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Alternative Sources of Energy

1.1 Introduction

The basic human needs to survive are air, water, food, space to live, and energy, as well as the ability to reproduce, and humans have been constantly searching for means to harvest and convert energy to hence survive. But the interrelation of energy with other needs has not been so evident as in the recent years. When the industrial revolution in Europe caused an evolution of societies and large areas of increasing population density, people realized that factors such as comfortable housing and energy would be relevant to the development of a country. Fossil fuels have become essential in modern societies, and new strategies have been developed to guarantee their uninterrupted supply. In the last 250 years, our population, and correspondingly the demands for industrial and commercial goods, has increased. We have to consider that we live on a planet of constant size and constrained resources, and increased population and their demands may have consequences: economic constraints, new frontiers, wars, international agreements, and heavy pollution [1–3]. Engineers and scientists are working toward the optimized use of resources. Humans are excavating the lands for charcoal, petroleum, gas, uranium, and other minerals, polluting the atmosphere, rivers, oceans, and food sources. Burning fossil fuels and thermal energy conversion just increase entropy and contribute to exhaustion of our planet's energy resources.

In the past the approach to generate large amounts of electrical energy was realized by means of constructing large power plants, which were considered more efficient than smaller ones on an economic scale, such as the Three Gorges Dam in China (18 GW with structure for 22.5 GW), Itaipu Binacional in Brazil (14.0 GW), Sayano–Shushenskaya Dam in Russia (6.4 MW), Churchill Falls Generating Station in Canada (5.43 GW), and Guri Dam in Venezuela (2.0 GW). However, such large power plants caused immense floods, massive power transmission lines and towers, air pollution, modified waterways,

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devastated forests, large population densities in cities, and wars for the dominion of energy resources. Because of these trends in development, distances to energy sources are increasing, material capacities are reaching their limits, fossil reserves are being exhausted, and pollution is becoming widespread. New alternatives must be devised if humanity is to survive today and for the centuries to come.

1.2 Renewable Sources of Energy

The Earth receives solar energy as radiation from the sun in quantity that far exceeds the needs of the entire humankind. The sun generates wind, rain, rivers, and waves by heating the plane. Along with rain and snow, sunlight is necessary for plants to grow. Biomass, the organic matter that makes up plants, in general can be used to produce electricity, transportation fuel, and chemicals. Plant photosynthesis (essentially, the chemical storage of solar energy) creates a range of biomass products, from wood fuel to rapeseed, which can be used for heat, electricity, and liquid fuels.

Hydrogen can also be extracted from many organic compounds, as can water. Hydrogen is the most abundant element on Earth, but it does not occur naturally in gas form. It is always combined with other elements, such as oxygen to form water. Once separated from another element, hydrogen can be burned as a fuel or converted into electricity.

The sun also powers the evapotranspiration cycle, which allows water to generate power in hydro schemes—the largest source of renewable electricity today. Interactions with the moon produce tidal flows, which can produce electricity.

Although humans have been tapping into renewable energy sources (such as solar, wind, biomass, geothermal, and water) for thousands of years, only a fraction of their technical and economic potential has been captured and exploited. Yet renewable energy offers safe, reliable, clean, local, and increasingly cost-effective alternatives for all our energy needs. It can dismantle the power promoted by petroleum, coal, and radioactive materials [2–6].

Research has made renewable energy more affordable today than it was 30 years ago. Wind energy has declined from 40 cents per kilowatt hour (¢/kWh) to less than 5¢. Electricity from the sun through photovoltaics (which literally means "light electricity") has dropped from more than $1/kWh in 1980 to nearly 15¢/kWh today. Ethanol fuel costs have plummeted from $4/gal in the early 1980s to $1.20 today. As a result, renewable energy resource development will result in new jobs, local power plants, and less dependence on oil and radioactive materials from foreign countries [5–7].

There are some drawbacks in developing renewable energy solutions. An example is when solar thermal energy is used, because solar rays are captured through collectors (often huge mirrors) and solar thermal generation requires large tracts of land, and affects natural environment. The environment is also affected when buildings, roads, transmission lines, and transformers are built. In addition, the fluid often used for solar thermal generation is toxic, and spills can occur. Solar or photovoltaic cells are produced using the same technologies as those used to create silicon chips for computers, and this manufacturing process also uses toxic chemicals. In addition, toxic chemicals are used in batteries that store solar electricity through nights and on cloudy days. Manufacturing this equipment also has environmental effects. Therefore, even though the renewable power plant does not release air pollution or use fossil fuels, it still has an effect on the environment.

Wind power has also some drawbacks, involving primarily land use. For example, the average wind farm requires 17 acres to produce 1 MW of electricity (about enough electricity for 750–1000 homes). However, farmers and ranchers can use the land beneath wind turbines. Wind farms can cause erosion in desert areas, and they affect natural views because they tend to be located on or just below ridgelines. Bird deaths also result from collisions with wind turbines and wires. This is the subject of ongoing research. Ultimately, combined with energy efficiency, renewable energy can provide everything fossil fuels offer in terms of energy services: from heating and cooling to electricity, transportation, chemicals, illumination, and food drying.

Energy has always existed and has been used and transformed in one form or another. For example, the energy in a flashlight's battery becomes light energy when the flashlight is turned on. Food, the most natural stored chemical energy, resides in fat tissues and cells as potential energy. When the body uses that stored energy to do work, it becomes kinetic energy. Telephones transform a voice into electrical energy variations, which flow over wires or are transmitted through air. Other telephones change this electrical energy into sound energy through speakers. Cars use stored chemical energy in fuel to move, and they change chemical energy into heat and kinetic energy. Toasters change electrical energy into heat. Computers, television sets, and DVD players change electrical energy into coordinated types of mechanical movement and image and sound energy to reproduce the ambient of life. That means that as soon human beings are awake in the morning, they begin to use more energy than that keeping them alive to switch lights on, for a bath, morning cooking, heaters on, car on, going to work, and so on.

In all such transformations of energy, intermediary transformations are involved. For example, consider the case for a home computer. Electricity allows self-organization of the main processor, according to a preestablished program, to convert ventilator movement to the cooling process for the main processing unit and the motherboard. The alternating current (ac) source power after being distributed to all houses is converted into integrated direct current (dc) power to feed peripheral plates. After many electric processes, the monitor produces a luminous energy on screen. Many processes and intermediary sources are integrated into a simple computer. They produce heat, light, movement, and circulation of electrical current to make it an impressively organized machine. This diversity of energy forms is an example of the changes happening in power systems since the primary source conversion.

1.3 Renewable Energy versus Alternative Energy

All forms of energy are renewable after a lapse of time. For example, coal can be renewed in nature after millions, perhaps billions, of years. Sugar cane would take no more than one year to be replanted. Therefore, a source of energy is considered renewable if the time it takes to be recovered is referred to human life duration. Furthermore, a renewable energy source cannot run out and causes so little damage to the environment that its use does not need to be restricted. On the other hand, no energy system based on mineral resources is renewable because, one day, the mineral deposits will be used up. This is true for fossil fuels and uranium. The debate about when a particular mineral resource will run out becomes irrelevant in this context. A renewable energy source is replenished continuously.

Renewable energy sources—solar, wind, biomass (under specific conditions), and tides—are based directly or indirectly on solar energy. Hydroelectric power is not necessarily a renewable energy source because large-scale projects can cause ecological damage and irreversible consequences. Geothermal heat is renewable but must be used cautiously to guard against irreversible ecological effects.

There is no shortage of renewable energy because it can be taken from the sun, wind, water, plants, and garbage to produce electricity and fuels. For example, the sunlight that falls on the United States in one day contains more than twice the energy the country normally consumes in a year. California has enough wind gusts to produce 11% of the world's wind electricity.

Clean energy sources can be harnessed to produce electricity and process heat, fuel, and valuable chemicals with less effect on the environment than fossil fuel would cause. Emissions from gasoline-fueled cars and factories and other facilities that burn oil affect the atmosphere through the greenhouse effect. About 81% of all US greenhouse gases (GHGs) are carbon dioxide emissions from energy-related sources.

At the International Climate Convention in Kyoto (1997), it was agreed that the developed nations of the world must reduce their GHG emissions. The European Union (EU) committed to reducing emissions of carbon dioxide (CO_2) by 8% from levels in 1990 by the year 2010. The United States was to reduce emissions by 6% and Japan by 7%. These agreements were laid down in the Kyoto Protocol and aimed for a society that uses renewable energies, not fossil fuels [8–10].

Table 1.1 lists the relative gaps between GHG emissions in the non-emissions trading system (ETS) sectors for the first commitment period and the original 2008–2012 Kyoto targets, including land-use change and forestry (LUCF) with and without the use of Kyoto mechanisms, as well as the gap between GHG emissions (along with LUCF) and the Chalmers publication library (CPL)

Table 1.1 Comparison between the original Kyoto credits and the expected actual results (2014–2020).

Country	With Kyoto credits	Without Kyoto credits
Austria	−0.6	+20
Belgium	−2.3	+2
Bulgaria	−39.9	−42
Croatia	−5.8	−6
Czech Republic	−3.8	−17
Denmark	−0.2	+3
Estonia	−10.6	−46
EU15	−5.4	−4
Finland	−4.3	−2
France	−6.3	−7
Germany	−4.3	−5
Greece	−7.9	−8
Hungary	−30	−35
Ireland	−6.3	−3
Italy	+0.7	+1
Latvia	−14.3	−16
Lithuania	−15.7	−44
Luxembourg	+1.7	+23
The Netherlands	−1.5	+3
Poland	−24.3	−25
Portugal	−15.5	−13
Romania	−39.2	−40
Slovakia	−3.8	−15
Slovenia	5.7	−1
Spain	−2.8	+10
Sweden	−18.1	−18
United Kingdom	−11.7	−12

Table 1.2 Emission of CO_2/kWh by renewable sources of power.

Renewable source	Emissions of CO_2/kWh (g)
Waste incineration	600
Biogasifier	−3,800
Biomass	−4,000
Photovoltaic cells	120
Wind turbine	10
Hydraulic power station	25
Nuclear power station	55
Gas-fired power station	400
Coal-fired power station	1,160

Source: Ref. [11–14]. © European Union, 1995–2013.

target with (and issued ERUs) and without Kyoto credits (program for research and innovation in 2014–2020). Gaps are expressed in percentage of base year emissions (including ETS and non-ETS). Negative and positive values, respectively, indicate over-delivery or shortfall as basis for the new EU program for research and innovation in 2014–2020.

It is understandable that the world worries about emissions because our environment is unable to absorb them all. Table 1.2 lists some renewable sources of energy and their approximate production, or absorption, of CO_2/kWh.

Because every source is more or less intensive in what it produces, special measures have to be considered when considering global energy solutions. These include availability, capability, extraction costs, emissions, and durability. Table 1.3 shows indicators of renewable energy technologies, and Table 1.4 illustrates the intensity and frequency characteristics of some renewable sources.

The atomic energy industry seems to be profiting from concerns about GHGs and global climate change. The reason is that most people believe that nuclear energy does not emit GHGs. However, the waste of nuclear energy is either stored in long-lasting containers and thrown into the sea or kept in underground caves. Nevertheless, in the developed northern hemisphere, nuclear energy has little political or social support. The United States has not built a single reactor since the accident in Harrisburg, Pennsylvania, in 1979. In addition, there is no expansion of nuclear power generation in any EU member state. On the contrary, there is support for reduction in and closure of their atomic programs. Eight Western European countries (Denmark, Iceland, Norway, Luxembourg, Ireland, Austria, Portugal, and Greece) have never had a nuclear energy program and have instead favored the alternative programs of

Table 1.3 Indicators of renewable energy technologies.

Renewable energy technology	Volatility (approximate time variation)	Resource availability	Range of generation cost (EU cents/kWh)	Preferred voltage level of grid connection (kV)
Biogas	Year	High	5.18–26.34	1.30
Biomass	Year	High	2.87–9.46	1.30, except co-firing
Geothermal electricity	Year	Low: country specific	3.34–6.49	10.110
Large hydro power: run-of-river power plants	Months	Low	2.53–16.37	220.380
Storage power plants	Months	Low	Not considered	220.380
Small hydro power	Months	High	2.69–24.93	10.30
Landfill gas	Year	Low	2.50–3.91	1.30
Sewage gas	Year	Medium	2.85–6.24	1.30
Photovoltaics	Days, hours, seconds	High	47.56–165.32	<1
Solar thermal electricity	Days, hours, seconds	Low: country specific	12.48–66.97	1.30
Tidal	12 hours	High	Not considered	10.380
Wave	Weeks	High	9.38–45.16	10.380
Wind onshore	Hours, minutes	Low: country specific	4.63–10.80	30.380
Offshore	Hours, minutes	Low: country specific	6.09–13.39	110.380

Source: Ref. [11, 12]. © European Union, 1995–2013.

renewable energy (see Figure 1.1). Outside Europe, only China, South Korea, Japan, Taiwan, and South Africa aspire to expand the share of nuclear power generated in their countries [11–13, 16, 17].

Today, the atomic energy industry is targeting developing countries, and the Kyoto Protocol is paving the way. The protocol provides for the use of "flexible instruments," which were introduced so that wealthy nations could achieve their emission reductions in other countries by paying royalties to compensate for pollution levels. One instrument is the Clean Development Mechanism (CDM), which facilitates the financing of clean technologies (through investment in solar energy, wind turbines, hydroelectric power stations, and energy-saving

Table 1.4 Intensity and frequency characteristics of renewable sources.

System	Major periods	Major variables	Power relationship	Comment	Approximate time variation
Direct sunshine	24 hours, 1 year	Solar beam radiance $G_b^*(\mathrm{W/m^2})$, beam angle from vertical q_z	$P \propto G_b \cos\theta_z$; $P_{max} \cong 1\,\mathrm{kW/m^2}$	Daytime only, highly fluctuating	Hours to seconds
Diffuse sunshine	24 hours, 1 year	Cloud cover, perhaps air pollution	$P <\sim 300\,\mathrm{W/m^2}$	Significant energy, however	Day
Biofuels	1 year	Soil condition, solar radiation, water, plant species, wastes	stored energy 10 MJ/kg	Many variations, linked to forestry and agriculture	Year
Wind	1 year	Wind speed v_o nacelle height above ground z, height anemometer mast h	$P \propto v_o^3$ $\frac{v_z}{v_h} = \left(\frac{z}{h}\right)^b$	Highly fluctuating b ≈ 0.15	Minutes to hours for wind farms
Wave	1 year	Reservoir height H_s, wave period T	$P \propto H_s^2 T$	High power density ≈ 50 kW/m across wave front	Week
Hydro	1 year	Reservoir height H, water volume flow rate	$P \propto HQ$	Established resource	Months
Tidal	12 hours, 25 minutes	Tidal range R; contained area A; estuary length L; depth h	$P \propto R^2 A$	Enhanced tidal range if $L/\sqrt{h} \approx 36{,}000 m^{1/2}$	12 hours
Deep geothermal	None	Temperature of aquifer or rock formation, hence temperature difference from ambient	$P \propto (\Delta T)^2$	Very few suitable locations for electricity generation	None
Surface geothermal	Seasons	Temperatures of low depth ground ($h > 1\,\mathrm{m}$, typically $h > 15\,\mathrm{m}$)	$P \propto (\overline{\Delta T} - ke^{-h})$	Almost everywhere at an average temperature $\overline{\Delta T}$	Half a year

Source: Twidel, 2003—the symbols are standard in the technologies [15]. © European Union, 1995–2013.

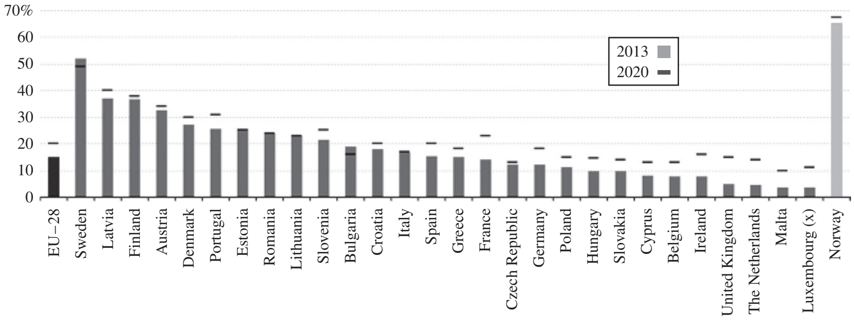

Figure 1.1 Share of renewable powers in gross final energy demand, 2013 and 2020 (dash mark) (%). *Source*: From Refs. [11, 12]. © European Union, 1995–2013.

technologies) and the transfer of these technologies from the northern to the southern hemisphere. Wealthy nations can use emission reductions achieved via the CDM to meet their Kyoto commitments, but the same cannot be said with respect to developing nations. Developing countries gain access to clean, endemic sources and compromise their future in much the same way, as did the northern hemisphere. Is this the ideal win–win solution? The atomic energy industry claims that nuclear energy can be used as an effective solution in the struggle to prevent climate change.

From socioeconomic and environmental points of view, renewable energy increases supply security, has the lowest environmental effect of all energy sources, allows for local solutions, and offers sustainable energy development worldwide. Renewable energy also offers wider opportunities for investment, avoided fuel costs, CO_2 emissions savings, and new jobs. In general, renewable energy technologies are important because of the income that results from manufacturing, project development, servicing, and, in the case of biomass, rural jobs and income diversification for farmers.

From what has been discussed in this section, we can divide the sources of energy into three categories: the ones coming from the sun, the ones coming from the Earth, and the ambiguous (see Table 1.5). Those coming from the sun, like hydropower, wind power, photovoltaics, solar thermal power, and photosynthesis, are welcome and clean. Those coming from the Earth, like coal, uranium, plantations, and petroleum, are not welcome and polluting. Ambiguous ones include geothermal, fuel cells, and biomass. Surface geothermal is welcome because sunshine has warmed the Earth's surface for billions of years. In compensation, the deep geothermal is not welcome since taking boiling water from the Earth's core to feed steam turbines and exchanged it for cold water to fill back where the steam was may not be a good idea in a continuous and worldwide spread. Fuel cells fed by hydrogen from petrol hydrocarbons are not welcome unless if hydrogen is obtained by splitting water molecules using

Table 1.5 Origin of the energy sources.

Origin	Primary sources
Sun (renewable)	Hydro, wind, photovoltaics, solar thermal, photosynthesis, tidal, sea wave, MHD
Earth (not renewable)	Coal, uranium, and petroleum
Ambiguous (can be either types)	Geothermal, plantations, fuel cells, biomass
Harvesting types	Piezoelectric, thermocouple
Space	Cosmic rays

heat from sun irradiation concentrated by mirrors. Biomass used in biodigestors and derived from rubbish to produce power is welcome, but if it is from burnt wood, it is not. Plantations can exhaust the soil after several cycles, but if a rational cycle is selected, it may not. These matters are discussed in greater detail in the next chapters.

1.4 Planning and Development of Integrated Energy

Many studies show that the global wind resource technically recoverable is more than twice the projection for the world's electricity demand in 2020. Similarly, theoretical solar energy potential (see Chapters 5 and 6 for solar thermal and solar or photovoltaics) corresponds to almost 90,000,000 metric tons of electricity per year, which is almost 10,000 times the world total primary energy supply [2–4]. The rapid deployment of renewable energy technologies, and their wider deployment in the near future, raises challenges and opportunities regarding their integration into energy supply systems, as deeply discussed in the Paris Climate Change Conference (COP 21 in November 2015).

The planning and development of integrated energy must consider the environment itself, existence of energy sources, system needs, and local needs where it is desirable to install a renewable energy source. The capability of the grid supply, the electrical and mechanical behavior of the load, the distributed generation (DG) sources, and the effects on the regional economy defines how successful the investment may be.

1.4.1 Grid-Supplied Electricity

The thickness, and hence cost, of conducting cable is inversely proportional to the voltage of power; therefore, high voltages are preferred for electricity supply along transmission and sub-transmission lines. The practical limits relate to safety issues, especially sparking and insulation at high voltage. In practice, the voltage of long distance transmission is 50–750 kV. Local area distribution is 6–50 kV, and supply to consumers is 100–500 V. Internally, in equipment, it is 3–48 V.

The grid electricity is converted from the primary source typically by

Moving wires in magnetic fields (Faraday effect)
Photovoltaic generation with sunlight (photovoltaic effects)
Chemical transformations as in fuel cells and batteries (electrochemical effects)

Transformation of transmission voltages is possible with ac to ac using transformers. However, between dc and dc or between ac and dc, it is necessary to use electronic interfaces, which have become increasingly reliable and cheaper because of solid-state power electronics. Transmission with ac power has more loss per unit of distance than with dc power due to stray capacitances and inductances along lines, which increase current losses. Nevertheless, the ease of transformation means that the majority of power transmission is accomplished with high-voltage ac up to 350 km. The economic facilities of high-voltage dc transmission systems favor distances greater than 500 km.

To regulate power, voltage, speed, and frequency, each method depends on instantaneous matching of load to generation. Generation is distinguished by its economic and physical ability to vary the voltage to match load levels. Examples are

1) Base load generation (difficult or expensive to vary; e.g., nuclear power, large coal, and large biomass)
2) Peak generation (easier to vary quickly but may be expensive; e.g., gas turbines and fuel cells)
3) Standby generation (easy to rapidly increase generation from off or idling modes; e.g., diesel, fuel cells, and gas turbines)
4) Intermittent generation (e.g., run-of-the-river hydroelectricity, photovoltaics, wind, and most renewables, except biomass and geothermal)

Note that fuel cells can be used as peak or standby generation, depending on the availability of hydrogen or fuel gas and the maximum excess power that can be withdrawn from the cell without overly compromising its useful life. The same note is applied to reservoir hydropower, which may be either base (plenty of water) or peaking (limited water) load. Note also that intermittent does not mean unpredictable availability but guarantees that load always equals generation.

1.4.2 Load

It is important to realize that electricity users do not want electricity alone. They want service, such as transportation (vertical or horizontal), lighting, water, welding, motor movement, communication, or ambient conditioning.

The success of the electricity supply must be judged by the availability, quality, and cost of the service. The quality of a service (e.g., heating or water supply) tends to be measured by an intensive parameter (e.g., temperature or pressure) and the availability of that parameter. The cost of the service is measured by an extensive parameter (e.g., energy or kilowatt hours) linked to its availability. The desire for the service presents a demand on the grid system, which power engineers see as load.

Ordinary consumers use the name of the service (e.g., television) for the function instead of the word "load," which is most efficient to use for the consequent electricity consumption and "demand" for the desire of consumers for service. This subtle distinction is maintained in this book.

Satisfactory service can be maintained without the continuous consumption of electricity. For instance, water of a satisfactory temperature can be supplied from a previously heated tank. If the value of the intensive parameter is maintained (i.e., shower temperature), the consumer is satisfied even if the electrical supply is interrupted. A demand that is satisfied by intermittent power is an interruptible load, also called a switchable load. If load and tariff management are used to optimize a power system (e.g., to increase the penetration of renewable energy), it is quite acceptable to use it to induce new trends in energy use.

1.4.3 Distributed Generation

DG is the application of small generators, typically 1–10 MW, scattered throughout a system to provide electrical energy closer to consumers. Current DG power sources include hydropower, wind, photovoltaics, diesel, fuel cells, and gas turbines. Renewable and other generators located downstream in a distribution network and involving small, modular electricity generation units close to the point of consumption are defined in this book as DG.

In this section, we provide a qualitative analysis of the issues that drive the effects of DG on a transmission system. More technical details and deeper insights are dealt with in Chapter 13, where we also define the services that DG can provide to distribution systems. In this section, the transmission services that DG is technically capable of providing are identified, and guidelines are developed to enable DG to participate in markets for these services.

Studies, reports, and experts in the field of DG [1–4] refer broadly to the benefits that DG can provide to transmission and distribution systems. The amount of generation relative to system total load, or penetration, is the most important factor in determining the influence of DG on transmission operation. A single 2-MW generator may have a considerable effect on the operation of a distribution system but goes entirely unnoticed on a transmission system. On the other end of the spectrum, if a fully mature DG market supplies 30% or more of total customer load, the effect and importance to transmission operation will be undeniable. Tougher questions are "What are the effects at penetration levels between the two extremes" and "how should they be treated in respect to system control and economic valuation?" This is addressed by focusing on (i) localized transmission benefits that a relatively small penetration of well-sited DG can provide and (ii) the benefits to the larger transmission system that can feasibly be achieved by growing DG penetrations.

DG can provide services to the distribution system such as capacity support, contingency capacity support, loss reduction, voltage support, voltage regulation, power factor control, phase balancing, and equipment life extension. DG can be defined as generation located at or near a load. Combined heat and power (CHP) is associated with prime movers that provide shaft power to generators and encompasses two broad categories: reciprocating engines and turbines. (Fuel cells may soon make a significant entrance on the CHP stage as well, but they are not yet ready for prime time.) CHP systems (also known as cogeneration) are generally developed by a user to avoid the purchase of power from the grid or by the energy service provider that retails the power to the site.

CHP is considered a subset of DG and can be used when there is a potential for profitable use of thermal energy. CHP is an energy cascade that captures energy normally rejected as part of a process. In the traditional case, steam is raised with a boiler on site, and power is purchased from the local utility. The thermal energy in the steam is then employed for another use.

1.5 Renewable Energy Economics

To meet the demand for a broad range of services (e.g., household, commerce, industry, and transportation needs), energy systems are needed. An energy supply sector and the end-use technology to provide these energy services are also necessary. In the United States, EU, Russia, and Japan, the electricity supply system is composed of large power units—mostly fossil fueled and centrally controlled—with average capacities of hundreds of megawatts. Conversely, renewable energy sources are geographically distributed and, if embedded in distribution networks, are often closer to customers and therefore subject to smaller losses.

In the power sector, most utilities have limited experience interconnecting numerous small-scale generation units with their distribution networks. Complicating matters, the possible level of renewable power penetration depends on the existing electrical infrastructure. For example, transporting to land the power produced by a large offshore wind farm is (economically) possible only where sufficient electricity grid capacity is available. In some locations, new electricity infrastructures have been set up to provide high penetration levels of up to 100% electricity from renewable powers.

Distributed electricity generation, close to the end customer, differs fundamentally from the traditional model of a large power station that generates centrally controlled power. The DG approach is new and replaces the concept of economy of scale (using large units) with the economy of numbers (using many small units), although it has yet to prove itself.

Far from being a threat, DG-based renewable energy can reduce transmission and distribution losses as well as transmission and distribution costs, provide consumers with continuity and reliability of supply stimulate competition in supply, adjust prices via market forces, and be implemented in a short time and with gradated resources because of its modular nature. The International Monetary Fund (IMF) predicts appreciable savings for the transmission and distribution grids because of the increased use of DG. This is a significant and driving argument when recent blackouts in the United States, Brazil, and Italy are taken into account.

1.5.1 Calculation of Electricity Generation Costs

When calculating generation costs, a distinction must be made between existing and potential plants. For existing plants, the running costs (short-term marginal costs) are relevant only for the economic decision as to whether to use the plant for electricity generation. Conversely, for new capacities, long-term marginal costs are important.

1.5.1.1 Existing Plants

Annual running costs are split into fuel costs and operation and maintenance (O&M) costs. Fuel costs are a function of the fuel price of the primary energy carrier and efficiency. O&M costs refer to electricity output, hence must be coupled with full-load hours. In general, one average operation time (full-load hour) is taken for each technology band. Analytically, generation costs for existing plants are given by

$$C = C_{var} = C_{fuel} + \tilde{C}_{O\&M} - R_{heat} = \frac{p_{fuel}}{\eta_{el}} + \frac{C_{O\&M}}{H} \cdot 1000 - p_{heat} \frac{\eta_{heat}}{\eta_{el}} \cdot \frac{H_{heat}}{H_{el}} \tag{1.1}$$

where:

C = Generation costs per kWh in EU/MWh
C_{var} = Running costs per energy unit in EU/MWh
C_{fuel} = Fuel costs per energy unit in EU/MWh
$\tilde{C}_{O\&M}$ = O&M costs per energy unit in EU/MWh
R_{heat} = Revenues gained from purchase of heat in EU/MWh
p_{fuel} = Fuel price primary energy carrier in EU/MWh$_{primary}$
p_{heat} = Heat price in EU/MWh$_{heat}$
η_{el} = Efficiency—electric generation
η_{heat} = Efficiency—heat generation
H_{el} = Full-load hours—electricity generation per annum in h/year
H_{heat} = Full-load hours—heat generation per annum in h/year

The full-load hours represent the equivalent time of full operation for a year. This is calculated for a power plant by dividing the amount of electricity generated per year by the plant's nominal power capacity. For theoretical cost–resource curves, this reflects an important aspect: the suitability of sites. In the case of wind energy, the full-load hours are determined by the wind speed distribution and the rated wind speed of the machines. Knowing the expected full-load hours, the quantity of electricity to be generated can be calculated. Hence, costs per unit are determined. The number of full-load hours divided by the number of hours in a year (8765 hours, on average) equals the system capacity (dimensionless).

1.5.1.2 New Plants

Electricity generation costs consist of variable costs and fixed costs. Generation costs are given by

$$C = C_{var} + \frac{C_{fix}}{q_{el}} = \left(C_{fuel} + \frac{C_{O\&M}}{H_{el}} \cdot 1000 - R_{heat} \right) + \frac{1000 \cdot I \cdot CRF}{H_{el}} \tag{1.2}$$

where:

C = Generation costs per kWh in EU/MWh
C_{var} = Running costs per energy unit in EU/MWh
C_{fix} = Fixed costs in EU
q_{el} = Amount of electricity generation in MWh/year
C_{fix}/q_{el} = Fixed costs per energy unit in EU/MWh
C_{fuel} = Fuel costs per energy unit in EU/MWh
$\tilde{C}_{O\&M}$ = O&M costs per energy unit in EU/MWh
R_{heat} = Revenues gained from purchase of heat in EU/MWh
I = Investment costs per kW in EU/kW
CRF = Capital recovery factor ($CRF = (z \cdot (1+z)^{PT})/((1+z)^{PT} - 1)$)
z = Interest rate
PT = Payback time (PT) of the plant in years
H_{el} = Full-load hours—electricity generation per annum in h/year

Fixed costs occur whether or not a plant generates electricity. These costs are determined by investment costs (I) and the capital recovery factor.

1.5.1.3 Investment Costs

Investment costs differ according to technology and energy source. In general, investment costs per unit of capacity for renewable energy systems are higher than for conventional technologies based on fossil fuels. In addition, differences exist among renewable energy technologies (e.g., investment costs per unit of capacity for small hydropower plants are generally at least twice those for wind turbines).

Investment costs decrease over time and are usually derived annually. It is usual to consider renewable powers as having zero fuel costs, apart from biomass (biogas, solid biomass, and sewage and landfill gas), so running costs are determined by O&M costs only. Therefore, the running costs for renewable energy systems are normally low compared with those of fossil fuel systems.

1.5.1.4 Capital Recovery Factor

The capital recovery factor allows investment costs incurred in the construction phase of a plant to be discounted. The amount depends on the interest rate and the PT of the plant. For the standard calculation of generation costs, these factors may be set as follows for all technologies:

PT of all power plants: 15 years
Interests rate (z): 6.5%

Different interest rates may be applied in any economic study. The interest rate depends on stakeholder behavior and is a function of a guaranteed political planning horizon of the promotion scheme of technology of the investor category.

Generation costs are calculated per unit of energy output, so fixed costs must be related to generation. Hence, fixed costs per unit of output are lower if the operation time of the plant—characterized by full-load hours—is high. Deriving generation costs for CHP plants is similar to calculating them for plants that produce electricity only. Both short-term marginal costs (i.e., variable costs) and fixed costs must be considered for new plants. Of course, variable costs differ between CHP and conventional electricity plants because the revenue from heat power must be considered in the former. In general, no taxes are included in the various cost components.

1.6 European Targets for Renewable Powers

Worldwide, several scenarios share the goal of sustainability in general or in the energy field. Thus, groundbreaking targets toward this goal are important for renewable energy and end-use energy efficiency. Such targets can guide policymakers during decision-making and send important signals to investors, entrepreneurs, and the public. Case studies have demonstrated how concrete targets can lead to increased impact in various fields. In the case of renewable energies, policymakers formulate concrete policies and support measures to foster their development. Investors develop related strategies and renewable businesses as targets convince them that their investment will yield the projected returns.

Renewable energy is available in many environmental energy flows, harnessed by a range of technologies. The parameters used to quantify and analyze these forms are listed in Table 1.4.

A study by C. Kjaer [5] emphasizes 10 requirements for any community-wide mechanism to create a sound investment climate for renewable powers:

1) Compatibility with the “polluter pays” principle
2) High investor confidence
3) Simplicity and transparency in design and implementation
4) High effectiveness in deployment of renewable powers
5) Encouragement of technological diversity
6) Encouragement of innovation, technological development, and lower costs
7) Compatibility with the power market and with other policy instruments
8) Facilitation of a smooth transition (“grandfathering”)
9) Encouragement of local and regional benefits, public acceptance, and site dispersion
10) Transparency and integrity by protecting consumers and avoiding fraud and free riding

1.6.1 Demand-Side Management Options

In the transport sector, biofuels are just beginning to be developed in Europe. However, in some countries, such as Brazil, sugarcane and oily plants already play important roles in the energy matrix. Moreover, the integration of renewable powers requires the adaptation of an infrastructure that has grown over a century of development based exclusively on fossil fuels. Besides the gradual substitution of vehicles in circulation, it is necessary to develop a new supply chain for the production and distribution of biofuels, hence requiring a substantial investment. However, development of the fossil fuel-based transport system also required investment, which was subsidized by the public sector in many countries.

In the heating sector, the full integration of renewable energy requires an adaptation of historical infrastructures. In many parts of Europe, it is already possible to construct buildings completely independent of fossil fuels or electricity for heating needs. This is achieved using state-of-the-art renewable heating and cooling applications linked with energy efficiency measures and demand-side management (see Appendices A and B).

A substantial economic restriction to the integration of renewable heating (i.e., solar thermal, biomass, and geothermal) results in the long lifetime of buildings. The installation of renewable heating systems is more cost-effective during the construction of a building or when the overall heating system is being refurbished. This means that there is a small window of opportunity for cost-effective integration of renewable heating. If this opportunity is lost, a building will remain dependent on fossil fuels or electricity to cover its heating demand for decades. For this reason, it is essential that all possible measures be taken to ensure that renewable heating sources are installed in all new buildings. It is also necessary to promote the use of renewable heating systems whenever a conventional heating system is being modernized.

Renewable heating sources can also be used for cooling. An increasing number of successful systems are being installed, based mainly on solar thermal and geothermal energy. The growing demand for cooling is affecting electricity systems in Europe, and several countries are now reaching peak electricity demand in summer instead of winter. These problems can be mitigated by the development and commercialization of renewable cooling technologies.

The existing infrastructure and market dominance of conventional heating and cooling technologies create a substantial barrier to the growth of renewable heating. Biomass heating and cooling can be competitive in areas where the fuel supply chain is well developed, but this is not yet the case in many parts of the world. Solar thermal systems can be good economic investments, but in many areas, users are not aware of this. In addition, most heating installers are trained only on conventional heating systems and therefore encourage customers to stick to conventional heating. The integration of distinct energy intensity profiles can be considered in these cases.

The choices that millions of citizens make for their homes and offices are crucial to the future integration of renewable energies in the heating and cooling sectors. Raising awareness among the public and training the professionals involved (e.g., conditioning and acclimatization installers, building engineers, architects, and managers of heat-intensive buildings or devices) are therefore very important.

Increasing use of renewable energies must be accompanied by energy efficiency and demand-side management measures at the customer end. Renewable energy development and energy efficiency are interdependent. The EU has always stressed the need to renew commitment at the community and member-state levels to promote energy efficiency more actively. In light of the Kyoto agreement to reduce carbon dioxide emissions, improved energy efficiency, together with increased use of renewable powers, will play a key role in meeting the EU's Kyoto target economically (see Table 1.1). In addition to a significant positive environmental effect, improved energy efficiency will lead to a more sustainable development and enhanced security of supply as well as many other benefits. An estimated economic potential for energy efficiency improvement of more than 18% of present energy consumption still exists today in the EU because of market barriers that prevent the satisfactory diffusion of energy-efficient technology and the efficient use of energy. This potential is equivalent to more than 1900 TWh, roughly the total final energy demand of Austria, Belgium, Denmark, Finland, Greece, and the Netherlands combined.

Special emphasis should be placed on urban areas, where a high proportion of energy is consumed. Urban areas are characterized by highly developed infrastructures, which do not always easily allow a rapid increase in renewable energy generation. The fact that electrical network infrastructures are generally over-dimensioned in urban areas can, in some cases, allow a high penetration of photovoltaic generators and wind energy without changing the existing cabling, transformer stations, and so on. However, in general, the future energy infrastructure will need to be designed from the beginning to accommodate renewable energy effectively at a high level. The small contributions that every home make by using energy derived directly from nature (such as wind, heat, coolant, light, photovoltaic electricity, and clean air) will make the biggest difference in the end.

1.6.2 Supply-Side Management Options

The European renewable energy industry has already reached an annual turnover of $10 billion and employs 200,000 people. Europe is the global leader of renewable energy technologies, and the use of renewable powers has a considerable effect on the investments made in the energy sector. Renewable energy replaces imported fuels, with beneficial effects on the balance of payments. Although, per unit of installed capacity, renewable energy technology is more capital intensive, when the external costs that have been avoided are taken into account, investing in renewable powers turns out to be cheaper for society than business-as-usual investments in conventional energy. Renewable energy technologies are often on a smaller scale than fossil fuel and nuclear projects, and they can be brought online more quickly and with lower risks. Finally, deployment of renewable powers creates more employment than do other energy technologies.

The development of smarter, more efficient energy technology over the past decades has been spectacular. Technologies have improved, and costs have fallen dramatically (see Figure 1.2) as estimated by the leveled cost that an equal-valued fixed revenue delivered over the life of the asset's generating profile would cause the project to break even [6, 7]. This can be roughly calculated as the net present value of all costs over the lifetime of the asset divided by the total electrical energy output of the asset.

The levelized cost of electricity (*LCOE*) is given by

$$LCOE = \frac{sum\ of\ costs\ over\ lifetime}{sum\ of\ electrical\ energy\ produced\ over\ lifetime} = \frac{\sum_{n=1}^{y} \frac{I_n + M_n + F_n}{(1+r)^n}}{\sum_{1}^{n} \frac{E_n}{(1+r)^n}} \tag{1.3}$$

where:

I_n = Investment expenditures in the year n
M = O&M expenditures in the year n
F_n = Fuel expenditures in the year n
E_n = Electrical energy generated in the year n
r = Discount rate
y = Expected lifetime of system or power station in years

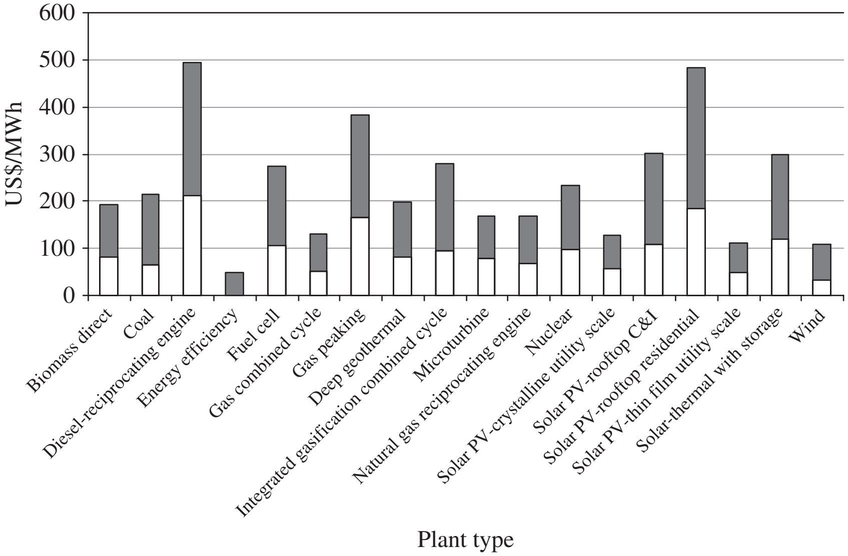

Figure 1.2 List of the minimum and maximum NREL-LCOEs. *Source*: © Investment bank Lazard, 2015.

The examples of wind and solar or photovoltaic cells are striking. Investment costs for wind energy declined by around 3% per annum over the past 20 years. For solar or photovoltaic cells, unit costs have fallen by a factor of 10 in the past 20 years (stimulated initially by the space program).

In EU, renewable powers already make up a significant share of total energy production. Germany, for example, has doubled its renewable output in the past five years to 8% of the total electricity production. Denmark now has got 18% of its electricity from wind power alone and created an industry with more jobs than in the electricity sector. Spain has leapt from using virtually no renewable powers a few years ago to become the second biggest wind power country in Europe, with 6000 MW of capacity. Countries such as Finland, Sweden, and Austria have supported the development of very successful biomass power and heating industries through fiscal policies, sustained R&D support, and synergistic forestry and industrial policies. In addition to saving significant carbon dioxide emissions, equipment from all three countries is exported worldwide. Table 1.6 presents some typical technical and economical characteristics of selected renewable energy technologies, and Table 1.7 presents the US Electricity Production Mix in 2015 and Table 1.8 presents some selected global indicators of renewable energy.

Table 1.6 Technical and economical characteristics of selected renewable energy technologies.

	Unit capacity	Electrical efficiency	Thermal efficiency	Lifetime	Full-load operating
Type of source	**kW**	**%**	**%**	**Years**	**Hours**
Gas diesel engines	3–10,000	30–45	45–50	15	5,000
Microturbines	25–250	15–35	50–60	15	5,000
Stirling engines	10–150	15–35	60–80	15	5,000
Steam engines	0.5–10,000	15–35	40–70	15	5,000
Wind power	0.1–5,000	40–50	—	20	2,500
Fuel cells	0.5–2,000	38–55	40–70	15	5,000

Table 1.7 US electricity production mix, 2015.

Primary source	Production (%)
Coal	33
Natural gas	33
Nuclear	20
Hydropower	6
Other renewables	7
Biomass	1.6
Geothermal	0.4
Solar	0.6

Source: Ref. [8–10].

1.7 Integrating Renewable Energy Sources

Integration of renewable energy sources involves integrating in a system any energy resource that naturally regenerates over a short period. This time scale is derived directly from the sun (such as thermal, photochemical, and photoelectric energy), indirectly from the sun (such as wind, hydropower, and photosynthetic energy stored in biomass), or from other natural movements and mechanisms of the environment (such as geothermal and tidal energy). In the long term, renewable energies will necessarily dominate the world's energy supply system for the simple reason that there is no alternative. Mankind

Table 1.8 Selected global indicators of renewable energy.

Selected global indicators	2014	2015	Units
Investment in new renewable capacity (annual)	270	285	Billion USD
Existing renewables power capacity, including large-scale hydro	1,712	1,849	GWe
Existing renewables power capacity, excluding large hydro	657	785	GWe
Hydropower capacity (existing)	1,055	1,064	GWe
Wind power capacity (existing)	370	433	GWe
Solar PV capacity (grid-connected)	177	227	GWe
Solar hot water capacity (existing)	406	435	GWth
Ethanol production (annual)	94	98	Billion liters
Biodiesel production (annual)	29.7	30	Billion liters
Countries with policy targets for renewable energy	164	173	

cannot survive indefinitely off the consumption of finite energy resources, concentrate supplies on some points on Earth, or carelessly spread its population over the world.

Today, the world's energy supply is based largely on fossil fuels and nuclear power. These sources of energy will not last forever and have proved to be a major cause of environmental problems. Environmental effects of energy use are not new, but it is increasingly well known that they range from deforestation to local and global pollution. In less than three centuries since the industrial revolution, mankind has burned away roughly half of the fossil fuels accumulated under the Earth's surface for hundreds of millions of years. Nuclear power is also based on limited resources such as uranium, and the use of nuclear power creates such incalculable risks that nuclear power plants cannot be ensured.

Renewable sources of energy are in line with an overall strategy of sustainable development. They help reduce and not create dependence on energy imports, thereby ensuring a sustainable security of supply. Furthermore, renewable energy sources can improve the competitiveness of industries, at least in the long run, and have a positive effect on regional development and employment. Renewable energy technologies are suitable for off-grid services; they can serve remote areas of the world without expensive and complicated grid infrastructure.

The ability to integrate electricity generated from renewable powers into grid supplies is governed by several factors, including

The variation with time of power generated
The extent of the variation (availability)

The predictability of the variation
The capacity of each generator
The dispersal of individual generators
The reliability of plants
The experience of operators
The technology for integration
The regulations and customs for embedded generation

Despite these difficulties, the experience for the past 25 years has shown that ever-increasing amounts of electricity from renewable powers can be integrated into grid supplies without significant financial penalty. The standard response of grid operators that are accustomed to large-scale centralized generation is that intermittent and dispersed renewable energy generation cannot be so integrated. However, given the requirement to accept specific renewable energy generation, the technology and methods have followed successfully. Examples include

Electrical safety equipment and grid–fault disconnectors
Grid-linked inverters for photovoltaic or solar cells and power from buildings
Doubly fed induction generators for variable speed wind turbines
Voltage reinforcement on rural power lines
Co-firing of steam boilers with biomass
Gas turbines for the output of gasifiers

The outstanding example of ever-increasing integration of renewable energy generation into the grid is Jutland, western Denmark, due to their willing application of new technologies and practices. In the early 1980s, the limit for wind power exported to the grid was considered to be 20% of the total supply. However, by 2003, about 40% of the annual electricity supply was from wind, and at times, significant areas were supplied totally by wind power.

Nevertheless, there are fundamental limitations for any renewable energy generation technology and plant; for instance, the sun never shines at night. In addition, in the middle of large towns and cities, the surface roughness for wind move is not acceptable for small towers. Therefore, it is essential to integrate renewable energy generation options with control and storage such that they complement each other.

1.7.1 Integration of Renewable Energy in the United States

The United States currently relies heavily on coal, oil, and natural gas for its energy. Fossil fuels are nonrenewable: they draw on finite resources that will eventually dwindle and become too expensive or too environmentally damaging to retrieve. In contrast, renewable energy resources such as hydropower, wind energy, and solar energy are replenished constantly and will never run out.

As in any other place, most renewable energy in the United States comes directly or indirectly from the sun. Sunlight, or solar energy, can be used directly for heating and lighting, to generate electricity, and for cooling as well as for a variety of commercial and industrial uses. The sun's heat also drives winds (whose energy is captured with wind turbines) and evaporates waters, turning them into rain or snow, which then flows into rivers or streams and whose energy may be captured in water dams.

Other renewable sources include geothermal energy, which is tapped from the Earth's internal heat for electric power production and heating and cooling buildings, and the oceans' tides, which come from the gravitational pull of the moon and sun. In fact, ocean energy comes from a number of sources. In addition to tidal energy, there is the energy of the oceans' waves, which are driven by tides and winds. The sun also warms the surface of oceans more than it warms ocean depths, which creates a temperature difference that can be used as an energy source. All these forms of ocean energy can be used to produce electricity.

In contrast to fossil energy, renewable energy is an attractive source for several reasons: clean environment, long-lasting life, increased jobs, increased comfort, and industry and energy self-sufficiency through decreased dependence on other nations. An economy that uses less energy also produces less pollution, and an energy-efficient economy can grow without using more energy. Energy efficiency means using less energy to accomplish the same task resulting in spending less money on energy by homeowners, schools, government agencies, businesses, and industries. The money that would have been spent on energy can instead be spent on consumer goods, education, services, and products. From 1970 to 2000, US energy consumption grew only 45% although the US gross domestic product increased 160%. In other words, the energy used per dollar of gross domestic product decreased 44% from 1970 to 2000. By 1999, GHG emissions from energy use had risen 13% above the levels in 1990. During that period, energy use increased 14.9%.

1.7.2 Energy Recovery Time

The cost of electricity depends entirely, or largely, on the size of power stations. Between 1960 and 1980, the ideal size of a station rose from 400 to 1000 MW. These days, 5 MW is regarded as ideal because small-scale power generation permits a flexible response to energy demand and return of capital. Small-scale units such as wind turbines, photovoltaic cells, fuel cells, and bio-gasification plants represent the future.

Regardless of the type of primary source, it takes energy to convert energy from one type into another. The lower the specific energy content, the more energy intensive the conversion process is. When the specific energy content is low, the energy process chain uses more energy than it generates in electricity.

Most of the primary energy extracted today has a profitable content that makes conversion cost-effective.

However, if any energy were to gain momentum, a point would come when the specific energy conversion would no longer be cost-effective. The amount of time a power plant needs to operate before all the energy consumed in the chain has been earned back (and the power plant begins to produce net energy), or the energy recovery time, is highly dependent on the specific energy content of the primary source. It is difficult to compare this figure with the energy recovery time for fossil fuel-powered power stations. A fossil fuel power station has to recover only the electricity used for construction and other constituent processes in the chain. In such a case, the recovery time for power stations fired by gas and oil is 0.09 of a full-load year (approximately 0.13 of a calendar year); for coal-fired power stations, it is 0.15 of a full-load year (approximately 0.21 of a calendar year) [4, 16, 17]. Nevertheless, unlike modern gas-fired power stations that generate and supply commercial heat, alternative sources of energy such as nuclear power plants, wind turbines, and photovoltaic systems can generate only electricity. All the energy used in the chain is recovered in the form of electricity, which increases recovery time considerably. As a frame of reference, assume that fossil fuel-fired power stations must recover the energy used in their construction only in the form of electricity. This results in a recovery time of 0.7 of a full-load year for gas- or oil-fired power stations, which is approximately one calendar year. Coal-fired power stations have a longer recovery time. Table 1.9 is a comparative list of the recovery time of selected sources of energy.

Improvements in conversion yields and production methods will help reduce the recovery time for photovoltaic systems in the future. Photovoltaic technology is at a peak of development and now is in the sharply rising section of the learning curve, which means that prices will fall significantly, as more capacity is commercialized. It is conceivable that the recovery time for photovoltaics will drop to less than one year as technical progress continues. Nuclear energy, on the other hand, is a mature technology; the price of nuclear power will not decrease as more nuclear power stations are built. In the past, there were even

Table 1.9 Recovery time of selected sources of energy.

Alternative source	**Recovery time (years)**
Wind	0.62–0.90
Gas and oil	1
Photovoltaic system	1.5–3
Nuclear power station	10–18

Source: Ref. [4]. © European Union, 1995–2013.

cost hikes of approximately 14% a year until the mid-1980s. Since 1979, no new nuclear power stations were ordered in the Organization of Economic Cooperation and Development (OECD) countries, which ended the competitive time in which further price rises could occur. Clearly, the recovery time for nuclear power stations is much longer than that of other power stations and will never decrease. In contrast, the recovery time for photovoltaic systems, in particular, is certain to decrease if new technologies and materials are used.

Environmental issues such as the greenhouse effect have focused attention on fossil fuel combustion and electricity generation around the world. In Australia, 47% of the annual emissions of greenhouse carbon dioxide come from fossil fuel-fired power plants [16, 17]. As coal-based plants are retired, due to age and greenhouse concerns, there is an opportunity for renewable energy generation sources to grab a larger share of the global electric energy market.

Wind systems, solar systems, storage components, and complete energy systems are now commercially available from many suppliers [5] to fill niche markets.

Fundamental research (especially in the production of thin-film solar or photovoltaic devices, hydrogen from sun-mirrored heat, and new forms of batteries) is occurring in many countries, and these activities are steadily reducing the cost of renewable energy systems. However, there are still issues to resolve before such systems gain a bigger portion of the electric energy marketplace. Such systems must lower the overall cost of delivered energy, gain acceptance by a conservative industry, and convince the industry's customers that renewable energy systems are safe, reliable alternatives to conventional grid-supplied power.

Another issue is that although the energy supply may be free, the cost of using wind and solar energy is not because structures and energy collectors must be built and energy storage must be provided. Any initiative that increases the energy collected or stored will lead to a reduction in the price of energy delivered from a complete system [5, 8]. Balanced and optimized are terms frequently used to indicate that a system is designed to size the renewable, storage, and fuel-based components to deliver minimal all-of-life costs in a specific site and for a specific customer-loading pattern. Such a system operates to maximize renewable energy capture and to minimize all-of-life costs of components.

1.7.3 Sustainability

Humans require only a few basic needs in order to survive and be sustainable: air, water, food, space, reproduction, and energy. Everything else is exceeding human demands. The Fifth Environmental Action Programme of 2000 established a EU legislation and defined sustainable development as "that which meets the needs of the present without compromising the ability of future generations to meet their own needs" [12, 13]. The policy objectives underlying this definition were to ensure compatibility between economic growth and efficient and secure energy supplies together with a clean environment.

Environmentally polluting by-products are produced by conventional energy generation, which also depends on finite energy sources that are gradually being depleted. However, energy is essential for socioeconomic progress in developing and industrialized countries, and the demand for energy will increase with global population. For example, waste to energy (WTE) or energy from waste (EFW) is the process of generating energy in the form of electricity and/or heat from the primary treatment of waste. Incineration or combustion of organic materials such as waste with energy recovery is the most common WTE implementation. All new WTE plants in OECD countries incinerating waste (residual MSW, commercial, industrial, or RDF) must meet strict emission standards, including those on nitrogen oxides (NO_x), sulfur dioxide (SO_2), heavy metals, and dioxins.

Targets established in the EC white paper of 1997 foresees a 12% share of renewable powers in Europe's total energy consumption by 2010 (double the 1997 share). Individual targets for each renewable energy technology are also set. Annual growth rates between 1995 and 2001 show that one sector (wind) is far beyond the target and that others (i.e., hydro, geothermal, and photovoltaics) are in line with expectations. To reach the overall and sector targets (which is feasible), specific support actions have to be taken soon for technologies that lag behind, such as biomass and solar thermal. Therefore, the deployment status of energy consumption by energy source in the United States did not improve much since 1995 and worsen in some cases as illustrated in Table 1.10.

Given the present state of market progress and political support, the expectation is that if strong additional support measures are adopted, the overall contribution of renewable energy consumption in 2020 will be 20%. These estimates are based on a conservative annual growth scenario for the technologies. To reach the target, strong energy efficiency measures have to be taken to stabilize energy consumption between 2010 and 2020. Further prediction would include the Hubbert curves and the energy depletion curves (see Figure 1.3). These novelties in the energy market have opened discussions about what would be necessary socially, politically, and economically for a country to adapt to new environmental surroundings.

In particular, when the director of the National Aeronautics and Space Administration's Goddard Institute for Space Studies enlightened the US Congress to the fact that human-induced global warming was detectable in the climate record, some skeptical members of the Congress argued that the data were unclear and inconclusive. According to the Goddard Institute, the consequences predicted for global warming include worldwide floods, droughts,

Table 1.10 US energy use and consumption by energy source.

	Production	Use
Source	**1995 (%)**	**2014 (%)**
Coal	21.69	18.00
Natural gas	24.54	26.60
Petroleum	27.22	35.10
Nuclear	7.95	8.27
Hydroelectric	3.83	2.56
Biomass	3.25	4.49
Solar	0.08	0.32
Wind	0.03	1.60
Deep geothermal	0.36	—

Source: © Renewable Energy Manual, 2014.

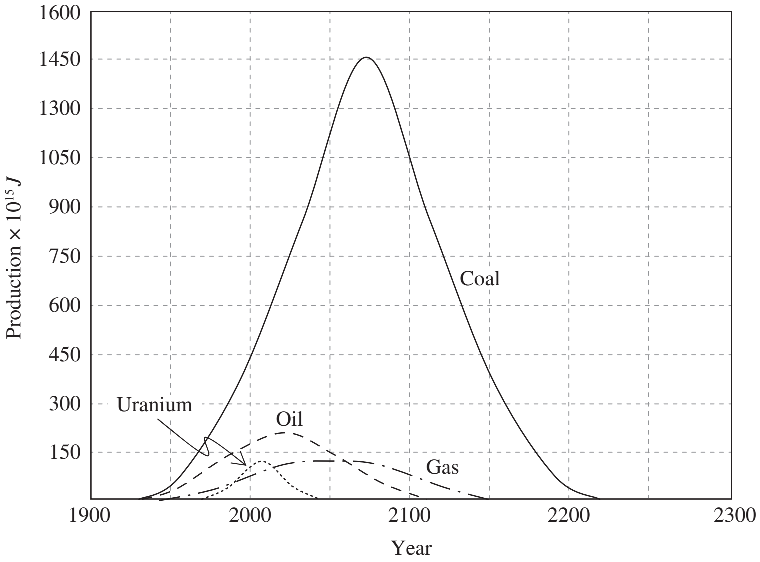

Figure 1.3 Energy depletion curves.

rising sea levels, category 5 hurricanes, and typhoons. These effects, though, were widely debated. Agreement was barely reached when deep reductions in carbon emissions cannot be made economically without the use of energy-efficient and renewable energy technologies.

Since then, standards have become necessary to regulate new power interconnections with distribution systems. The Institute of Electrical and Electronics Engineers (IEEE) Standard for Interconnecting Distributed Resources with Electric Power Systems is the first in the 1547 series of planned interconnection standards [7–9]. There are major obstacles to an orderly transition to the use and integration of distributed power resources with electric power systems, as discussed in Chapter 15. Examples include the lack of uniform national standards and tests for interconnection operation and certification, uniform national building, and electrical and safety codes. Resolving this requires time to develop and promulgate consensus. The 1547 standard is a milestone for the IEEE standard-setting process and demonstrates a model for ongoing success for further national standards and for moving forward in modernizing the national electric power system.

1.8 Modern Electronic Controls for Power Systems

Renewable and alternative energy sources must eventually be integrated with existing electric systems. Power electronics are a crucial enabling technology toward this end. Power electronics are part of electronic application systems that encompass the entire field of power engineering, from generation to transmission and distribution to transportation, storage systems, and domestic services. The progress of power electronics has generally followed microelectronic device evolution and influenced the current technological status of renewable energy conversion.

Figure 1.4 depicts the 2015 US energy flow in the net primary consumption given in quads and exajoules. A quad is 1 quadrillion (1015) Btu, and an exajoule is 1018 J.

The power produced by renewable energy devices such as photovoltaic cells and wind turbines varies on hourly, daily, and seasonal bases because of the variation in the availability of the sun, wind, and other renewable resources. This variation means that power is sometimes not available when it is required and that on other occasions there is excess power. The variable output from renewable energy devices also means that power conditioning and control equipment is required to transform this output into a form (i.e., voltage, current, and frequency) that can be used by electrical appliances. Therefore, energy must be stored and power electronics used to convert this energy.

Power-processing technology can be classified according to the energy, time, and transient response required for its operation. As the cost of power electronics falls, system performance improves. Applications are proliferating, and it is expected that this trend will continue with high momentum in this century. Modern industrial processes, transportation, and energy systems benefit tremendously in productivity and quality enhancement with the help of

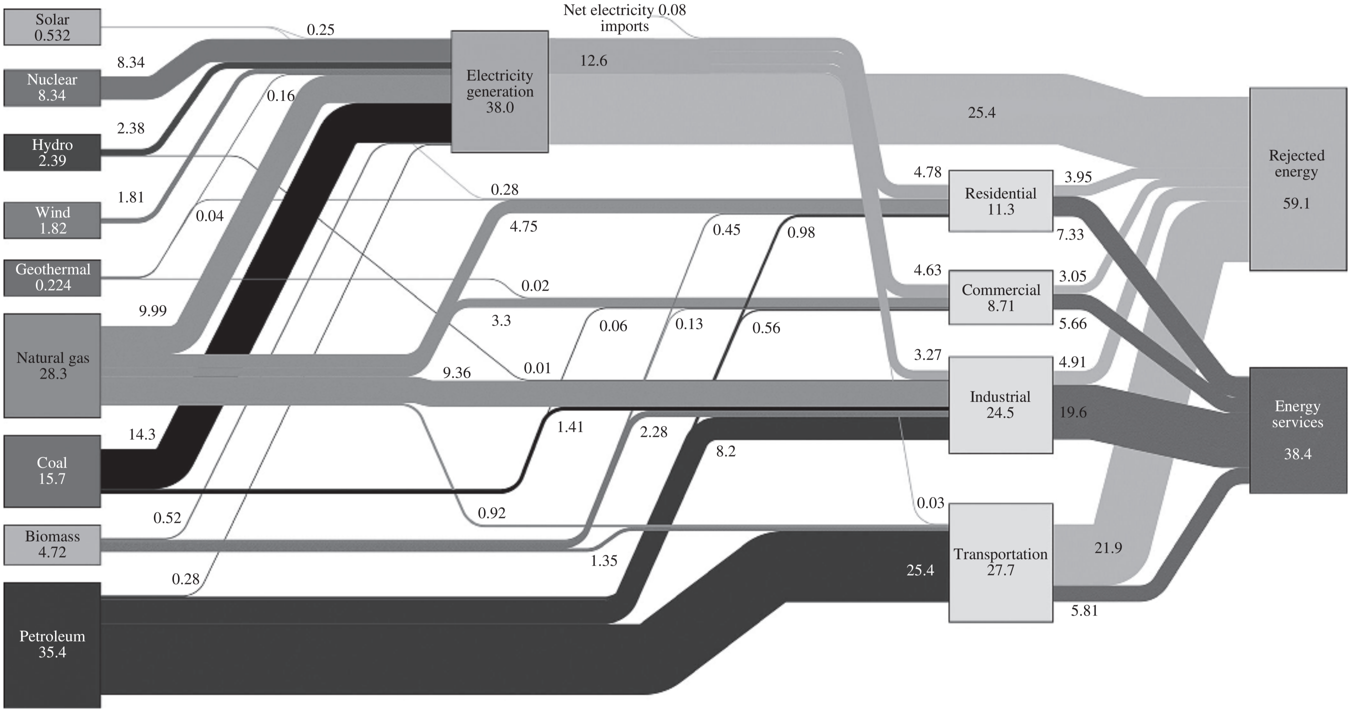

Figure 1.4 Estimated US consumption in 2015: 97.5 quads. *Source*: Data is based on DOE-EIA0035(2016/6) [9]. © Lawrence Livermore National Laboratory, 2016.

power electronics, on which efficient energy conversion from renewable sources depends leading to the future emphasis of the environmentally clean sources of power—such as wind, photovoltaics, and fuel cells.

In this book, we are concerned with how alternative and renewable energy can be integrated electrically. Power electronic technology plays a major role in the injection of electrical power to the utility grid, as discussed in Chapter 12. If only photovoltaic and fuel cell systems are used, a dc-link bus could be used to aggregate them, and ac power could be integrated through dc-to-ac conversion systems (inverters). If only hydro or wind power is used, variable-frequency ac voltage control can be aggregated into an ac link through ac-to-ac conversion systems that can be created through several approaches discussed in this book.

Of course, alternative energy sources such as diesel and gas can also be integrated with renewable powers. They have a consistent and constant fuel supply, and the decision to operate them is based more on straightforward economics. Gas microturbines and diesel generators are commercially available with synchronous generators that supply 60 Hz, and a direct interconnection with the grid is typically easier to implement. When integrating and mixing these sources, a microgrid can be based on a dc- or ac-link structure. The design of such a microgrid must incorporate energy storage with seamless control integration of source, storage, and demand.

1.9 Issues Related to Alternative Sources of Energy

Figure 1.5 reunites all modern issues related to implantation of an alternative source of energy developed in this book. Beginning with the selection of the primary source, this has to do with consumers, proximity, availability, or facilities for extraction of electrical power. From there it is necessary to select the type of energy conversion, for instance, from mechanical, radiation, or chemical to electricity. This electricity may be in dc or ac, whose magnitude and frequency must be controlled.

For alternative sources of energy, it is fundamental to maximize the extraction of power from the primary source so as to compensate the investment. It is quite possible to be able to manage the heat usually generated by any power supply to be converted into electricity. Use of heating source was not very usual in the conventional power plants by the distance between the source and the consumer. Particularly, fuel cells may almost double their efficiency if electricity and heat are consumed. Almost all alternative sources of energy can be complementary to each other as, for example, wind and photovoltaic or hydro and fuel cells due to their availability period in the nature. A decision has to be made if the small power plant has to be standing alone or interconnected to the other distribution system.

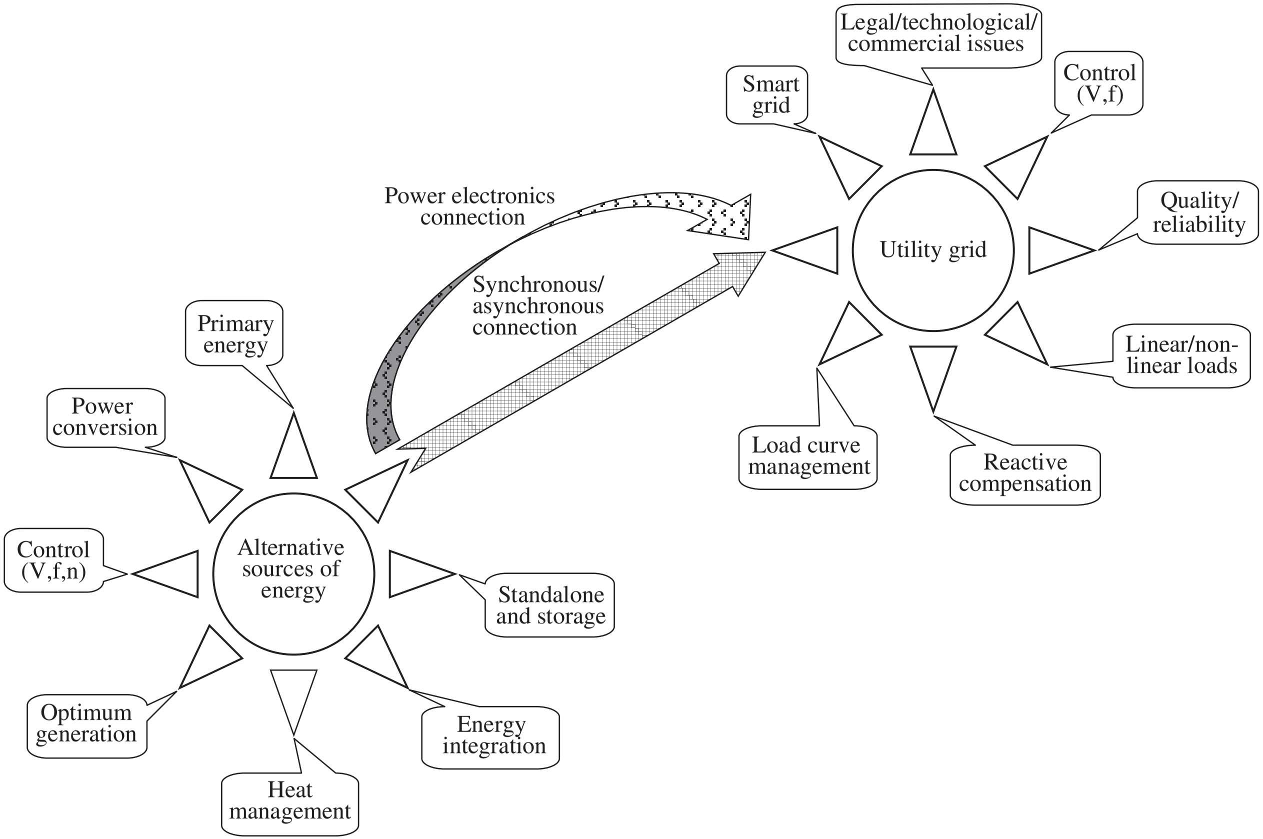

Figure 1.5 Issues related to interconnection of alternative sources of energy.

Another important decision is whether to connect or not the alternative power plant to the mains and how to do it (directly or through power electronics). Synchronous and asynchronous generators can be both connected directly to the mains grid without many problems. Dc generators such as photovoltaic, dc rotating machines, and fuel cells definitely have to use power electronics to control the frequency, rotation, and voltage levels (see Table 1.11).

Current applications of smart grid in distribution systems are taking into consideration the existence or absence of alternative sources of energy. These sources can be used to cope with transient problems or as backup for critical loads, like hospitals, alarms, and security installations (Table 1.12).

Table 1.11 Applications of primary sources.

Primary source	Conversion	Usual application
Biomass	Mechanical	Electrical power
Combined cycle	Mechanical	Electromechanical
Deep geothermal	Mechanical	Electrical power
Diesel	Mechanical	Electrical power
Fuel cells	Chemical	Electrical power
Fluidized bed	Mechanical	Electromechanical
Horizontal ocean thermal	Mechanical	Electrical power
Hydropower	Mechanical	Electrical power
Integrated gasification	Mechanical	Electromechanical
Magneto-hydrodynamics	Electrical	Electrical power
MHD	Electrical	Electrical power
Microturbine	Mechanical	Electrical power
Nuclear	Thermomechanical	Electrical power
Photovoltaics	Electrical	Electrical power
Piezoelectric	Electrical	Electrical power
Sea tidal power	Mechanical	Electrical power
Sea wave power	Mechanical	Electrical power
Solar thermal	Direct	Heating
Surface geothermal	Direct	Conditioning
Thermocouple	Electrical	Electrical power
Traditional boiler	Mechanical	Electrical power
Vertical ocean thermal	Mechanical	Electrical power
Wind power	Mechanical	Electrical power
WTE	Combustion	Electrical/heat power

Table 1.12 US average estimated levelized cost (2013 $/MWh) of electricity (LCOE) entering service in 2020.

Plant type	Capacity factor (%)	Levelized capital cost	Fixed O&M	Variable O&M (including fuel)	Transmission investment	Total system LCOE	Subsidy	Total LCOE including subsidy
Dispatchable technologies								
Conventional coal	85	60.4	4.2	29.4	1.2	95.1		
Advanced coal	85	76.9	6.9	30.7	1.2	115.7		
Advanced coal with CCS	85	97.3	9.8	36.1	1.2	144.4		
Natural gas-fired								
Conventional combined cycle	87	14.4	1.7	57.8	1.2	75.2		
Advanced combined cycle	87	15.9	2.0	53.6	1.2	72.6		
Advanced CC with CCS	87	30.1	4.2	64.7	1.2	100.2		
Conventional combustion turbine	30	40.7	2.8	94.6	3.5	141.5		
Advanced combustion turbine	30	27.8	2.7	79.6	3.5	113.5		
Advanced nuclear	90	70.1	11.8	12.2	1.1	95.2		
Geothermal	92	34.1	12.3	0.0	1.4	47.8	−3.4	44.4
Biomass	83	47.1	14.5	37.6	1.2	100.5		
Non-dispatchable technologies								
Wind	36	57.7	12.8	0.0	3.1	73.6		
Wind offshore	38	168.6	22.5	0.0	5.8	196.9		
Solar PV	25	109.8	11.4	0.0	4.1	125.3	−11.0	114.3
Solar thermal	20	191.6	42.1	0.0	6.0	239.7	−19.2	220.6
Hydroelectric	54	70.7	3.9	7.0	2.0	83.5		

Legal, technological, and commercial issues are related to the decision of either building up or not a power plant to inject power into the grid.

Regulations try to make a safer, standardized, and reliable injection of power into the grid. With respect to the technological side, one wants to make sure whether the harmonic, sags, tilts, droops, and other common events in small power plants are not going to affect substantially the other consumers. Commercial units must satisfy all regulations, including quality and reliability, and have available spare parts everywhere and be long-lasting units because blackouts are very disturbing when affecting many people.

The small power plant control in power systems is mostly related to load management, reactive compensation, and coping with nonlinear loads. The power supply depends essentially on a careful control design taking into account cost, reliability, and power supply quality.

Increasing efficiency of a facility will not resolve the humanly energetic needs if we keep increasing the number of facilities. Durability and usage sharing are thinkable strategies. As discussed in the COP21, the forms of energy originated from the sun will be perhaps the only way out if we want to survive in our planet.

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