ibrahim, 2019).



Gambar 7.1: Payback Period

Secara umum proses perhitungan *payback period* dapat dilihat pada gambar 2.1, di mana pada awalnya seluruh komponen *benefit* dan *cost* diekuivalen ke nilai annual. Kemudian membagi investasi dengan annual *benefit*. Adapun analisi dengan *payback period* adalah sebagai berikut:

1. PBP < n, investasi layak dilakukan (menguntungkan)
2. PBP > n, investasi tidak layak dilakukan (merugikan)
3. PBP= n, investasi tidak menguntungkan dan tidak merugikan

Cara menghitung payback period adalah dengan membagikan nilai investasi (Cost Of Investment) dengan aliran kas neto yang masuk per tahun (Annual Net Cash Flow). Berikut adalah rumus payback period.

1. Jumlah Aliran Kas Per Tahun Yang Berbeda
   Payback Period=n+ (a-b)/(c-b) x 1 tahun
   Keterangan
   N= Tahun terakhir dari investasi awal yang belum dapat menutupi modal awal
   a= Jumlah investasi awal.

b= Jumlah kumulatif arus kas dari tahun ke n

c= Jumlah kumulatif arus kas dari tahun ke n + 1

2. Jumlah Aliran Kas Per Tahun Yang Sama

$$Payback\ Period = \frac{Investasi\ Awal}{Arus\ Kas}\ x\ 1\ tahun$$

Keterangan

Periode pengembalian jika cepat: layak

Periode pengembalian jika lama: tidak layak

Periode pengembalian yang lebih cepat yang dipilih, jika usulan proyek investasi lebih dari satu

7.3 Tujuan Metode Payback Period

Menurut Drs. M. Giatman (2006), analisis payback period (PP) pada dasarnya bertujuan untuk mengetahui seberapa lama (periode) investasi akan dapat dikembalikan saat terjadinya kondisi pulang pokok (break even point).

$$k_{(pbp)} = \sum_{t-0}^{k} CF_t\ \geq 0$$

Di mana:

K = Periode Pengembalian

CFt = Cash Flow Periode ke t

Jika cost dan cash flow benefit bersifat annual, maka persamaannya menjadi:

$$k_{(pbp)} = \frac{Investasi}{Annual\ Benefit}\ x\ periode\ waktu$$

Kriteria keputusan dilakukan agar rencana suatu investasi tersebut layak ekonomis atau tidak, diperlukan suatu kriteria tertentu. Rencana investasi dengan payback period dikatakan layak apabila:

$$Jika\ k\ \leq n\ dan\ sebaliknya$$

Jika k < n dan sebaliknya.

k= Jumlah Periode Pengembalian

n= Umur Investasi

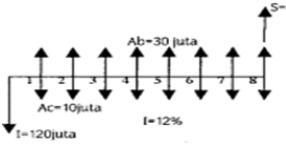
Analisis *Payback Period* pada awalnya berguna untuk mengetahui seberapa lama (periode) investasi yang dapat dikembalikan ketika terjadi kondisi pulang pokok (break even point). Definisi lainnya adalah jumlah periode (tahun) yang diperlukan untuk mengembalikan (menutup) ongkos investasi awal dengan tingkat pengembalian tertentu. Persamaan yang diambil berdasarkan aliran kas, baik tahunan maupun yang merupakan nilai sisa. (Pujawan, 2022)

Contoh Soal:

Suatu investasi sebesar 120 juta rupiah akan diikuti oleh biaya operasional 10 juta rupiah/tahun dan benefit 30 juta rupiah/tahun, umur investasi 8 tahun, setelah itu aset akan laku terjual 30 juta rupiah. Hitunglah payback period investasi tersebut!

Jawaban:

Penyelesaian soal sebagai berikut:



$$k_{(PBP)} = \frac{Investasi}{Annual\ Benefit} \text{ x periode waktu}$$

$$k_{(PBP)} = \frac{Rp\ 120\ juta}{Rp\ 30\ juta - Rp10\ juta} \text{ x tahun}$$

$$k_{(PBP)} = 6 \text{ tahun}$$

Karena k= 6 tahun < n= 8 tahun, maka periode pengembalian (payback period) investasi memenuhi syarat/layak.(Drs. M. Giatman, 2006)

Dengan menggunakan rumus tersebut, maka bisa didapatkan kurun waktu payback period yang diperlukan untuk bisa mengembalikan modal ataupun dana investasi yang dikeluarkan pada suatu pengerjaan proyek. Selain itu, perhitungan tersebut juga akan membantu dalam memperhitungkan waktu yang Di butuhkan untuk bisa kembali mendapatkan modal.

Dengan menggunakan rumus perhitungan tersebut, maka bisa memilih proyek yang lebih mampu mengembalikan dana dalam kurun waktu cepat. Mau bagaimanapun, kecepatan suatu proyek dalam menyelesaikan pekerjaannya akan memengaruhi proses pengembalian modal yang lebih cepat.

Itu berarti, semakin sedikit waktu yang diperlukan dalam pengerjaan, maka risiko yang diterima suatu perusahaan akan semakin sedikit juga. Jika jangka waktu payback period sebentar, maka risiko yang diterima oleh perusahaan

akan semakin sedikit. Dengan waktu payback period yang singkat, maka akan membuat para investor atau pemilik bisnis untuk meminimalkan adanya kerugian.

Perhitungan dengan menggunakan rumus tersebut mudah dilakukan dan terlihat sederhana, sehingga seharusnya bisa dilakukan oleh semua orang yang bergerak pada berbagai jenis bisnis atau usaha, baik itu skala kecil, skala menengah, ataupun skala besar.

7.4 Kelebihan dan Kekurangan Payback Period

Payback period memiliki beberapa kelebihan sebagai berikut:

1. Memudahkan di untuk merencanakan investasi untuk proyek dengan menentukan lamanya waktu pengembalian dana investasi.
2. Menunjukkan informasi dari lamanya break even project.
3. Membandingkan 2 proyek yang punya risiko dan rate yang sama dengan cara melihat jangka waktu pengembalian investasi, dan memilih payback period yang lebih pendek.

Payback period memiliki beberapa kekurangan sebagai berikut:

1. Mengabaikan penerimaan investasi yang sudah diperoleh setelah payback periode terpenuhi.
2. Nilai waktu uang yang dapat terabaikan (time value of money).
3. Tidak dapat menunjukkan informasi seputar tambahan value dari perusahaan.
4. Keuntungan tidak terukur/nilai yang akan diperoleh.

Ada contoh kasus yang dapat menjelaskan tentang analisis periode pembayaran kembali (payback period) yang akan diuraikan dalam contoh di bawah ini.

Contoh:

Suatu manajemen pada perusahaan PT ABC ingin memutuskan apakah ingin membeli alat produksi pada komponen elektronika. Pembelian mesin produksi seharga Rp 250 jt, akan menghasilkan keuntungan bersih sebesar Rp 70 per tahunnya. Lantas, berapakah payback period time untuk mesin tersebut?

Jawaban:

Diketahui:

Nilai Investasi = Rp. 250.000.000,

Kas Masuk Bersih= Rp. 70.000.000,-

Di tanyakan:

Periode pengembalian modal= ……. ?

Penyelesaian:

Periode pengembalian modal = Nilai Investasi: Kas Masuk Bersih

Periode pengembalian modal = Rp. 250.000.000,-: Rp. 70.000.000

Periode pengembalian modal = 3,57

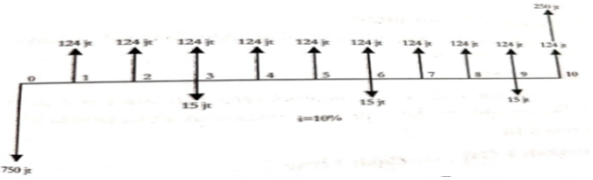
Berdasarkan persamaan yang dihasilkan, maka payback period suatu mesin produksi itu adalah 3,57 tahun lamanya.

Contoh:

Perusahaan ingin mengubah proses pengemasan yang sebelumnya dilakukan manual oleh manusia menjadikan otomatis oleh robot. Dengan begitu perusahaan tersebut harus melakukan investasi packing machine dengan harga 750 juta rupiah. Packing machine tersebut juga memerlukan biaya maintenance sebesar 15 juta setiap tiga tahun sekali. Dengan mengubah system pengemasan menjadikan automasi dengan mesin, perusahaan dapat menghemat biaya tenaga kerja sebesar 124 juta rupiah pertahun. Mesin ini di perkirakan bertahan hingga 10 tahun sebelum akhirnya harus diganti dengan teknologi baru. Pada akhir tahun ke-10 packing machine di perkirakan dapat dijual dengan harga 250 juta rupiah. Jika tingkat bunga sebesar 10%, lakukan perhitungan payback period? Berapa lama modal yang dinvestasikan akan kembali?

Jawaban:

Diketahui., sesuai gambar cash flow berikut:



Ditanyakan Payback Period (PBP)……?

Penyelesaian:

EUAB= 250 jt (A/F, 10%,10) + 124 jt

= 250 jt (0.063) + 124 jt

= Rp 139.75 jt

EUAC= 15 jt (P/F, 10%, 3). (A/P, 10%, 10) + 15 jt (P/F, 10%, 6) (A/P, 10%, 10) + 15 jt (P/F, 10%, 9) (A/P, 10%, 10)

= 15 jt (0.751) (0.163) + 15 jt (0.564) (0.63) + 15 jt (0.424) (0.163)

= Rp 4.25 juta

Sehingga:

PBP= 1/(EUAB-EUAC)

= 1/(139.75-4,25)

= 5.53

Berdasarkan perhitungan diatas, maka payback period time atau periode pengembalian modal untuk suatu mesin produksi adalah 5.53 satuan periode (Muhammad Faisal Ibrahim, 2019)

Contoh:

Tentukan periode pembayaran kembali *payback periode* pada soal berikut!

Data Investasi:

Biaya Investasi	Rp 396.000.000
Biaya Perawatan Tahunan	Rp 12.000.000
Keuntungan Tahunan	Rp 80.000.000
Biaya Overhaul	Rp 90.000.000
Nilai sisa	Rp 30.000.000
Lama Kegunaan	12 tahun
MARR	20%

Jawab:

Tabel data Arus Kas dan Keuntungan

Tahun	**Jumlah Biaya**	**Jumlah Keuntungan**
0	Rp 396.000.000	-
1	Rp 408.000.000	Rp 80.000.000
2	Rp 420.000.000	Rp 160.000.000
3	Rp 432.000.000	Rp 240.000.000
4	Rp 534.000.000	Rp 320.000.000
5	Rp 546.000.000	Rp 400.000.000
6	Rp 558.000.000	Rp 480.000.000
7	Rp 670.000.000	Rp 560.000.000
8	Rp 762.000.000	Rp 640.000.000
9	Rp 774.000.000	Rp 720.000.000
10	Rp 786.000.000	Rp 800.000.000

Pada periode ke-10 terlihat bahwa nilai keuntungan jauh lebih besar daripada biaya sehingga periode ke-10 disebut sebagai pembayaran kembali yang berarti di mana sudah melampaui titik impas. Maka payback periode (pp) sama dengan 10 tahun. (Ai Nurhayati, 2022)

Bab 8

Menghitung Nilai Investasi Return on Investment (ROI)

8.1 Pendahuluan

Investasi merupakan kegiatan penting yang memerlukan biaya besar dan berdampak jangka panjang terhadap kelanjutan usaha (Giatman, 2006). Salah satu keharusan bagi setiap pengusaha adalah memahami bagaimana cara mengukur kinerja dan profitabilitas suatu investasi, salah satu bentuk perhitungan yang popular adalah menggunakan Return on Investment (ROI). Pada semua jenis investasi, penggunaan kedua perhitungan tersebut penting saat menganggarkan modal dan mengambil keputusan. Dalam melakukan melakukan investasi baru, investor sering kali bergantung pada ROI yang diproyeksikan.

Alasan utama dari pentingnya memahami ROI adalah karena merupakan tolok ukuran keuntungan bisnis yang paling tepat. Dengan mengetahui tingkat pengembalian investasi dan pertumbuhan tahunan segala kegiatan operasional dapat dievaluasi tingkat pengembalian investasinya.

8.2 Pengertian Return on Investment

Berikut ini adalah beberapa pengertian ROI (Return on Invesment) menurut para ahli, yaitu:

1. "ROI adalah salah satu bentuk dari rasio profitabilitas yang dimaksudkan untuk mengukur kemampuan perusahaan dengan keseluruhan dana yang ditanamkan dalam aktiva yang digunakan untuk operasinya perusahaan untuk menghasilkan keuntungan" (Munawir, 2004).
2. "ROI merupakan perbandingan laba dengan investasi yang digunakan untuk menghasilkan laba" (Mulyadi, 2001).
3. "Return On Investment adalah rasio yang menunjukkan kemampuan perusahaan untuk mendapatkan keuntungan yang digunakan untuk menutupi investasi yang dikeluarkan" (Sutrisno, 2015).

Return on Investment (ROI) atau sering disebut dengan *The Rate of Return* (ROR) merupakan persentase kenaikan atau penurunan investasi selama periode tertentu.

8.3 Kegunaan ROI

Menurut (Munawir, 2004) Return On Investment mempunyai beberapa kegunaan antara lain:

1. Rasio ROI bersifat menyeluruh artinya apabila perusahaan telah menjalankan praktek akuntansi yang baik maka manajemen dapat menggunakan teknik analisis ROI untuk mengukur efisiensi penggunaan operating asset.
2. Apabila data industri yang sejenis tersedia maka perusahaan dapat mengadakan perbandingan tingkat ROI dengan perusahaan-perusahaan lain yang sejenis.

3. Analisis ROI dapat digunakan untuk mengukur tingkat efisiensi aktivitas divisi dalam mengalokasikan semua biaya dan modalnya ke dalam divisi yang bersangkutan.
4. Mengukur profitabilitas dari masing-masing produk yang dihasilkan oleh perusahaan.
5. Selain berguna untuk keperluan kontrol, ROI juga berguna untuk keperluan perencanaan. Hal ini menjadikan ROI sebagai dasar untuk pembuatan keputusan investasi.

8.4 Faktor Yang Memengaruhi Return On Investment

Return On Investment dipengaruhi oleh beberapa faktor adalah sebagai berikut (Weston and Brigham Eugene, 1998) :

1. Penyusutan (Depreciation), ROI sangat peka terhadap kebijakan penyusutan. Bila suatu perusahaan menyusutkan aktivanya dalam waktu singkat, maka tingkat pengembalian investasinya (ROI) akan lebih rendah.
2. Nilai buku aktiva (book value of asset), duatu divisi yang umurnya relatif sudah lama dan menggunakan aktiva yang sebagian besar telah disusutkan maka biaya penyusutan dan dasar perhitungan investasinya tentu akan lebih rendah. Keadaan ini menjadikan ROI divisi tersebut akan tinggi.
3. Penetapan harga transfer (transfer price), bila harga transfer daripada suatu aktiva ditetapkan relatif tinggi maka ROI akan tinggi juga.
4. Jika waktu (time period), semakin lama jangka waktu yang dibutuhkan perusahaan dalam menghasilkan laba semakin kecil pula ROI yang dihasilkan oleh perusahaan tersebut.
5. Kondisi perusahaan (industry condition), jika suatu perusahaan beroperasi atau berada pada lingkungan sektor industri yang

menguntungkan dan tingkat pengembalian yang tinngi, maka perusahaan tersebut memiliki ROI yang tinggi.

Sedangkan menurut Munawir (2007), besarnya ROI dipengaruhi oleh dua faktor :

1. *Turnover* dari *operating assets* (tingkat perputaran aktiva yang digunakan untuk operasi) yang telah diuraikan dalam point 2.
2. *Profit Margin*, yaitu besarnya keuntungan operasi yang dinyatakan dalam prosentase dan jumlah penjualan bersih. *Profit margin* ini mengukur tingkat keuntungan yang dicapai oleh perusahaan dihubungkan dengan penjualan.

8.5 Rumus perhitungan ROI

Ada 2 rumus cara menghitung ROI

Rumus cara 1 :

$$ROI = \frac{Pengembalian\ Investasi\ Bersih}{Biaya\ Investasi} \times 100\%$$

Rumus cara 2 :

$$ROI = \frac{Nilai\ Investasi\ Akhir - Nilai\ Investasi\ Awal}{Biaya\ Investasi} \times 100\%$$

Cara menghitung *Return on Investment* dengan rumus cara ke 2 dilakukan dengan membandingan nilai investasi awal dan akhir yang relatif dengan biaya investasi. Namun cara manapun yang hendak dipakai, semuanya akan memberikan hasil yang sama.

8.6 Interpretasi Hasil Perhitungan Rumus ROI

Ketika melakukan perhitungan ROI hasil akhir bisa bernilai fositif dan nilai negative. Jika nilai perhitungan ROI positif maka hal ini mengindikasikan bahwa aktivitas investasi memiliki tingkat keuntungan yang baik. Namun, jika hasil perhitungan ROI menunjukkan nilai negative, hal ini mengindikator bahwa investasi yang dilakukan menghasilkan kerugian.

Supaya rumus ROI bisa bermanfaat dalam menghasilkan perhitungan yang akurat, maka perlu juga diperhitungkan nilai return dan biaya total secara menyeluruh. Setelah itu baru rumus annualized ROI dapat digunakan untuk melakukan perbandingan antara beberapa jenis investasi.

8.7 Kelebihan dan Kekurangan ROI

8.7.1 Kelebihan ROI

Penggunaan rumus ROI memiliki 3 kelebihan utama dalam analisis investasi dan bisnis, yaitu:

1. Memberi pengetahuan tentang komparasi beberapa jenis investasi atau bisa pula digunakan untuk mencari tahu tingkat persaingan bisnis di pasaran.
2. Memiliki efektivitas tinggi dalam mengetahui profitabilitas dari masing-masing investasi atau produk dari sebuah perusahaan.
3. Cara perhitungan ROI yang sederhana, bisa dilakukan oleh siapa saja, termasuk investor pemula.

8.7.2 Kelemahan ROI

Menurut Munawir (2004), *Return On Investment* juga mempunyai kelemahan di antaranya:

1. ROI tidak dapat digunakan sebagai dasar perbandingan antar perusahaan bila terdapat perbedaan-perbedaan dalam penerapan

kebijakan yang dilaksanakan oleh perusahaan walaupun perusahaan tersebut sejenis.

2. Adanya fluktuasi nilai dari uang, aktiva yang dibeli pada saat tingkat inflasi yang tinggi akan berbeda nilainya dengan aktiva yang dibeli pada saat tingkat inflasi rendah. Hal ini berpengaruh terhadap earning perushaan.
3. Tidak dapat digunakan untuk mengadakan perbandingan antara dua perusahan atau lebih dengan mendapatkan kesimpulan yang memuaskan.

8.8 Contoh Kasus ROI

1. Kasus Pertama

   Anda membeli sebuah rumah seharga Rp 500 Juta, Setahun kemudian rumah tersebut Anda jual dengan harga Rp 600 juta. Pada saat menjual rumah anda harus mengeluarkan biaya seperti komisi untuk agen penjualan rumah, surat-surat, dan biaya-biaya lain sebesar Rp 30 juta

   Selain itu, ketika membeli rumah, bisa jadi Anda meminjam di bank dengan bunga sebesar 20%, yang berarti Rp 100 juta ini adalah biaya investasi Anda.

   Maka cara hitung ROI investasi adalah:

   a. Pengembalian Investasi Bersih:
      = 600.000.000-500.000.000-30.000.000
      = 70.000.000
   b. Biaya Investasi yang anda keluarkan adalah Rp 100.000.000

   Maka ROI dapat dihitung dengan rumus

   Rumus cara 1

$$ROI = \frac{Pembelian\ Bersih\ atas\ Investasi}{Biaya\ Investasi} \times 100\%$$

$$ROI = \frac{70.000.000}{100.000.000} \times 100\%$$

ROI= 70%

Rumus cara 2 :

Menggunakan ilustrasi seperti pada metode 1, maka penjelasan dari komponen-komponen yang digunakan pada metode 2 adalah:

a. Nilai Investasi Awal adalah besarnya jumlah uang yang Anda investasikan di awal. Pada ilustrasi, maka Nilai Investasi Awal adalah Rp 500 juta
b. Nilai Investasi Akhir adalah harga jual dikurangi biaya yang Anda keluarkan selama penjualan.

Pada ilustrasi, Anda menjual rumah seharga Rp 600 juta sedangkan biaya yang harus dikeluarkan adalah sebesar Rp 30 juta

a. Maka Nilai Investasi Akhir adalah
   = Rp 600.000.000 – Rp 30.000.000
   = Rp 570.000.000
b. Biaya investasi yang Anda keluarkan adalah Rp 100.000.000
   Berdasarkan data di atas, maka cara menghitung ROI menggunakan metode 2 adalah sebagai berikut :

$$ROI = \frac{Nilai\ Investasi\ Akhir - Nilai\ Investasi\ Awal}{Biaya\ Investasi} \times 100\%$$

$$ROI = \frac{570.000.000 - 500.000.000}{100.000.000} \times 100\%$$

ROI= 70 %

2. Kasus ke Dua

Perusahaan A ingin membeli sebuah alat yang bisa melakukan pekerjaan yang awalnya dilakukan oleh 12 orang pekerja. Harga dari alat tersebut yaitu 250 juta rupiah, sedangkan gaji dari masing-masing pekerja yang ingin dihilangkan tersebut yaitu senilai 3,6 juta rupiah. Untuk menghitung ROI selama satu tahun, maka perhitungannya yaitu:

a. Pendapatan investasi adalah besarnya gaji yang bisa dihilangkan.
   = 12 x 3.600.000 x 12
   = Rp 518.400.000
b. Biaya investasi adalah harga beli alat, yaitu Rp250.000.000

Berdasarkan data di atas, maka cara menghitung ROI adalah sebagai berikut :

$$ROI = \frac{518.400.000 - 250.000.000}{250.000.000} \times 100\%$$

$$ROI = \frac{268.400.000}{250.000.000} \times 100\%$$

$$ROI = 107{,}36\% = 1{,}0736$$

Nilai ROI di atas melebihi 100 persen yang artinya dapat menutupi modal yang dikeluarkan terhadap alat tersebut. Hal itu berarti pembelian alat tersebut dapat dipertimbangkan. Sebab, menurut perhitungan ROI, alat tersebut bisa memberikan keuntungan.

3. Kasus ke Tiga

   Perusahaan B melakukan investasi dengan nilai 200 juta rupiah kepada usaha penjualan alat musik. Keuntungan dari penjualan tersebut adalah 280 juta. Dengan demikian perhitungan ROI adalah sebagai berikut:

$$ROI = \frac{280.000.000 - 200.000.000}{200.000.000} \times 100\%$$

$$ROI = \frac{80.000.000}{200.000.000} \times 100\%$$

$$ROI = 40\% = 0{,}4$$

4. Kasus ke Empat

   Perusahaan C mengeluarkan dana senilai 5 juta rupiah untuk mengiklankan produknya. Dari iklan itu, ada banyak respon positif dan 150 di antaranya tertarik untuk membelinya. Perusahaan ini pun mendapatkan hasil penjualan senilai 8 juta rupiah. Disini dapat kita ketahui bahwa pendapatan investasi senilai 8 juta rupiah dan biaya investasinya senilai 5 juta rupiah:

   Jika dimasukkan ke dalam rumus, maka:

$$ROI = \frac{8.000.000 - 5.000.000}{5.000.000} \times 100\%$$

$$ROI = \frac{3.000.000}{5.000.000} \times 100\%$$

$$ROI = 60\% = 0.6$$

Bab 9

Komplikasi Masalah-Masalah Nyata

9.1. Pendahuluan

Depresiasi: Penyusutan atau pengurangan nilai suatu investasi nilai pasar atau nilai terhadap pemilik Depresiasi dapat dibedakan menjadai beberapa sebab sebagai berikut: Penyusutan fisik (deterioration): Penyusutan yang disebabkan oleh berkurangnya kemampuan fisik (performance) dari suatu aset untuk menghasilkan produksi karena kemerosotan dan keausan mengakibatkan cost operasional dan maintenance meningkat, sedangkan kemampuan produksi semakin menurun. Penyusutan Fungsional (Obsolescence): Penyusutan dan penurunan karena kekunoan/using atau tidak up to date lagi. Bentuk ini lebih sulit ditentukan, karena penurunan nilai disebabkan berkurangnya permintaan dan peminat, tugas atau fungsinya sebagaimana rencana semula. Pengurangan ini bisa disebabkan antara lain: pergantian mode, pusat-pusat kependudukan berpindah pindah, munculnya mesin atau alat yang lebih efisien dan mudah dioperasikan, pasar sudah mulai jenuh, atau sebaliknya dengan meningkatnya permintaan produk perlu mengganti mesin dengan kapasitas yang lebih besar karena mesin lama dianggap tidak cukup lagi (inadequate) (Blank and Tarquin, 2012).

Depresiasi penyusutan atau penurunan nilai asset bersamaan dengan berlalunya waktu aset yang terkena depresiasi hanya fixed asset (asset tetap) yang pada umumnya bersifat fisik misalnya bangunan, mesin/peralatan, armada dan lain sebagainya.

Arti yang lebih umum depresiasi merupakan penyusutan nilai dari suatu fasilitas (mesin, kendaraan, peralatan, perabotan, bangunan dan lain sebagainya) diakibatkan lama waktu dan tingkat pemakaiannya.

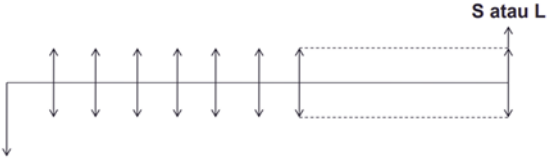
Depresiasi pada suatu fasilitas biasanya disebabkan karena satu atau lebih faktor-faktor:

1. kerusakan fisik akibat pemakaian dari alat/fasilitas tersebut
2. kebutuhan produksi atau jasa yang lebih baru
3. penurunan kebutuhan produksi atau jasa
4. fasilitas yang menjadi usang karena adanya perkembangan teknologi
5. penemuan fasilitas-fasilitas yang biasa menghasilkan produk yang lebih baik dengan ongkos yang lebih rendah dan tingkat keselamatan yang lebih baik

Ada 3 aspek yang menyebabkan timbulnya depresiasi yaitu:

1. Deteoriasi (penyusutan fisik)
2. Obsolescence (penyusutan fungsional)
3. Moneter (penyusutan nilai uang)

Depresiasi memengaruhi fixed asset gambar 9.1



Gambar 9.1: Depresiasi metode SL (garis Lurus)

Besarnya depresiasi tahunan yang dikenakan pada suatu fasilitas akan tergantung pada beberapa hal, yaitu:

1. cost investasi dari fasilitas tersebut
2. waktu pemakaian awalnya

3. hitungan masa pakainya
4. nilai sisa yang ditetapkan
5. sistem atau metode depresiasi yang digunakan

Tidak semua jenis fasilitas dapat didepresiasikan. Beberapa syarat yang harus dipenuhi agar suatu fasilitas dapat didepresiasikan, antara lain:

1. -Harus digunakan untuk keperluan bisnis atau memperoleh penghasilan
2. -Umur ekonomisnya bisa dihitung dan lebih dari satu tahun
3. -Harus merupakan sesuatu yang digunakan, sesuatu yang menjadi usang atau sesuatu yang nilainya menurun.

Ada sebuah perusahaan PT. Parpagalote membeli alat transportasi dengan harga Rp.39.000.000,-. Usia pakai ekonomis dari alat tersebut adalah 6 tahun dengan perkiraan nilai sisa sebesar Rp. 3.000.000/-Pakai metode depresiasi garis lurus (SL) untuk menghitung:

1. Besarnya depresiasi tiap tahun
2. Nilai buku alat tersebut pada akhir tahun kedua dan akhir tahun kelima
3. Buat tabel depresiasi dan nilai buku selama masa

Beberapa metode depresiasi yang umum dikenal dan biasa digunakan adalah sebagai berikut:

1. Metode Straight Line (SL)
   Metode depresiasi SL didasarkan atas asumsi bahwa berkurangnya nilai suatu fasilitas secara linier terhadap waktu atau umur dari fasilitas tersebut.
   Besarnya depresiasi tiap tahun dengan metode SL dihitung berdasarkan:

$$D_t = \frac{P - S}{N} \qquad (9.1)$$

di mana:
Dt = besarnya depresiasi pada tahun ke-t
P = ongkos awal dari fasilitas yang bersangkutan
S = nilai sisa dari fasilitas tersebut
N = masa (umur) pakai
Karena fasilitas didepresiasikan dengan jumlah yang sama tiap tahun maka fasilitas tersebut dikurangi dengan besarnya depresiasi tahunan dikalikan t

$$\mathbf{BVt = P - t\ Dt} \qquad (9.2)$$

Contoh perhitungan straight line (SL)

PT. Laju Utama mengadakan membeli berupa alat transportasi dengan seharga Rp.39.000.000,-. Umur pakai ekonomis dari alat tersebut adalah 6 tahun dengan perkiraan nilai sisa sebesar Rp. 3.000.000,-. Pakai metode depresiasi garis luurus (SL) untuk menghitung

a. Besarnya depresiasi per tahun
b. Nilai buku alat tersebut diakhir tahun kedua dan diakhir tahun kelima
c. Sajikan tabel depresiasi dan nilai buku selama masa pakainya

Penyelesaian:
Untuk menghitung besarnya depresiasi tiap tahun kita pakai rumus:

$$D_t = \frac{P - S}{N}$$

$$D_t = \frac{39 - 3}{6} = 6$$

Jadi besarnya depresiasi per tahun adalah Rp.6.000.000,-
Untuk menghitung nilai buku pada akhir tahun kedua adalah: BVt = P – t Dt
BV2 = Rp.39.000.000,-– 2 x Rp.6.000.000,-= Rp.27.000.000,-Untuk estimasi waktu di tahun ke lima adalah: BV5 = Rp.39.000.000,-– 5 x Rp.6.000.000,-= Rp.9.000.000,-

Tabel Depresiasi:

Posisi di Akhir tahun	Depresiasi setiap tahunnya	Nilai buku
0	0	39 juta
1	6 juta	33 juta
2	6 juta	27 juta
3	6 juta	21 juta
4	6 juta	15 juta
5	6 juta	9 juta
6	6 juta	3 juta dan seterusnya

2. Metode sum of years digit (SOYD)

SOYD merupakan metode yang dirancang untuk membebankan depresiasi lebih besar pada tahun-tahun awal dan semakin kecil untuk tahun-tahun berikutnya

Metode SOYD membebankan depresiasi lebih cepat dari metode dengan SL

Besarnya depresiasi tiap tahun dengan metode SOYD dihitung berdasarkan:

$$D_t = \frac{\text{sisa umur fasilitas}}{SOYD}(ongkos \text{ awal} - \text{nilai sisa})$$

$$\mathrm{D}_t = \frac{N - t + 1}{SOYD}(P - S);\ (\mathrm{t} = 1,2,...\mathrm{N}) \qquad (9.3)$$

di mana:

Dt = besarnya depresiasi pada tahun ke-t

SOYD = jumlah digit tahun dari 1 sampai N

Besarnya SOYD dari suatu fasilitas yang umurnya N tahun adalah:

SOYD = 1 + 2 + 3 +….+ (N-1) + N = N (N+1)/2

Besarnya nilai buku pada suatu saat dapat diperoleh tanpa harus menghitung depresiasi pada tahun-tahun sebelumnya

$$BV_t = P - \frac{t(N - t/2 + 0.5)}{SOYD}(P - S)$$

Contoh perhitungan SOYD

Pakai data-data dari Green road, untuk menentukan dan menghitung besarnya depresiasi SOYD serta nilai buku tiap tahun

Penyelesaian:

Jumlah digit tahun = 1+2+3+4+5+6 = 21

$$\begin{bmatrix} D_1 = \frac{6-1+1}{21} = (39-3) = \frac{6}{21}(36\,juta) = Rp.10{,}286\,juta \\ D_3 = \frac{6-3+1}{21} = (39-3) = \frac{4}{21}(36\,juta) = Rp.6{,}857\,juta \end{bmatrix}$$

Maka besarnya depresiasi pada jumlah digit 6 tahun sebesar Rp. 10.286.000,-dan untuk 4 tahun sebesar Rp.6.857.000.,-

Tabel Depresiasi.

Akhir tahun	Depresiasi/thn	Nilai buku
0	0	39,000 juta
1	6/21 x 36 jt = 10,286 jt	28,714 juta
2	5/21 x 36 jt = 8,571 jt	20,143 juta
3	4/21 x 36 jt = 6,857 jt	13,286 juta
4	3/21 x 36 jt = 5,143 jt	8,143 juta
5	2/21 x 36 jt = 3,429 jt	4,714 juta
6	1/21 x 36 jt = 1,714 jt	3,000 juta

9.2 Tujuan Depresiasi Aset

Secara umum ada beberapa alasan perlu dilaksanakan perhitungan depresiasi ini, yaitu:. Untuk menyediakan dana pengembalian modal yang telah diinvestasikan dalam kekayaan fisik, dana ini sifatnya sebagai saving untuk menjamin kontinuitas/keberlanjutan usaha bila mesin habis masa pakainya (berakhir life time) dan segera perlu diganti dengan barang dan jenis yang baru. Secara teoritis dana depresiasi yang telah disimpan sebelumnya (disediakan) dapat dialokasikan serta dibayarkan untuk pembelian mesin yang baru. Untuk memungkinkan adanya biaya penyusutan yang dibebankan pada biaya produksi atau jasa yang dihasilkan dari penggunaan asetaset di mana itu adalah sebagai dasar pengurangan pembayaran pajak-pajak pendapat atau usaha yang harus dibayarkan (Joyowiyono, 1992).

1. *Straight Line* (SLD)/Depresiasi Garis Lurus Metode SLD ini adalah metode yang paling sederhana dan yang paling sering dijumpai dan dipakai dalam perhitungan depresiasi aset, karena metode ini relatif sederhana. Metode ini pada dasarnya memberikan hasil perhitungan depresiasi yang sama setiap tahun selama umur perhitungan aset. Maka setiap nilai nuku aset setiap akhir tahun jika dibuatkan grafik akan membentuk garis lurus.
2. *Straight Line* (SLD)/Depresiasi Garis Lurus SLD = (I S) N Di mana: SLD: Jumlah depresiasi per tahun I: Investasi (nilai aset awal) n: Lamanya aset akan didepresiasi S: Nilai sisa aset akhir umur produktif Jumlah aset yang telah didepresiasi selama t tahun adalah: Dep t = t (I S) N Nilai buku (book value) tiap akhir t tahun depresiasi adalah:
   BV t = I Dep t = I t (I S) N
3. *Straight Line* (SLD)/Depresiasi Garis Lurus CONTOH:
   PT. Gopastrans perusahaan angkutan mempunyai beberapa buah truk dengan harga Rp80.000.000,-/buah. Berdasarkan pengalaman truk-truk yang sama mempunyai umur produktif selama tahun dan setelah itu truk dapat dijual seharga 60.000.000,-.
   Hitunglah besarnya depresiasi yang harus dikeluarkan per tahun, jumlah besar depresiasi selama 3 tahun serta nilai buku pada akhir tahun 3 tersebut jika metode depresiasi menggunakan SLD. Penyelesaian:
   Depresiasi per tahunan adalah: SLD = (I S) N SLD = (80 60) SLD = Rp 4 juta pertahun
   Straight Line (SLD)/Depresiasi Garis Lurus Penyelesaian:
   Jumlah Depresiasi yang dibayarkan selama 3 tahun adalah: σ Dep t = t (I S) N σ Dep 3 = 3 (80 60) σ Dep 3 = Rp 7 juta Nilai buku pada tahun ketiga adalah: BV = I-Dep BV 3 = 80-7 BV 3 = Rp 08 juta Tahun ke-Nilai Buku Depresiasi/N(I-S) Dep t
4. *Sum of Year Digits* (SOYD) Metode ini memiliki pola pembayaran depresiasi yang tidak sama setiap tahunnya, Yaitu didasarkan pada besar bobot digit dari tahun pemakaian Di tahun-tahun awal

depresiasi yang dikeluarkan lebih besar dari tahun berikutnya, di mana penurunannya merupakan fungsi dari berkurangnya umur aset tersebut. Penggunaan depresiasi ini biasanya dikenakan pada aset yang mempunyai pola perilaku keuntungan yang besar pada awal investasi dan mengecil sesuai dengan perjalanan umur investasi Metode ini sering juga digunakan dalam rangka mengantisipasi/pengamanan *cash flow* masa depan yang berisiko tinggi, sehingga kemungkinan terjadinya biaya pengembalian modal dapat dikurangi.

Rumus: SOYD t = Umur sisa aset *Sum of Year Digits* (I S)

Di mana: SOYD t = Depresiasi SOYD periode ke t Umur sisa aset = n, yaitu umur aset jumlah periode depresiasi yang telah dibayarkan *Sum of Year Digits* = σ digit = N (N +)

Maka SOYD t = N t SOYD t = σ digit n σ digit (I S) (I S).

Sum of Year Digits (SOYD) CONTOH:

Suatu *asset* dengan nilai investasi Rp 0 juta, umur 7 tahun nilai sisa 0 juta rupiah akan dihitung besarnya depresiasi/tahunan, dan nilai buku setiap tahunnya.

Penyelesaian:

Sum of Year Digits (SOYD) Investasi (I) = Rp 0 juta Nilai Sisa (S) = Rp 0 juta Umur Aset = 7 tahun σ digit = N (N +) σ digit = 7 (7 +) σ digit = 8 Angka 8 juga dapat diperoleh dari = 8 SOYD t = N t t= SOYD t = t= SOYD t = t=3 SOYD t = t=4 SOYD t = t= SOYD t = (I S) σ digit = 7 8 (00)= 0 0 = 6 8 (00)=,4 0 0 = 8 (00)=7, = 4 8 (00)=4, = 3 8 (00)=0,7

Penyelesaian: t=6 SOYD t = t=7 SOYD t = = 8 (00)=7,4 0 0 = 8 (00)=3,7. *Sum of Year Digits* (SOYD) Dapat pula dibuat tabel seperti berikut: N SOYD Dep BV,43 7,86 4,9 0,7 7,4 3,7-46,43 64,9 78,8 89,9 96,,7,7 4,4 30,7 3,7 0

Declining Balance (DBD) Metode ini memiliki asumsi bahwa nilai aset menurun lebih cepat pada tahun-tahun awal daripada tahun-tahun akhir dari usia gunanya. Perlu diingat dalam metode ini adalah nilai jual (nilai sisa) harus

lebih besar daripada nol. Depresiasi dihitung berdasarkan laju/tingkat penyusutan tetap (R) yang dikalikan dengan nilai aset tahun sebelumnya.

Contohnya: jika harga awal aset 00 juta rupiah dikenakan laju depresiasi 0%, maka besarnya depresiasi tahun pertama adalah 0% x Rp00 juta= Rp 0 juta; depresiasi tahun kedua adalah 0%x (Rp00 juta Rp 0 juta)= Rp 9 jut a; tahun ketiga 0%x(Rp90 juta-Rp 9 juta) = Rp 8, juta, dan seterusnya.

Secara matematis perhitungan DBD adalah sebagai berikut: DBD t =RxBV t-;

di mana: DBD t = depresiasi tahun ke-t BV t-= nilai buku tahun ke-t R = tingkat/laju depresiasi tahunan Jika BV t-0 = I atau harga aset awal, maka DBD =RxI

Jika BV t-0 = I atau harga aset awal, maka DBD =RxI 3.

Declining Balance (DBD) DBD = R x BV BV = I R x I = (I-R)I BV = BV R x BV = (I-R) I Maka BV t = (-R) t I Jika BV t = BV t-DBD t Maka BV t = BV t-R x BV = (-R)BV t-Jika BV 0 = DBD t BV n Maka R = S I = R(-R) t-x I = S n

Contoh Kasus: Suatu asset dengan nilai investasi Rp 0 juta, umur 7 tahun nilai sisa 0 juta rupiah akan dihitung besarnya depresiasi/tahunan, dan nilai buku setiap tahunnya. 3.

Declining Balance (DBD) Penyelesaian: R = S n = 0 I Periode (t) =0, =,% R = S I-, %, %, %, %, %, %, % n DBD t BV t-, %(0), %(9,9), %(7,9), %(,7), %(43,), %(33,4), %(,8) 0 9, 9 7, 9,7 43, 33, 4,8 0,0

Declining Balance (DBD)

Double Declining Balance (DDBD) Jika metode depresiasi DBD digunakan untuk tujuan-tujuan perhitungan pembayaran pajak, tingkatan penyusutan maksimum yang dibenarkan dua kali tingkat penyusutan metode garis lurus (SLD) Jadi untuk suatu aset dengan usia pemakaian diperkirakan n tahun, maka tingkat penyusutan maksimum yang diizinkan adalah (I/n). Metode penyusutan/depresiasi semacam ini dinamakan *Double Declining Balance* (DDBD) Dimungkinkan tingkat penyusutan sebesar, atau, kali lipat penyusutan garis lurus (Tim Dosen Ekonomi Teknik, 2009).

Double Declining Balance merukapan kelipatan 00% x SLD Di mana: SLD = N (I S), jika I-S = Book value t-Maka SLD t = N (Book Value t) DDBD = 00% x SLD t = 00% x N (Book Value t) Maka DDBD t = N (Book Value t)

Double Declining Balance (DDBD) Pada saat t=0, nilai buku (BV) = Investasi (I), maka: t= DDBD = N I = I N t= DDBD = N N t=3 DDBD 3 = N I n ⊕ I N N N = I N 0 N N = I N N + N I = Φ N Dari persamaan di atas jika dilanjutkan ningga t ke n akan diperoleh DDBD tahun ke-n sebagai berikut: DDBD n = I N N n Total depresiasi DDBD pada tahun ke-n adalah: σ DDBD n = I N N N N n+ ⊂.. () N + N Dikalikan dengan N

σ DDBD N.. () = I N N + N + N N n 4. *Double Declining Balance* (DDBD) Jika persamaan () () akan diperoleh sebagai berikut: σ DDBD N = I N + N n DDBD n = Nilai buku (Book Value) pada tahun ke-n adalah: BV = Investasi-DDBD t BV n =I-I N n n BV n =I N

Catatan: areana DBDx00% = DDBD mempunyai indeks/N dan DBD sendiri dengan indeks/N, maka untuk DBD 0% indeks/N cukup diganti dengan,/n. Formula ini berlaku pula untuk faktor pengali yang lain

Contoh kasus:

Suatu asset dengan nilai investasi Rp 0 juta, umur 7 tahun nilai sisa 0 juta rupiah akan dihitung besarnya depresiasi/tahunan, dan nilai buku setiap tahunnya. 4. Double Declining Balance (DDBD) Penyelesaian: Investasi (I) = Rp 0 juta Nilai Sisa (S) = Rp 0 juta Umur Aset = 7 tahun n DDBD n = I N N t = DDBD = (0) 7 t = DDBD = (0) 7 t = 3 DDBD 3 = (0) 7 t = 4 DDBD 4 = (0) = 7 40 = = = 7 0,743 0 =34,86 0,743 =4,490 0,743 =7,493 0,743 3 =,496

Double Declining Balance (DDBD) n DDBD n = I N N t = DDBD = (0) 7 t = 6 DDBD 6 = (0) 7 t = 7 DDBD 7 = (0) 7 Nilai buku akhir periode: BV n =I N n BV 7 =0 7 BV 7 =, =0(0,0949) = = = 7 0,743 4 =8,96 0,743 =6,376 0,743 6 =4,4

Double Declining Balance (DDBD)

DDBD *to Convertion* SLD Salah satu persoalan metode DDBD adalah nilai buku pada periode akhir tidak selalu sama dengan nilai sisa. Terdapat beberapa kemungkinan dari nilai buku akhir periode dibandingkan nilai sisa, yaitu:

Book value t=n > Nilai Sisa *Book value* t=n = Nilai Sisa *Book value* t=n < Nilai Sisa Jika BV n > S akan menimbulkan masalah dalam menetapkan nilai aset dari perusahaan, karena akan memunculkan biaya semu (sunk cost), untuk itu perlu dihindarkan (F. Karamah, 2021).

Ada dua metode yang dapat dilakukan: Melanjutkan perhitungan depresiasi sampai ditemukan nilai sisa. Mengaplikasikan metode DDBD dengan SLD

Metode nomor tidak selalu dapat dilakukan, terutama jika umur aset tidak mungkin lagi ditambah atau aset betul-betul tidak produktid lagi Metode kedua, yaitu menggabungkan metode DDBD dengan SLD yang disebut Metode DDBD *to Convertion* SLD. DDBD *to Convertion* SLD Grafik Hubungan nilai buku dengan nilai sisa

DDBD *to Convertion* SLD Masalahnya adalah kapan DDBD dikonversikan pada SLD, apakah pada titik A, B, atau C.??? Maka dilakukan beberapa pendekatan:

DDBD *to Convertion* SLD

1. Metode pemakaian tabel Diberikan dalam tabel di samping, di mana kolom tahun awal penggunaan SLD dipandu dengan nilai rasio antara nilai sisa dengan investasi. Jika angka rasio yang diperoleh 0 s.d < 0,0 dipakai kolom. Jika rasionya 0,0 s.d <0,0 dipakai kolom 3. Jika rasionya 0,0 s.d. < 0, dipakai kolom 4. Sedangkan jika rasionya 0, dipakai kolom. Kolom ke-menyatakan umur investasi/aset yang akan didepresiasikan, maka nilai sel yang berada antara hasil rasio dengan umur aset menyatakan tahun awal penggantian metode DDBD ke SLD. Tahun awal Penggunaan SLD (n) N (Umur S/I 0-S/I 0,0-S/I 0,0-Aset) S/I 0, <0,0 <0,0 <0,

   Contoh kasus:

   Suatu aset bernilai Rp.900.000.000 mempunyai umur depresiasi tahun dengan nilai sisa ditargetkan 30 juta rupiah. Hitung dan tentukan besarnya depresiasi dengan menggunakan metode DDBD *to Convertion* SLD. DDBD to Convertion SLD Penyelesaian: Investasi (I) = Rp 900 juta Umur = tahun Nilai Sisa = Rp 30 juta, Maka rasio S/I = 30/900 = 0,033 jadi rasionya berada pada kolom ke-Didapat dari tabel bahwa tahun peragantian metode (n) = 4, artinya metode berubah dari DDBD ke SLD pada tahun ke-4. DDBD *to Convertion* SLD t= DDBD = (900) t= DDBD = (900) t=3 DDBD 3 = (900) = = = Nilai buku pada akhir periode ke-3 adalah: BV n =I N n 0,60 0 =360 0,60 =6 0,60 =30 BV 3 =900 BV 3 = 94 3 =900(0,6)

   DDBD *to Convertion* SLD SLD untuk tahun sisa (tahun ke-4 dan ke-) SLD t = (BV N n t S) SLD 4 = (94 30) 4 SLD 4 = (64) = 8 Dengan

demikian, jadwal lengkap depresiasi aset adalah: Tahun ke-Depresiasi BV Keterangan DDBD DDBD DDBD SLD SLD

2. Metode Perhitungan Langsung Metode perhitungan langsung, di mana masing-maisng metode menghitung depresiasi tiap tahunnya, depresiasi yang terbesar untuk tahun yang sama dipakai sebagai pilihan. Hanya saja dalam perhitungan SLD tidak memakai rumus/N(I-S), tetapi rumus yang dipakai adalah: SLD t = (BV N n t S) Di mana: N-(n-) = umur aset tersisa = nilai buku periode tahun sebelumnya dari metode DDBD BV t-Langkah perhitungan adalah sebagai berikut.

   Hitung depresiasi dengan metode SLD dan DDBD secara bersamaan. Bandingkan nilai SLD dan DDBD untuk masing-maisng tahun yang sama 3. Saat nilai SLD DDBD, maka konversi dilakukan

   Contoh kasus: Suatu aset bernilai Rp.900.000.000,.-mempunyai umur depresiasi tahun dengan nilai sisa ditargetkan 30 juta rupiah.

   Hitung serta tentukan besarnya depresiasi dengan menggunakan metode DDBD *to Convertion* SLD. DDBD to Convertion SLD Penyelesaian: Investasi (I) = Rp 900.000.000,.-Umur = tahun Nilai Sisa = Rp 30.000.000,.0-

   DDBD *to Convertion* 3 SLD 4 t SLD t = N n (BV t S) DDBD n = I N N n BV n = N (900 30)=74 (900) (40 30)=7, (900) 3 (34 30)=98 (900) 4 (94 30)=8 (900) 4 n Keterangan = DDBD =6 34 DDBD 3 =30 94 DDBD 4 =78 SLD (94 30)=8 30 SLD

Unit of Production beberapa jenis aset tidak begitu terpengaruh oleh variabel waktu, tetapi lebih banyak ditentukan oleh produktivitas kerjanya, seperti pesawat terbang, mesin-mesin tertentu yang sangat terpengaruh oleh aktivitas produksinya, dan berbagai aset dalam bentuk deposit alam Aset-aset tersebut depresiasinya dihitung tidak selalu merupakan fungsi waktu, tetapi berdasarkan fungsi produksinya Misalnya, umur pesawat terbang tersebut tidak dihitung berdasarkan indikator tahun berapa dia dibuat, atau seberapa tahun dia telah dioperasikan, tetapi sudah berapa lama jam terbangnya, begitu juga untuk nilai sisa deposit yang terkandung dalam perut bumi setelah dieksploitasi tidak ditentukan berapa lama dieksploitasi, tetapi sebaliknya,

sudah berapa banyak deposit tersbut diambil dan seberapa banyak yang masih tersisa.

Rumus Umum:

Di mana: Produksi Produksi UPD t = Produksi t σ n (I S) Produksi = jumlah produksi pada tahun dimaksud = jumlah produksi keseluruhan (sesuai estimasi)

Contoh:

Suatu mesin ekskavator yang dibeli dengan harga Rp 700.000.000,-dipakai untuk menambang pasir/kerikil. Berdasarkan spesifikasinya ekskavator tersebut mampu menambang pasir sebanyak 0.000m 3 dan setelah itu masih mempunyai nilai sisa 0 juta rupiah. Jika jadwal kerja penambangan seperti data di bawah, hitunglah depresiasi tahunan ekskavator tersebut. Tahun Kebutuhan Pasir/Kerikil 4.000m m m m 3.000m 3.000m m 3

Unit of Production Penyelesaian: UPD t = Produksi t σ n (I S) t Produksi t= UPD = 4.000m m3 (Rp 700 Rp 0) = Rp 44 juta t= UPD = 6.000m m3 (Rp 700 Rp 0) = Rp 66 juta t=3 UPD 3 = 0.000m m3 (Rp 700 Rp 0) = Rp 0 juta t=4 UPD 4 = 0.000m m3 (Rp 700 Rp 0) = Rp 0 juta t= UPD =.000m m3 (Rp 700 Rp 0) = Rp 6 juta t=6 UPD =.000m m3 (Rp 700 Rp 0) = Rp juta

Penyelesaian:

Jadi jadwal pembayaran depresiasi adalah: 6. *Unit of Production* Tahun Skedul Produksi Depresiasi m m m m 3.000m 3.000m m 3 Rp 44 juta Rp 66 juta Rp 0 juta Rp 0 juta Rp 6 juta Rp juta Rp juta

9.3 Pajak

Pajak Pendapatan Pemerintah ingin meningkatkan pendapatan dan meningkatkan kesejahteraan secara menyeluruh. Perusahaan mencoba untuk membayar pajak sesedikit mungkin dan selambat mungkin. Pajak selalu menjadi masalah bagi perusahaan, tetapi terkadang pajak diabaikan ketika membuat keputusan: misalnya ketika memilih satu kemungkinan terbaik dari dua proyek. Titik berat pada pajak pendapatan (bukan pajak properti atau pajak penjualan) Langkah dasar dalam menghitung pajak pendapatan adalah: 1. Tentukan pendapatan yang kena pajak (termasuk pemasukan, pengeluaran,

potongan depresiasi) 2. Hitung pajak dengan menggunakan tingkat pajak marginal 3. Mengurangi pajak terhutang dengan beberapa kredit (misalnya kredit pajak investasi) (Tim Dosen Ekonomi Teknik, 2009).

Struktur Pajak Pendapatan Perusahaan Negara (USA, 1996)

Tabel 9.1: Tingkat pajak perusahaan

Pendapatan Kena Pajak	Tingkat Pajak	Formulasi
$0 - $50K	15%	$0.15X
50K – 75K	25%	7.5 K + 0.25(X – 50 K)
75K – 100K	34%	13.75 K + 0.34(X – 75 K)
100K – 335K	34% + 5%	22.25 K + 0.39(X – 100 K)
335K – 10M	34%	113.9 K + 0.34(X – 335 K)
10M – 15M	35%	3.4 M + 0.35(X – 10 M)
15M – 18.33M	35% + 3%	5.15 M + 0.38(X – 15 M)
18.33M -	35%	6.42 M + 0.35(X – 18.33 M)

Contoh kasus: Perhitungan tingkat pajak perusahaan – 1

Perusahaan dengan pendapatan kena pajak sebesar $80,000 harus membayar pajak sebesar:

$50,000* 0.15 + 25,000* 0.25 + 5,000* 0.34 = $15,450

Atau $13,750 +0.34 (80,000 – 75,000) = $15,450

Tingkat pajak marginal sebesar 34%

Tingkat pajak rata-rata sebesar (15.45K/80K) * 100% = 19.31%

Contoh kasus: Perhitungan tingkat pajak perusahaan – 2

Perusahaan dengan pendapatan kena pajak sebesar $400,000 harus

membayar pajak sebesar: $113,900 + 0.34 (400,000 – 335,000) = $136,000

Tingkat pajak marginal adalah 34%. Tingkat pajak rata-rata sebesar (136K/400K) * 100% = 34%

Arus Kas Sebelum dan Sesudah Pajak

Arus Kas Sebelum Pajak = Pendapatan Kotor – Biaya Operasi (9.4)

Pendapatan Kena Pajak = Arus Kas Sebelum Pajak – Pemotongan –barang tidak kena pajak .(9.5)

Pajak = Pendapatan Kena Pajak * Tingkat Pajak – Kredit Pajak (9.6)

Arus Kas Sesudah Pajak = Arus Kas Sebelum Pajak – Pajak (9.7)

di mana

Biaya Operasi: tenaga kerja, material, suplai bahan bakar, sewa, biaya bunga, asuransi

Pemotongan: pajak negara, pajak properti, depresiasiBarang-b arang tidak kena pajak: jumlah pinjaman (pokok), nilai buku dar i properti yang dijual.

Pajak Pendapatan Negara Dikurangkan dari Pendapatan Kena Pajak Daerah:

Misalkan s = tingkat pajak pendapatan marginal negara f = tingkat pajak pendapatan marginal daerah

Pajak Pendapatan Negara = Pendapatan Kena Pajak * s (9.8)

Pajak Pendapatan Daerah = Pendapatan Kena Pajak * (1 – s) * f (9.9)

atau

C.F.A.T = C.F.B.T – T.I *s – T.I (1 – s)* f = C.F.B.T. – T.I * (f + s – fs) (13.7)

di mana, (f + s – fs) disebut tingkat pajak efektif

Catatan:

C.F.A.T = *Cash Flow After Tax*, Arus Kas Sesudah Pajak

C.F.B.T = *Cash Flow Before Tax*, Arus Kas Sebelum Pajak

T.I. = *Taxable Income*, Pendapatan Kena Pajak

Contoh kasus: Pembiayaan Rumah

Anda membeli sebuah rumah seharga $200,000 dengan uang muka sebesar $20,000. Anda harus mengambil hipotik dari bank untuk sisa $180,000. Seorang bankir menawarkan hipotik dengan tingkat bunga 12.5% pertahun dan dibayarkan tahunan selama 30 tahun. Tingkat pajak efektif adalah 35%. Berapakah tingkat bunga yang dipengaruhi pajak untuk dua tahun pertama ?

Perhitungan Sebelum Pajak

Pembayaran tahunan seragam =-$180,000 (A/P, 0.125, 30) =-$23,177

Tabel 9.2: Perhitungan Pinjaman atau Hutang Serta Pembayarannya

Tahun	Biaya Bunga	Hutang Sebelum Pembayaran	Pembayaran	Hutang Setelah Pembayaran
0				$180,000
1	$22,500	$ 202, 500	-$23,177	$179,323
2	$22,415	$201,739	-$23,177	$178,562
3	$22,320	$200,882	-$23,177	$177,705
	. . .	. . .	. . .	. . .
30	$2,575	$23,177	-$23,177	$0

Bunga hipotik dikurangi/dipotong dari pendapatan kena pajak untuk perorangan. Bunga lainnya tidak dapat dikurangi. Pembayaran bunga oleh perusahaan atas pinjaman dan atas saham adalah pengurang pajak (tax deductible).

Kondisi pada Tahun pertama:

Hutang pokok yang dibayarkan = $23,177-$22,500 = $677

Bunga yang dibayarkan = $22,500

Penghematan pajak = 0.35 * 22,500 =-$7,875 (pengurangan/potongan)

Bunga bersih = $22,500-$7,875 = $14,625

Tingkat bunga yang dipengaruhi pajak untuk tahun 1:

= $14,625/$180,000 = 8.125%

Perhatikan bahwa 8.125% = 12.5% (1 – 0.35)

Kondisi pada Tahun kedua:

Hutang pokok yang dibayarkan = $23,177-$22,415 = $762

Bunga yang dibayarkan = $22,415

Penghematan pajak = 0.35 * 22,415 =-$7,845 (pengurangan/potongan)

Bunga bersih = $22,415-$7,845 = $14,570

Tingkat bunga yang dipengaruhi pajak untuk tahun 1:

= $14,570/$179,323 = 8.125%

Arus kas sesudah pajak:

Tahun 1:-$677 – 0.65($22,500) =-$15,302

Tahun 2:-$762 – 0.65($22,415) =-$15,332

Contoh Kasus: Depresiasi dan Pajak

Ada 2 proyek, A dan B. di mana keduanya membutuhkan biaya awal $120,000 untuk mengadakan peralatan dan peralatan tersebut mendatangkan manfaat tahunan sebesar $20,000 untuk kedua proyek.

Kedua peralatan tersebut mempunyai umur 10 tahun, tetapi A mempunyai nilai sisa $0 dan B nilai sisanya $60,000. Proyek mana yang harus dipilih dengan tingkat bunga 10%? Asumsikan depresiasi garis lurus, biaya peminjaman diabaikan (untuk penyederhanaan) dan tingkat bunga efektif 40%.

Tabel 9.3: Perhitungan arus kas proyek A

Tahun	BTCF	Depresiasi	Pendapatan kena pajak	Pajak	ATCF
0	-120,000				-120,000
1	20,000	12,000	8,000	3,200	16,800
2	20,000	12,000	8,000	3,200	16,800
	....	....	....	....	....
10	20,000	12,000	8,000	3,200	16,800
				PW =	-$16,771

Tabel 9.4: Perhitungan arus kas proyek B

Tahun	BTCF	Depresiasi	Pendapatan kena pajak	Pajak	ATCF
0	-120,000				-120,000
1	20,000	6,000	14,000	5,600	14,400
2	20,000	6,000	14,000	5,600	14,400
	....	....	....	....	....
10	20,000	6,000	14,000	5,600	14,400
				PW =	-$8,386

Catatan:

BTCF = *Before Tax Cash Flow*, arus kas sebelum pajak

ATCF = *After Tax Cash Flow*, arus kas sesudah paja

Contoh: Pembiayaan Peralatan (Putro, 2012)

Sebuah mesin dibeli dengan modal investasi pinjaman. Pembelian mesin tersebut akan mengurangi biaya tenaga kerja. Biaya awal mesin tersebut adalah $67,000, di mana $47,000 dibayar tunai dan $20,000 dengan uang pinjaman dengan tingkat bunga 9%. Pinjaman tersebut mensyaratkan pembayaran utang pokok pada akhir tahun ke-5, dengan bunga dibayar setiap tahun. Pembelian mesin ini memberikan kredit pajak investasi. Diperkirakan mesin tersebut mempunyai umur manfaat 5 tahun dan nilai sisa $22,000. Depresiasi menggunakan metode garis lurus. Dengan mesin tersebut, akan terjadi penghematan sebesar $23,000 per tahun. Tingkat pajak efektif marginal adalah 40%. Pada tahun ke-5, mesin tersebut dijual dengan harga $20,000. Kredit pajak investasi (ITC) adalah sebesar 3%-10% dari biaya awal investasi yang dikurangkan terhadap pajak pendapatan yang harus dibayarkan. Kredit (pengurangan) dikurangkan dari pajak, bukan dari pendapatan kena pajak. Arus kas ITC adalah pada akhir tahun 1. ITC yang akan digunakan adalah 2/3 dari 10%. Depresiasi (garis lurus) = (67,000 – 22,000)/5 = 9,000.

Pembayaran bunga tahunan =-20,000 * 0.09 =-1,800 Pendapatan kena pajak (tahun 1 – 4) = 23,000 – 9,000 – 1,800 = 12,200 Pendapatan kena pajak (tahun 5) = 12,200 – 2,000 (rugi penjualan) = 10,200

Pajak (tahun 1, termasuk ITC)

= 0.4 * pendapatan kena pajak – 67,000*0.1*2/3

= 4,880 – 4,466.7 = 413.3

Pajak (tahun 2 – 5) = 0.4*pendapatan kena pajak

ATCF (tahun 1 – 5) = BTCF – Pajak – Pinjaman

Tabel 9.5: Contoh perhitungan pajak

Th.	BTCF & hutang	Depr.	Arus kas Hutang	Bunga atas hutang	Pendapatan kena pajak	Pajak terutang	ATCF
0	-67,000		20,000				-47,000
1	23,000	9,000	-1,800	1,800	12,200	413.3	20,787
2	23,000	9,000	-1,800	1,800	12,200	4880	16,320
3	23,000	9,000	-1,800	1,800	12,200	4880	16,320
4	23,000	9,000	-1,800	1,800	12,200	4880	16,320
5	23,000 20,000 (dijual)	9,000	-1,800 -20,000	1,800 (bayar hutang)	10,200	4080	17,120
						IRR = 25.8%	

IRR setelah pajak dapat dihitung dengan:

NPW(i) =-47K + 16,320 (P/A,i,5) + 4,467 (P/F,i,1) + 800 (P/F,i,5) = 0

IRR = 25.8% (dapat dicari dengan menggunakan excel atau matlab biasa)

Penjualan Properti yang dapat terdepresiasi:

Jika SVt < BVt OL = SVt – BVt (9.10)

Jika SVt > BVt OG = SVt-BVt (9.11)

Jika SVt > BV0 = IC CG = SVt-BVt (9.12)

Catatan:

OL = Ordinary Loss (Rugi Biasa)

OG = Ordinary Gain (Untung Biasa) = Depresiasi yang Diperoleh Kembali

CG = Capital Gain (Keuntungan Modal)

Rugi-rugi dan untung biasa, serta keuntungan modal ditambahkan ke pendapatan kena pajak

Bab 10

Analisa Kelayakan Pembangunan Embung

10.1 Pendahuluan

Bencana kekeringan masih menghantui warga di beberapa daerah di Indonesia. Sebagai contoh kekeringan yang terjadi di kabupaten Sampang – Jawa Timur. Berdasar data dari BPBD Sampang pada kurun waktu tahun 2019 sampai dengan 2022 selalu terjadi kekeringan pada musim kemarau. tahun 2019 tercatat 67 desa di 14 kecamatan yang mengalami kekeringan 2020 tercatat ada 78 desa yang mengalami kekeringan di 11 kecamatan, pada tahun 2021 di 74 desa dan 1 kelurahan dan krisis kekeringan selama tahun 2022 berjumlah 63 yang tersebar di 14 kecamatan.

Pembangunan embvung merupakan salah satu alternatif dari rekayasa sumber daya air untuk mengatasi kekeringan di suatu wilayah. Puspitaningrum, dkk (2015) Teknologi Embung merupakan salah satu teknologi untuk konservasi air terutama solusi/pemecahan masalah kekeringan.

Dalam realisasi atau pelaksanaan pembangunan embung di lapangan, selain aspek teknis untuk menentukan konstruksi juga memerlukan estimasi biaya yang diperkirakan harus dikeluarkan agar embung dapat terbangun. Biaya yang dikeluarkan tersebut harus di uji kelayakannya agar pembangunan

embung nantinya dipastikan akan membawa manfaat dibanding kerugian. Untuk meneliti kelayakan pada aspek ekonomi maka perlu dihitung besarnya biaya pembangunan embung. Biaya tersebut kemudian dijadikan bahan perbandingan dengan besarnya nilai manfaat embung. Penentuan kelayakan dalam segi ekonomi menggunakan BCR (Benefit Cost Ratio). Untuk analisa kelayakan dalam segi sosial masyarakat menggunakan sampling masyarakat untuk beberapa parameter yang sudah ditetapkan.

Berdasarkan identifikasi masalah diatas, maka perlu dilakukan analisa teknis dan analisa ekonomis untuk memastikan bahwa embung yang akan dibangun memang layak secara teknis dan ekonomis. Analisa teknis yang dilakukan untyuk menganalisa struktur bangunan terhadap daya dukung dan analisa erosi lahan untuk mengetahui laju sedimentasi yang akan masuk kedalam embung.

A ekonomis yaitu analisa biaya pelaksanaan pembangunan embung untuk kemudian dibandingkan dengan nilai manfaat untuk mengetahui rasio manfaat dan kerugian pada pembangunan embung tersebut.



Gambar 10.1: Kondisi kekeringan di kabupaten Sampang tahun 2019 (Sumber Lingkar jatim)

10.2 Definisi Embung

Embung adalah nama laian dari penyebutan kecil. Bendungan kecil ialah bangunan untuk menaikan elevasi muka air yang syaratnya tidak memenuhi untuk disebut menjadi bendungan besar (BWS, 2015), syarat bendungan besar:

1. Tinggi Bendungan lebih dalam dari 15 m yang diukur dari bagian bawah pondasi hingga puncak bagian.
2. Apabila tinggi dari bendungan berkisar antara 10 hingga 15 meter dapat juga disebut sebagai sebuah bendungan besar apabila syarat berikut terpenuhi di mana:
   a. Panjang pada bagian puncak bendungan lebih dari 500
   b. Besar kapasitas untuk tampungannya lebih dari 500.000 m3
   c. Perhitungan besarnya Debit puncak 2000 m3/detik

10.3 Tujuan Pembangunan Embung

Embung yang hendak dibangun ditujukan untuk memenuhi kebutuhan air yang dibutuhkan oleh warga sekitar area embung. Embung yang merupakan bagian dari bendungan dipergunakan untuk menampung air irigasi di waktu terjadinya kelebihan volume air sehingga dapat digunakan pada waktu tertentu saat dibutuhkan atau saat air irigasi tidak mencukupi.

Pada dasarnya Bendungan sendiri mempunyai fungsi cukup banyak seperti untuk pengairan irigasi, PLTMH, pengendalian banjir, peternakan dan lain sebagainya. Namun karena Bendungan yang ukuran dan volume tampung yang lebih kecil atau yang sering disebut Embung biasanya hanya digunakan untuk keperluan irigasi dan domestik saja (KP-02, 2010).

10.4 Analisa Kebutuhan Air

Analisa ini bertujuan untuk menentukan kebutuhan air bersih domestik ataupun irigasi yang diperlukan oleh penduduk beserta beberapa fasilitas-fasilitas sosial dan ekonomi yang dibutuhkan termasuk di dalamnya kebutuhan dimasa mendatang sehingga perencanaan volume Embung yang dibangun dapat mencakup secara keseluruhan dalam jangka waktu yang cukup panjang.

10.4.1 Jumlah Penduduk

Untuk memperkirakan kebutuhan air bersih yang akan disalurkan dari embung, faktor pertumbuhan penduduk sangatlah berpengaruh dan menentukan dalam proses perencanaan embung

Metode yang dapat digunakan dalam perencanaan ini ialah metode Geometrik. Perkiraan jumlah penduduk dengan metode ini mengansumsikan bahwa jumlah penduduk akan mengalamai penambahan secara geometric menggunakan dasar perhitungan bunga majemuk (Adioetomo & Samosir, 2010)

10.4.2 Jumlah Kebutuhan Air

Jumlah kebutuhan air yang dimiliki oleh masing-masing daerah akan sangat berbeda-beda bergantung dari tingkatn konsumsi penduduk. Tingkat kebutuhan air untuk domestik juga sangat bergantung dari tingkat kesejahteraan penduduk.

Analisa perhitungan yang dilakukan setidaknya dapat memperlihatkan besaran kebutuhan dasar serta besaran kebutuhan untuk pengembangan (development need) dengan mempertimbangkan teknologi yang siap pakai, standar-standar yang harus terpenuhi, serta perencanaan yang mengacu pada teknologi non standar.

Apabila mengacu pada sumber yang dimiliki maka

1. Jumlah kebutuhan domestiK
   a. Pemakaian air untuk SR = 120 lt/org/hr
   b. Penggunaan untuk KU/TA = 60 lt/org/hr (nilai standar pelayanan minum)
2. Kebutuhan non-domestik
3. Kebutuhan industry dengan penggunaan air = 0,1 – 0,3 l/ha/hr
   a. Kebutuhan industry dengan kriteria penggunaan air = 900 l/niaga/hr (niaga skala kecil) serta 5000 l/niaga/hr (niaga skala besar)
   b. Kebutuhan penggunaan pada fasilitas umum (ruang pendidikan, pemerintahan dsb) dengan kisaran pemakaian air = 10%-15% berdasar pada kebutuhan air domestic

4. Perkiraan direncanakan hingga 15 atau 20 tahun kedepan sesuai dengan rancana SPAM
5. Penggunaan untuk jumlah harian maksimum berkisar pada = 1,15 rata-rata perhari
6. Penggunaan air pada jam-jam puncak berkisar antara 1,5 hingga 1,7 pemakaian maksimum perhari

10.5 Analisa Volume Embung

Sesuai dengan fungsinya embung yang dibangun dimaksudkan agar air yang berlebihan pada musim penghujan dapat ditampung dan dipergunakan pada musim kemarau untuk kehidupan sehari-hari. Untuk mendapatkan hasil yang optimum maka hal yang pertama harus dipertimbangkan ialah mengenai volume dari embung tersebut atau sering disebut dengan kapasitas embung/kapasitas penampungan yang meliputi:

10.5.1 Kapasitas Efektif

Kapasitas eefektif ialah kapasitas volume tampung yang dapat melayani kebutuhan sehari-hari kebutuhan air penduduk. ➢ Kapasitas Mati

Kapasitas mati merupakan kapasitas volume tampung untuk sedimen sehingga tidak berdampak pada kapasitas efektif nantinya.

Perhitungan kapasitas tersebut perlu untuk direncanakan sebab merupakan bagian dari proses perencanaan dari bangunan-bangunan air seperti: Embung, Spillway maupun intake.

10.5.2 Konstruksi embung

Apabila dilihat dari kualitas konstruksi yang telah dilaksanakan di indonesia, embung yang dibangun memiliki kecenderungan untuk menggunakan konstruksi urugan. Embug urugan sendiri diklasifikasikan dalam type homogen, zonal dan sekat. Selain itu juga embung type urugan diklasifikasikan dari material yaitu urugan tanah dan urugan batu. Berdasarkan klsifikasinya, maka konstruksi embung mempunyai onti (core).

10.6 Analisa Ekonomi

Analisa ekonomi dalam studi pembangunan sumber daya air sudah merupakan hal rutin baik dalam tahap master plan, *reconnaissance*, *apprisial*, *feasibility study*, saat pembuatan PCR (Project Completion Report), maupun dalam tahapan yang dianggap perlu dalam studi-studi khusus untuk mengevaluasi keberhasilan atau kegagalan suatu proyek (Suyanto, Adhi. dkk, 2001, p.33). Proyek pengembangan yang dibiayai oleh bantuan dari bank atau lembaga keuangan lainnya terutama pada proyek yang didapat dari dana pinjaman atau obligasi pemerintah dan dititik beratkan pada aspek sosial profitabilitas/manfaat kepada perekonomian Negara secara keseluruhan. (Suyanto, Adhi. dkk, 2001, p.34)

Sasaran dari analisa keuangan ini untuk mengetahui apakah proyek dari segi keuangan dinilai layak, dalam artian mempunyai dana yang cukup untuk membiayai pengoperasian seluruh fasilitas yang ada, dan dapat membayar kembali seluruh pinjaman beserta bunganya. Sedangkan analisa ekonomi adalah untuk mengetahui seberapa jauh keuntungan yang akan diperoleh oleh masyarakat luas dengan adanya proyek tersebut (Cipta Karya, 1996, p.37).

Analisa kelayakan ekonomi pada sebuah proyek adalah untuk mengarahkan penggunaan sumber-sumber daya kepada proyek-proyek yang dapat memberikan hasil paling banyak untuk perkonomian sebagai keseluruhan. Di dalam analisa ekonomi pembangunan embung biaya konstruksi dihitung berdasarkan harga satuan yang berlaku pada wilayah tersebut.

10.6.1 Kelayakan Ekonomi

Kelayakan ekonomi adalah suatu analisa ekonomi yang telah memenuhi kriteria ekonomi yang telah ditetapkan terhadap suatu usulan atau perencanaan. Penilaiannya ditekankan pada Penilaian Ekonomi yang mencakup studi tentang manfaat dan biaya dari suatu usulan proyek terhadap masyarakat yang memanfaatkannya. (Cipta Karya, 1996, p.2)

10.6.2 Manfaat (Benefit)

Manfaat suatu proyek terdiri dari keuntungan langsung (direct benefit) dan keuntungan tidak langsung (indirect benefit), disamping itu, dikenal pula keuntungan yang tidak dapat diukur dengan uang (intangible benefit) dan keuntungan yang dapat diukur dengan uang (tangible benefit). 4 jenis manfaat

dari proyek yakni manfaat langsung (Direct Benefit), manfaat tidak langsung (Inderrect Benefit), Manfaat Nyata (Tangible Benefit) dan Manfaat Tidak Nyata (Intangible Benefit)

Manfaat Tak Langsung (Inderrect Benefit) adalah manfaat yang akan dinikmati secara berangsur-angsur dan dalam jangka waktu yang panjang. Manfaat tidak langsung (Indirect Benefit), yaitu berupa:

Manfaat nyata (Tangible Benefit) adalah manfaat nyata yang dapat diukur dalam bentuk suatu nilai uang.dan Manfaat tidak nyata (Intangible Benefit) adalah merupakan manfaat proyek yang tidak dapat selalu dinilai dengan uang, seperti:

1. Perbaikan lingkungan hidup
2. Perbaikan pemandangan
3. Perbaikan distribusi pendapatan
4. Integrasi nasional
5. Pertahanan nasional

10.7 Parameter Benefit dan Cost

Dalam pemilihan alternatif proyek-proyek adalah untuk proyek yang mempunyai manfaat (benefit) yang sama tetapi dengan biaya (cost) yang berbeda. Proyek yang dipilih adalah proyek yang mempunyai annual cost atau present value yang terendah.

10.7.1 Net Present Worth atau Net Present Value (NPV)

NPV adalah selisih antara benefit (penerimaan) dengan *cost* (pengeluaran) yang telah di *present value*-kan. Oleh karena metode ini memperhatikan time *value of money*, maka *proceed* yang dipergunakan adalah *cash flow* yang didiskontokan atas dasar biaya modal atau *rate of return* yang diinginkan. Dalam metode ini pertama-tama yang dihitung adalah nilai sekarang dari *proceeds* yang diharapkan atas dasar ”discount rate” tertentu, kemudian jumlah dari seluruh *proceeds* selama usianya dikurangi dengan PV dari jumlah investasi. Selisih antara PV keseluruhan *proceeds* dikurangi dengan PV dari pengeluaran modal dinamakan ”nilai sekarang netto”. Dalam menganalisa,

tanda ”GO/layak”, dinyatakan oleh nilai NPV yang sama atau lebih besar dari nol, artinya suatu proyek dapat dinyatakan bermanfaat untuk dilaksanakan bila NPV proyek tersebut sama atau lebih besar dari nol. Jika NPV = 0, berarti proyek tersebut mengembalikan persis sama dengan nilai modal yang ditanamkan. Jika NPV lebih kecil dari nol, berarti proyek tidak dapat menghasilkan senilai biaya yang dipergunakan, maka proyek tidak akan dipilih atau tidak layak untuk dijalankan.

$$NPV = \sum \frac{Bt - Ct}{(1+i)}$$

Keterangan:

Bt: Nilai Total Benefit (penerimaan) Pada Tahun Ke-1

Ct: Cost (Biaya) pata Tahun ke-t, terdiri atas biaya tetap, biaya variabel, biaya overhead, biaya administrasi dan umum.

n: Umur ekonomis proyek

i: discount rate

10.7.2 Net Benefit Cost Ratio (B/C)

Net Benefit Cost Ratio (Net B/C) adalah perbandingan antara present value net benefit dari tahun-tahun yang bersangkutan (pembilang/bersifat positif) dengan present value arus biaya dalam tahun di mana Bt-Ct (penyebut bersifat negatif).

Rumus:

$$Net\ B/C\ ratio = \sum_{t=0}^{n} \frac{Bt-Ct}{(1+i)} \text{ Untuk Bt-Ct} > 0$$

$$Net\ B/C\ ratio = \sum_{t=0}^{n} \frac{Ct-Bt}{(1+i)^t} \text{ Untuk Bt} - \text{Ct} < 0$$

Keterangan:

Bt: Nilai total benefit (penerimaan) pada tahun ke-t

Ct: Cost (Biaya) pata Tahun ke-t, terdiri atas biaya tetap, biaya variabel, biaya overhead, biaya administrasi dan umum.

n: Umur ekonomis proyek

i: discount rate

Kriteria:

Jika NPV ≥ 0, maka pengembangan bendungan layak untuk dilaksanakan.

Jika NPV ≤ 0, maka pengembangan bendungan tidak layak untuk dilaksanakan.

10.7.3 Laju Pengembalian Modal (Internal Rate of Return/IRR)

IRR merupakan tingkat bunga (rendemen) yang menggambarkan bahwa antara benefit (penerimaan) yang telah di present valuekan dan cost (pengeluaran) yang telah di present valuekan sama dengan nol. Dengan demikian IRR menunjukkan kemampuan suatu proyek untuk menghasilkan returns atau tingkat keuntungan yang dapat dicapainya. Kadang-kadang IRR ini digunakan sebagai pedoman tingkat bunga (i) yang berlaku, (Pudjosumarto, 1984, p.49). IRR adalah tingkat i yang memenuhi syarat:

10.8 Studi Kasus Analisa Kelayakan Pembangunan Embung

Desa Batuporo Barat – Kecamatan Kedungdung, Kabupaten sampan pada musim kemarau tahun 2019 hingga 2022 merupakan salah wilayah desa yang mengalami kekeringan kritis. Kekeringan terjadi di 13 desa. Berangkat dari hal tersebut dicoba untuk membuat/membangun embung dalam rangka penyediaan air baku untuk masyarakat setempat mengingat masih terdapat banyak lahan dan kondisi topografi yang memadai untuk dibangun embung didesa tersebut

1. Analisa Perkembangan Penduduk
   Berdasar data dari BPS Kabupaten samapng pada tahun 2020 Jumlah penduduk pada daerah studi tahun 2020 Desa Batoporo Barat 7.350 jiwa dengan laju pertumbuhan penduduk 0.87%. Perkiraan perkembangan penduduk diproyeksikan untuk masa 25 tahun yang akan datang. proyeksi pertumbuhan penduduk dengan metode pertumbuhan eksponensial. Dalam Hasnantio, M. Akbar (2006, p.11).

Perkiraan laju pertumbuhan eksponential diasumsikan pertambahan penduduk secara terus menerus setiap hari dengan angka pertumbuhan konstan. Rumus dari pertumbuhan eksponential:

$$Pn = Po.e^{r.n}$$

dengan:
Pn= jumlah penduduk pada tahun ke n (jiwa)
Po= jumlah penduduk pada awal tahun proyeksi (jiwa)
r = prosentase pertumbuhan penduduk (%)
n = jumlah tahun proyeksi (tahun)
e = bilangan logaritma natural (2,7182)

Tabel 10.1: Perhitungan proyeksi pertumbuhan penduduk

No.	Tahun	Jumlah penduduk
1	2020	7,350
2	2021	7,415
3	2022	7,480
4	2023	7,545
5	2024	7,611
6	2025	7,677
7	2026	7,744
8	2027	7,812
9	2028	7,880
10	2029	7,949
11	2030	8,019
12	2031	8,089
13	2032	8,159
14	2033	8,231
15	2034	8,303
16	2035	8,375
17	2036	8,448
18	2037	8,522
19	2038	8,596
20	2039	8,672
21	2040	8,747
22	2041	8,824
23	2042	8,901
24	2043	8,979
25	2044	9,057

2. Analisa Kebutuhan Air

Perhitungan kebutuhan air baku sesuai dengan proyeksi pertumbuhan penduduk serta kebutuhan air baku untuk domestic maupun non domestik dapat dilihat pada tabel perhitungan di bawah ini:

Tabel 10.2: perhitungan Kebutuhan Air Baku

No	Uraian	Satuan	Usulan Tahun					
			2022	2025	2030	2035	2040	2044
A	**PARAMETER YANG DITETAPKAN**							
1	Penduduk Yang Dilayani Tiap Sambungan :							
a	Sambungan Rumah (SR)	org/samb	6.00	6.00	6.00	6.00	6.00	6.00
b	Sambungan Hidran Umum (KU)	org/samb	130.00	130.00	130.00	130.00	130.00	130.00
2	2 Faktor Pemakaian Air :							
a	Harian Maksimum		1.15	1.15	1.15	1.15	1.15	1.15
b	Jam Puncak		1.50	1.50	1.50	1.50	1.50	1.50
3	Kebutuhan Air Bersih DI Daerah Pelayanan :							
a	Sambungan Rumah (SR)	ltr/org/hr	120.00	120.00	120.00	120.00	120.00	120.00
b	Sambungan Kran Umum (KU)	ltr/org/hr	60.00	60.00	60.00	60.00	60.00	60.00
4	Presentase Kebutuhan Non Domestik Dari Kebutuhan Domestik	%	20.00	20.00	20.00	20.00	20.00	20.00
5	Kehilangan	%	25.00	25.00	25.00	25.00	25.00	25.00
B	**JUMLAH PENDUDUK DAN TINGKAT PELAYANAN**							
1	Jumlah Penduduk Desa Batoporo Timur dan Batoporo Barat	Jiwa	7,480.00	7,677.00	8,019.00	8,375.00	8,747.00	9,057.00
2	Penduduk Yang Dilayani	%	85.00	85.00	85.00	85.00	85.00	85.00
3	Jumlah Penduduk Yang Dilayani Jiwa	Jiwa	6,358.00	6,525.45	6,816.15	7,118.75	7,434.95	7,698.45
4	Kebutuhan Air Domestik :							
a	Sambungan Rumah (SR)							
	*Pemakaian Air	ltr/org/hr	120.00	120.00	120.00	120.00	120.00	120.00
	*Jumlah Sambungan Unit	Unit	1,059.67	1,087.58	1,136.03	1,186.46	1,239.16	1,283.08
	*Kebutuhan Air	lt/dt	8.83	9.06	9.47	9.89	10.33	10.69
b	Sambungan Hidran Umum (KU)							
	*Pemakaian Air ltr/org/hr	ltr/org/hr	60.00	60.00	60.00	60.00	60.00	60.00
	*Jumlah Penduduk Yang Dilayani Jiwa	Jiwa	1,122.00	1,152.00	1,203.00	1,257.00	1,313.00	1,359.00
	*Jumlah Sambungan Unit	unit	8.63	8.86	9.25	9.67	10.10	10.45
	*Kebutuhan Air	ltr/dt	0.01	0.01	0.01	0.01	0.01	0.01
C	**KEBUTUHAN AIR**							
1	Kebutuhan Domestik	ltr/dt	8.84	9.07	9.47	9.89	10.33	10.70
2	Kebutuhan Non Domestik	ltr/dt	0.88	0.91	0.95	0.99	1.03	1.07
3	Kebutuhan Air Domestik + Non Domestik	ltr/dt	9.72	9.98	10.42	10.88	11.37	11.77
4	Kehilangan Air	ltr/dt	2.43	2.49	2.61	2.72	2.84	2.94
5	Kebutuhan Air Total	ltr/dt	12.15	12.47	13.03	13.60	14.21	14.71
	* Kebutuhan Harian Maksimum	ltr/dt	13.97	14.34	14.98	15.64	16.34	16.92
	* Kebutuhan Jam Puncak	ltr/dt	20.96	21.51	22.47	23.47	24.51	25.38

Sumber: Hasil Perhitungan

3. Analisa Volume Embung

Perhitungan kapasitas tampungan embung

a. Kapasitas tampungan berdasarkan kebutuhan Air (Vu) Data dari perhitungan kebutuhan air baku yang dibutuhkan pada tahun 2044 sebesar 14,71 l/det dan digunakan untuk melayani

kebutuhan air baku pada masyarakat setempat. (Ibnu Kasiro dkk, 1994)

Vu = 14,71 x 10-3 x 180 x 24 x 3600 = 228.799,20 m3

Tinggi elevasi muka air 6 m, maka luas area tampungan = 38.133,20 m2

b. Air yang Menguap (Ve)

Data evaporasi wilayah Batoporo 4,212 mm/hr

Ve = 4,212 x 360 x 10-3 x 38.133,20 = 57.822,13 m3

c. Volume Air yang Merembes (Vi)

Vi = 25% x 228.799,20 = 57.199,80 m3

d. Volume Tampungan Sedimen (Vs)

Vs = 5%.Vu = 5% x 228.799,20 = 11.439,96 m3

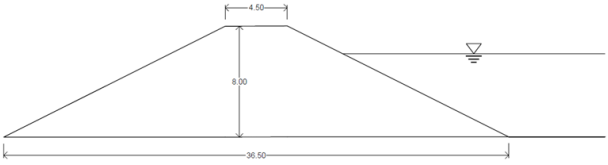
Kapasitas Total Embung yang Diperlukan (Vn)

Vn = Vu + Ve + Vi + Vs = 228.799,20 + 57.822,13 + 57.199,80 + 11.439,96 = 355,261.10 m3

4. Konstruksi embung

Embung dengan konstruksi urugan tanah dengan:

Elevasi dasar bendungan	: + 98,00
Elevasi muka air banjir	: + 106,00
Elevasi mercu pelimpah	: + 104,00
Tinggi ruang bebas	: 2.0 meter
Elevasi puncak mercu bendungan	: + 104,00 + 2.00
	: + 106,00
Tinggi bendungan	: 8 meter



Gambar 10.2: Struktur Embung (Sumber Hasil perhitungan)

5. Analisa biaya

Biaya terdiri dari biaya langsung dan biaya tidak langsung. Biaya langsung merupakan biaya yang berkaitan langsung dengan volume pekerjaan yang menjadi komponen hasil analisa volume harga satuan pekerjaan. Biaya konstruksi meliputi seluruh biaya yang digunakan untuk pembangunan dalam pembangunan embung. Berdasarkan perhitungan untuk item pekerjaan embung ada beberapa item yang harus dihitung seperti pada tabel berikut.

Tabel 10.3: Perhitungan Biaya Fisik Pekerjaan (Sumber Hasil perhitungan)

No.	Uraian Pekerjaan	Volume	Satuan	Harga satuan	Biaya
1	Pekerjaan persiapan	1	Ls	Rp 463,734,157.16	Rp 463,734,157.16
2	Pekerjaan Galian Dengan Alat	118,420.37	m3	Rp 99,199.00	Rp 11,747,181,985.72
3	Timbunan tanah dipadatkan dengan alat	100,657.31	m3	Rp 102,921.10	Rp 10,359,761,268.66
4	Gebalan Rumput	16,424.87	m2	Rp 55,071.00	Rp 904,534,089.61
					Rp 23,475,211,501.15

Tabel 10.4: Perhitungan Biaya Tidak Langsung (Sumber Hasil perhitungan)

No	Uraian Pekerjaan		Jumlah
1	Biaya Konstruksi	Rp	23,475,211,501.15
2	Biaya Administrasi (2.5%)	Rp	586,880,287.53
3	Biaya Tidak terduga (5%)	Rp	1,173,760,575.06
	Total	Rp	25,235,852,363.73
	PPn 11%	Rp	2,775,943,760.01
	Total	Rp	28,011,796,123.74

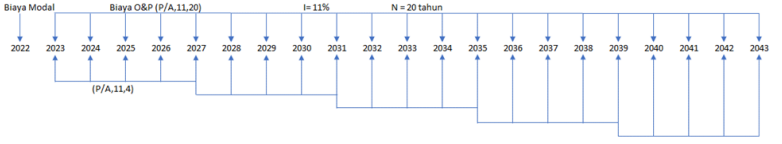
Biaya modal total untuk menentukan jumlah biaya selama embung tersebut beroperasi sampai habis usia gunanya. Usia guna embung direncanakan selama 20 tahun. Sehingga perhitungan biaya modal total menggunakan 20 tahun dengan biaya operasional sebesar 2.5% setiap tahun.

Biaya operasional dan perawatan per-tahun = 2.5% x Rp 25,235,852,373.73 = Rp 630,896,309.09

Agar perhitungan analisa ekonomi lebih sederhana dan mendekati kenyataan maka harus dihitung pada titik waktu yang sama. Dalam

studi ini baik analisa harga air baku ataupun analisa manfaat dijadikan nilai sekarang (present value). Tahun dasar yang digunakan adalah tahun selesainya pengerjaan proyek, yaitu tahun 2022. Pelaksanaan proyek diperkirakan selama satu tahun, dimulai tahun 2023, sedangkan manfaat yang dihasilkan dari adanya proyek ini selama 20 tahun.

Apabila suku bunga yang berlaku saat ini sebesar 11% maka present value untuk biaya dan manfaat adalah sebagai berikut:



Gambar 10.3: Diagram Benefit-Cost (Sumber hasil perhitungan)

6. Analisa Biaya
   a. Biaya pekerjaan

      Untuk memperoleh present value biaya modal digunakan faktor konversi F/P, karena biaya modal merupakan pembayaran tunggal/Single-Payment Present *Worth Factor* (Pujawan, 2004), hal ini ditandai dengan masa konstruksi selama satu tahun. Besarnya nilai faktor konversi diketahui dari tabel faktor bunga (terlampir).

No.	Kegiatan	Faktor Konversi
1	Pekerjaan sipil headworks	0,79 – 0,90
2	Saluran induk dan sekunder	0,82
3	Penggarapan lahan pertanian	0,75 – 0,85
4	Pencetakan sawah, perataan lahan	0,72 – 0,85
5	Kantor, bangunan	0,94 – 0,95
6	Pembebasan tanah	0
7	Pajak	0
8	Administrasi	0,95
9	O & P	0,85
10	Jasa konsultan	0,9
11	Penahan erosi lahan	0,86
12	Drainase	0,87

Sumber: Suyanto, Adhi. dkk (2001, p.42)

Besar biaya proyek di konversikan menjadi harga ekonomi
= Rp 28,011,796,123.74 x 0,85
= Rp 23,810,026,705.18
maka:
PV Biaya Modal = Biaya Modal (ekonomi) x (F/P,11,1)
= Rp 23,810,026,705.18 x 1,110
= Rp 26,429,129,642.75

b. Biaya (Cost) O&P
Biaya O&P dikeluarkan setiap tahun atau disebut *Annuity* dengan periode 20 tahun dan bunga 11 %. Sehingga untuk mendapatkan *present value*nya digunakan faktor konversi P/A.
Besar biaya O&P tiap tahun di konversikan menjadi harga ekonomi =
Rp 630,896,309.09 x 0.85 = Rp 536,261,862.73
PV Biaya O&P = Biaya O&P (ekonomi) x (P/A,11,20)
= Rp 536,261,862.73 x 7,963
= Rp 4,270,253,212.91

c. Manfaat (Benefit)Air Baku untuk Menetapkan Harga Air Baku
Manfaat air baku dihitung untuk menetapkan harga air baku dengan parameter B/C >1 dengan tingkat kenaikan inflasi harga air baku 20% per empat tahun dari harga yang telah ditetapkan oleh PDAM (sebagai acuan) sebesar Rp. 3.868,-/m3
Kenaikan Inflasi Harga Air Baku 20% per 4 tahun,:
1) 2023 : Rp. 3,868.00/m3
2) 2024 – 2027 : Rp. 3.868.00/m3
3) 2028 – 2031 : Rp. 4,642.00/m3
4) 2032 – 2035 : Rp. 5,570.00/m3
5) 2036 – 2039 : Rp. 6,684.00/m3
6) 2040 – 2043 : Rp. 8,020.00/m3
Perhitungan manfaat air baku Tahun 2023-2043, sebagai berikut:

Tabel 10.5: Tabel Perhitungan Manfaat Air Baku (Sumber hasil perhitungan)

No	Tahun	Kebutuhan air baku		Harga Jual Air		Manfaat Tahunan	
		lt/dt	m3/th		Rp/m3		Rp/th
1	2023	12.150	383,170.44	Rp	3,868.00	Rp	1,482,103,277.54
2	2024	12.256	386,500.19	Rp	3,868.00	Rp	1,494,982,741.24
3	2025	12.363	389,881.13	Rp	3,868.00	Rp	1,508,060,212.70
4	2026	12.470	393,262.07	Rp	3,868.00	Rp	1,521,137,684.16
5	2027	12.579	396,694.20	Rp	3,868.00	Rp	1,534,413,163.37
6	2028	12.690	400,177.52	Rp	4,641.60	Rp	1,857,463,980.40
7	2029	12.800	403,660.84	Rp	4,641.60	Rp	1,873,632,164.76
8	2030	12.912	407,195.59	Rp	4,641.60	Rp	1,890,039,033.58
9	2031	13.026	410,781.29	Rp	4,641.60	Rp	1,906,682,436.56
10	2032	13.139	414,367.23	Rp	5,569.92	Rp	2,307,992,297.62
11	2033	13.253	417,952.93	Rp	5,569.92	Rp	2,327,964,381.19
12	2034	13.370	421,641.25	Rp	5,569.92	Rp	2,348,508,017.28
13	2035	13.487	425,329.57	Rp	5,569.92	Rp	2,369,051,653.36
14	2036	13.604	429,017.88	Rp	6,683.90	Rp	2,867,514,347.34
15	2037	13.723	432,757.39	Rp	6,683.90	Rp	2,892,508,868.05
16	2038	13.843	436,548.09	Rp	6,683.90	Rp	2,917,845,546.15
17	2039	13.963	440,338.79	Rp	6,683.90	Rp	2,943,182,224.26
18	2040	14.087	444,231.88	Rp	8,020.68	Rp	3,563,043,860.60
19	2041	14.208	448,074.00	Rp	8,020.68	Rp	3,593,860,321.08
20	2042	14.333	452,018.27	Rp	8,020.68	Rp	3,625,496,101.44
21	2043	14.458	455,962.78	Rp	8,020.68	Rp	3,657,133,739.68
						Rp	50,482,616,052.36

Tabel 10.6: Perhitungan Manfaat Air Baku Periode 4 tahunan (Sumber hasil perhitungan)

No	Tahun	Kebutuhan air baku	Harga Jual Air		Faktor Konversi		Manfaat Tahunan
		m3/th		Rp/m3			Rp/th
1	2023	383170.44	Rp	3,868.00	P/A, 11,4 = 3.1024	Rp	4,598,077,208.24
2	2024 - 2027	391584.40	Rp	3,868.00	P/A, 11,4 = 3.1025	Rp	4,699,196,817.26
3	2028 - 2031	405453.81	Rp	4,641.60	P/A, 11,4 = 3.1026	Rp	5,838,951,733.31
4	2032 - 2035	419822.74	Rp	5,569.92	P/A, 11,4 = 3.1027	Rp	7,255,288,794.36
5	2036 - 2039	434665.54	Rp	6,683.90	P/A, 11,4 = 3.1028	Rp	9,014,449,249.68
5	2040 - 2043	450071.73	Rp	6,683.90	P/A, 11,4 = 3.1029	Rp	9,334,256,274.86
					PV	Rp	40,740,220,077.72

Analisa Net Benefit Cost Ratio (NPV)

$$NPV = \sum_{t=0}^{t=n} (Bt - Ct) * (\frac{1}{(1+i)^t})$$

Di mana:
Bt = Rp. 40,740,220,077.72
Ct = Rp 26,429,129,642.75 + Rp 4,270,253,212.91 = Rp 32,282,049,336.66
Suku bunga (i) = 11%
Waktu (t) = 0
Perhitungan NPV dapat dilihat pada tabel di bawah ini:

Tabel 10.7: Perhitungan NPV (Sumber hasil perhitungan)

Tahun ke	Benefit Rp.	Cost Rp.	Net Benefit Rp.	DF i = 11%	
0		Rp 28,011,796,123.74	-Rp 28,011,796,123.74	1.000	NPV Negatif
1	Rp 1,482,103,277.54	Rp 630,896,309.09	Rp 851,206,968.45	0.901	-Rp 28,011,796,123.74
2	Rp 1,494,982,741.24	Rp 630,896,309.09	Rp 864,086,432.15	0.812	
3	Rp 1,508,060,212.70	Rp 630,896,309.09	Rp 877,163,903.61	0.731	
4	Rp 1,521,137,684.16	Rp 630,896,309.09	Rp 890,241,375.06	0.659	
5	Rp 1,534,413,163.37	Rp 630,896,309.09	Rp 903,516,854.28	0.593	
6	Rp 1,857,463,980.40	Rp 630,896,309.09	Rp 1,226,567,671.31	0.535	
7	Rp 1,873,632,164.76	Rp 630,896,309.09	Rp 1,242,735,855.67	0.482	
8	Rp 1,890,039,033.58	Rp 630,896,309.09	Rp 1,259,142,724.49	0.434	
9	Rp 1,906,682,436.56	Rp 630,896,309.09	Rp 1,275,786,127.46	0.391	
10	Rp 2,307,992,297.62	Rp 630,896,309.09	Rp 1,677,095,988.53	0.352	
11	Rp 2,327,964,381.19	Rp 630,896,309.09	Rp 1,697,068,072.09	0.317	
12	Rp 2,348,508,017.28	Rp 630,896,309.09	Rp 1,717,611,708.18	0.286	
13	Rp 2,369,051,653.36	Rp 630,896,309.09	Rp 1,738,155,344.27	0.258	
14	Rp 2,867,514,347.34	Rp 630,896,309.09	Rp 2,236,618,038.25	0.232	
15	Rp 2,892,508,868.05	Rp 630,896,309.09	Rp 2,261,612,558.95	0.209	
16	Rp 2,917,845,546.15	Rp 630,896,309.09	Rp 2,286,949,237.06	0.188	NPV Positif
17	Rp 2,943,182,224.26	Rp 630,896,309.09	Rp 2,312,285,915.16	0.170	Rp 31,212,956,338.46
18	Rp 3,563,043,860.60	Rp 630,896,309.09	Rp 2,932,147,551.51	0.153	
19	Rp 3,593,860,321.08	Rp 630,896,309.09	Rp 2,962,964,011.98	0.138	
20	Rp 3,625,496,101.44	Rp 630,896,309.09	Rp 2,994,599,792.35	0.124	
	Rp 46,825,482,312.68	**Rp 40,629,722,305.61**	**Rp 6,195,760,007.07**		

d. Net Present Value (NPV)
Berikut ini rancangan Net Present Value (NPV) yang akan disajikan pada tabel kolom 6 Berdasarkan perhitungan dengan menggunakan rumus Net Present Value (NPV) selama 20 tahun dapat diperoleh hasil sebesar Rp 6,195,760,007.07. Tabel rancangan Net Present Value (NPV) Tabel 4.5 menunjukan NPV

> 0 maka rencana pembangunan embung dinyatakan layak untuk dilaksanakan (go).

e. Net Benefit Cost Ratio (Net B/C)

Rancangan Net Benefit Cost Ratio (Net B/C). Berdasarkan Tabel rancangan Net Benefit Cost Ratio (Net B/C), diperoleh jumlah Net Present Value(NPV) Positif sebesar Rp. 31,212,956,338.46 dan Net Present Value (NPV) Negatif sebesar Rp. 28,011,796,123.74, didapatkan:

Net B/C = Rp. 31,212,956,338.46: Rp. 28,011,796,123.74 = 1.114

Berdasarkan perhitungan diatas, diperoleh Net Benefit Cost Ratio (Net B/C) sebesar 1,114 hal ini menunjukkan bahwa Net B/C > 1. berarti pembangunan embung dinyatakan layak untuk dilaksanakan (go).

7. Kesimpulan

Embung dapat dikatakan layak pada aspek ekonomi dengan melihat hasil nilai B/C sebesar 1,1142 dengan usia guna 20 tahun. Harga air sebesar di awal ditetapkan Rp. 3868,-/m^3, Naik 20% ditahun ke-5, kemudian tiap 4 (empat) tahun naik 20%.

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Penulis lahir di Ujung Pandang, pada 12 Februari 1971 sebagai anak ke-4 dari 4 bersaudara dari pasangan Baginda Ali dan Hamisah. Saat ini penulis bertempat tinggal jl. Dr. Ratulangi Gang 1 No. 33, Kel. Parang, Kec. Mamajang, Makassar. Pendidikan Sarjana ditempuh di Progran Studi Teknik Elektro Fakultas Teknik Universitas Muslim Indonesia lulus pada tahun 1996. dan pada Tahun 2006, penulis diterima di Program Pascasarjana Teknik Elektro Universitas Hasanuddin dan menamatkan pada tahun 2009. Penulis biasa disapa dengan nama Risna. Saat ini adalah sebagai dosen tetap program studi Teknik Elektro Universitas Sawerigading Makassar. Mengampu mata kuliah Elektronika Telekomunikasi, Kinerja Sistem Telekomikasi, Sistem Komunikasi Serat Optik.



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banjir dan kekeringan, serta pengaruh fenomena perubahan iklim global saat ini terhadap perilaku hidrologis suatu daerah. Penulis juga telah meghasilkan beberapa buku Referensi yang ditulis secara kolaboratif diantaranya: Ekonomi Sumber Daya Alam, Pengetahuan Kebencanaan, Agroklimatologi, Sistim Irigasi dan Bangunan Air, Drainase Perkotaan, dan Statistik Deskriptif.

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Lahir di Lampoko pada tanggal. 1 Juli 1974, putri kedua dari 4 bersaudara , pasangan M.Syabiruddin Abdolo dengan Hj.ST.Marhamah menempuh pendidikan Diploma 3 Jurusan Teknik Kimia Politeknik Negeri Ujung Pandang tahun 1996. Alumni Program Studi Teknik Mesin Jurusan Teknik Mesin Fakultas Teknik Universitas Hasanuddin tahun 2002. Pada tahun 2010 mengikuti Program Magister pada Program Studi Teknik Mesin Jurusan Teknik Mesin Fakultas Teknik Universitas Hasanuddin dan lulus pada tahun 2012. Menempuh pendidikan S3 pada Program Pasca Sarjana Program Studi Teknik Mesin Jurusan Teknik Mesin Fakultas Teknik Universitas Hasanuddin pada tahun 2016. Terangkat menjadi Dosen Tetap pada Universitas Fajar dan ditempatkan di Fakultas Teknik Program Studi Teknik Mesin Universitas Fajar pada tahun 2008 dan aktif menjadi tenaga pengajar hingga sekarang.

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Anna Rosytha



Lahir di Surabaya, pada 23 Desember 1979. Ia tercatat sebagai lulusan Institut teknologi sepuluh Nopember Surabaya. Wanita yang kerap disapa Anna ini adalah anak dari pasangan Endang Rosadi (ayah) dan Siti Maimunah (ibu). Anna Rosytha merupakan pengajar ilmu Hidrologi dan Bangunan Air di Universitas Muhammdiyah Surabaya

EKONOMI TEKNIK

Dewasa ini teknologi telah berkembang dengan pesat sehingga dalam praktiknya untuk mewujudkan suatu kebutuhan manusia akan dihadapkan dengan berbagai pilihan/alternatif. Alternatif tersebut bisa dalam bentuk desain, rencana, prosedur, metode, material, waktu, dan lainnya. Karena setiap pilihan alternatif akan berdampak langsung pada pemakaian sumber daya, di mana sumber daya itu sendiri semakin mahal dan sulit, maka seyogyanya pemilihan alternatif harus didasarkan pada prinsip-prinsip efisiensi dan efektivitas dari pemanfaran sumber daya itu sendiri.

Prinsip ini akan menjadi lebih penting lagi bila persoalannya berkaitan dengan penerapan kegiatan keteknikan (engineeing), di mana pada umumnya kegiatan teknik akan melibatkan biaya awal (investasi) yang relatif besar dan berdampak langsung pula pada kebutuhan biaya operasional dan perawatan jangka panjangnya.

Buku ini membahas terkait :

Bab 1 Konsep-Konsep Dasar
Bab 2 Nilai Sekarang (Present Worth)
Bab 3 Infinite Analysis Period-Capitalized Cost
Bab 4 Rate of Return Analysis
Bab 5 Sensitivity Analysis
Bab 6 Breakeven Analysis
Bab 7 Payback Period
Bab 8 Menghitung Nilai Investasi Return on Investment (ROI)
Bab 9 Komplikasi Masalah-Masalah Nyata
Bab 10 Analisa Kelayakan Pembangunan Embung

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