Chapter 2
Energy and Environment Perspectives

2.1 Introduction

The inevitable increase in population and the economic development that must necessarily occur in many countries have serious implications for the environment, because energy generation processes (e.g., generation of electricity, heating, cooling, or motive force for transportation vehicles and other uses) are polluting and harmful to the ecosystem.

Energy is considered to be a key player in the generation of wealth and also a significant component in economic development. This makes energy resources extremely significant for every country in the world. In bringing energy needs and energy availability into balance, there are two main elements: energy demand and energy supply. In this regard, every country aims to attain such a balance and hence develop policies and strategies. A number of factors are considered to be important in determining world energy consumption and production, including population growth, economic performance, consumer tastes, technological developments, government policies concerning the energy sector, and developments on world energy markets.

As stated above, there is an intimate connection between energy and the environment. A society seeking sustainable development ideally must utilize only energy resources that cause no environmental impact (e.g., that release no emissions to the environment). However, since all energy resources lead to some environmental impact, it is reasonable to suggest that some (not all) of the concerns regarding the limitations imposed on sustainable development by environmental emissions and their negative impacts can be in part overcome through increased energy efficiency. Clearly, a strong relation exists between energy efficiency and environmental impact since, for the same services or products, less resource utilization and pollution is normally associated with increased energy efficiency. Energy conservation, that is, the use of energy resources in a rational manner, represents another factor that together with energy efficiency can lead to the stabilization of the rate of growth of energy demand, which is predicted to increase rapidly in the near future due to population growth and excessive use of various commodities (e.g., cars, computers, air conditioners, household electronic

İ. Dinçer and C. Zamfirescu, *Sustainable Energy Systems and Applications*,
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equipment, etc.). Any reduction in the energy demand of a society leads to the extension of its available energy resources.

This chapter discusses energy resources and the environmental impact associated with their use, including global warming and acid rain. The notion of sustainable energy engineering is defined. The main kinds of energy resources are listed and characterized in terms of resource amounts, production, and consumption. To be able to project a future sustainable economy, it is important to set the context by correlating various factors, such as the present energy resources, the population growth, and the evolution of energy demand in the next 30 to 50 years. Fossil fuels and nuclear fuel are finite, while other energy resources are renewable. The term *renewable energy* suggests an energy that can be renewed, or in other words cannot be depleted. A forecast of energy resource consumption and depletion up to the year 2050 is given. Some case studies are presented at the end of the chapter, and a number of problems are proposed.

2.2 What Is Sustainable Energy Engineering?

Since historical times, humans burned wood to obtain the high-temperature heat necessary for various purposes such as melting metals, extracting chemicals, converting heat into mechanical power, as well as cooking and heating. During burning, the carbon in wood combines with O_2 to form CO_2, which is then absorbed by plants and converted back to carbon for use as a fuel again.

The Industrial Revolution started in the eighteenth century in the United Kingdom, when, essentially, manual and animal labor had been replaced with machine labor, which needed other sources of high-temperature heat in addition to coal combustion. Oil, natural gas, and coal then started to be used extensively. As a consequence, the CO_2 concentration in air increased, leading to the beginning of global warming. During the past three decades, the public has become more aware of this issue, and researchers and policy makers have focused on this and related issues by considering energy, environment, and sustainable development.

The world population is expected to double by the middle of the twenty-first century, and economic development will almost certainly continue to grow. Global demand for energy services is expected to increase by as much as one order of magnitude by 2050, while primary energy demands are expected to increase by 1.5 to 3 times. Simultaneously, energy-related environmental concerns such as acid precipitation, stratospheric ozone depletion, and global climate change (the greenhouse effect) will increase. These observations and others demonstrate that energy is one of the main factors that must be considered in discussions of sustainable development.

Several definitions of sustainable development have been put forth, including the following common one: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Many factors contribute to achieving sustainable development. One of the most important is the requirement for a supply of energy resources that is fully sustainable. Increased energy efficiency is also important. The discussion in this chapter is intended to apply to both industrialized and developing countries.

While environmental issues in general have been influencing developments in the energy sector for some time, climate change poses an altogether different kind of challenge. Problems such as acid precipitation could be dealt with in part by administrative measures, such as vehicle exhaust standards or emission limits for power stations, which affect comparatively small numbers of economic factors. Technical fixes with a relatively limited scope, such as fitting flue gas cleaning equipment or catalytic converters, could contain the problem. However, emissions of greenhouse gases are so dispersed that it is not possible to take this local and relatively small approach in dealing with climate change. The nature of the problem demands a more comprehensive energy policy response that affects the actions of energy consumers and producers in all countries.

Sustainable energy engineering is a new branch of engineering with a specialty in designing, developing, and promoting sustainable energy-generation systems. This branch of engineering is interdisciplinary in nature. Advanced engineering thermodynamics (including its modern tools of analysis and design, such as exergy and constructal) stand at the base of sustainable energy engineering. Other disciplines that are important include engineering economics, environmental engineering, chemistry and biochemistry, policy, and the physical sciences. In principle, the aim of sustainable energy engineering is to develop and promote the art of using the energy resources available on earth in a manner that is sustainable, regardless of the nature of the resource. For example, fossil fuels can be combusted by paying an energy penalty. The combustion must be completely clean, with CO_2 capture and sequestration.

2.3 Fundamental Energy Sources on the Earth

Earth as a planet of the solar system draws its energy from three fundamental sources, namely, solar radiation, geothermal heat, and the planet's spinning torque combined with gravitational forces generated by the moon–earth–sun planetary system (which is sometimes called "lunar" energy). The lunar energy as a combination of planet spinning and gravitational forces generates tides that are a derived form of renewable energy, called tidal. Other forms of renewable energy can be derived from the fundamental ones. For example, geothermal energy represents a source of thermal energy originating from the earth's hot core. The geothermal energy can be either used directly as thermal energy for heating, or it can be converted into electricity by a heat engine. Solar energy is the source of many forms of renewable energies and phenomena such as wind, rain, lighting, hydro energy, crop growth and biomass, fossil fuels (which are derived from fossilized plants converted into hydrocarbons or coal), etc. In this section, we analyze the fundamental sources of energy in the following order: solar, geothermal, and tidal (lunar).

2.3.1 Solar Energy

Solar energy originates on the sun, which is a star consisting mainly of hydrogen gas and that concentrates more than 99% of the mass of the whole solar system. The average temperature of the sun is 5,500°C and the average sun–earth distance is 150 Gm. Sunlight consisting of a broad spectrum of electromagnetic radiation hits the terrestrial atmosphere after traveling more than 8 minutes through interplanetary space. The energy associated with the solar radiation drives almost all life systems on earth and the earth's climate and weather.

A general understanding of solar energy is suggested with the help of Fig. 2.1. There one sees the earth as a closed thermodynamic system having two kinds of boundary surfaces (refer to the paper by Reis and Bejan 2006). One of the boundaries is a hot surface with temperature T_H, heated by the sun, and that covers an area A_H extending from the southern to the northern polar circle and having the equator in the middle (depicted with white in Fig. 2.1). The second boundary is a cold surface of area A_L formed by the two polar zones (the South and North Pole) having the temperature T_L and cooled by the radiation heat transfer with the universe. The earth system operates as a heat engine between the temperature limits T_H and T_L. Solar and terrestrial radiations are delivered and rejected at the source and the sink, respectively, of the extraterrestrial solar–earth–universe heat engine depicted in Fig. 2.1.

The heat flux Q_H received by this heat engine at the hot surface is proportional to $A_H(T_S{}^4 - T_H{}^4)$, where T_S = ~5,500 K is the temperature of the solar radiation and $T_H \ll T_S$ is the average temperature on the globe, that is, ~300 K. Neglecting T_H with respect to T_S results in $Q_H \sim A_H T_S{}^4$.

Similarly, one can estimate the heat flux Q_L lost by the earth at cold surfaces, which is proportional to $A_L(T_L{}^4 - T_\infty{}^4)$, where the universe background temperature is $T_\infty \sim 3$ K (see Reis and Bejan 2006). Since $T_L \gg T_\infty$, it results that $Q_L \sim A_L T_L{}^4$. Therefore, the efficiency of the terrestrial heat engine can be estimated with

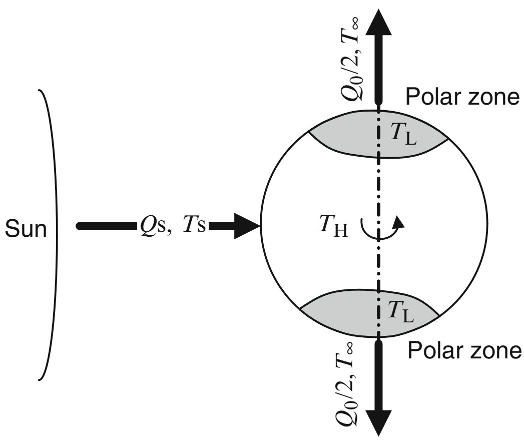

Fig. 2.1 The sun–earth–universe power plant that models solar energy conversion

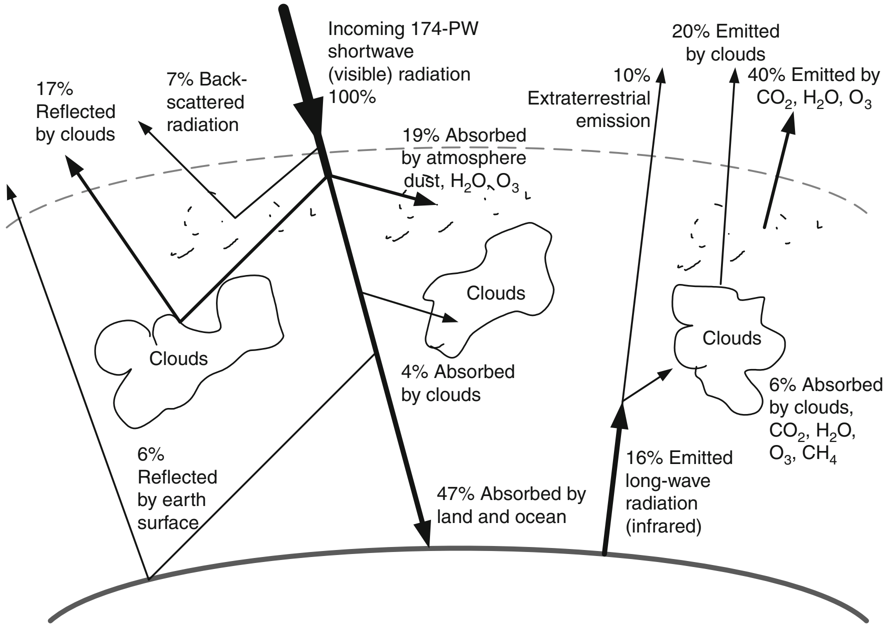

Fig. 2.2 The energy inventory of shortwave and long-wave radiation energy on the earth [data from Tiwari and Ghosal (2007)]

$\eta \sim (Q_H - Q_L)/Q_H = (1 - A_L T_L{}^4)/A_H T_S{}^4$, which is more than 0.99 and which means that due to the high temperature of the sun with respect to the temperature on the earth's surface, corroborated with the low background temperature of the universe, one may have on the earth a high efficiency of solar energy conversion into work. Nevertheless, the work generated by the sun–earth–universe heat engine is dissipated or used in various processes. The atmosphere and hydrosphere flows "consume" a significant part of this work. More exactly, winds and air movements in the atmosphere and oceanic currents in the hydrosphere are generated by solar energy.

Figure 2.2 presents the energy inventory of radiation associated with solar light as well as with terrestrial infrared emissions. All the percents shown on the figure refer to the incident solar radiation that is a flux of energy equal to about 174 PW (where 1 PW is 10^{15} W). About 30% of the incoming solar radiation is reflected back into the terrestrial atmosphere by the earth; this is called the "albedo" of the earth, which is defined as the ratio between the reflected and incident radiation and denoted by α. The reflection is caused by various phenomena, such as backscattering (7%), reflection by clouds (17%), and reflection by the earth's surface (6%). Then, about 19% of the incoming solar radiation is absorbed by the water vapor, dust, and ozone molecules present in the atmosphere, while about 4% is absorbed by clouds. The remaining 47% is absorbed by the earth.

The earth emits radiation at a temperature that corresponds to the average surface temperature (at 300 K the emitted blackbody radiation has a 10 μm wavelength, which

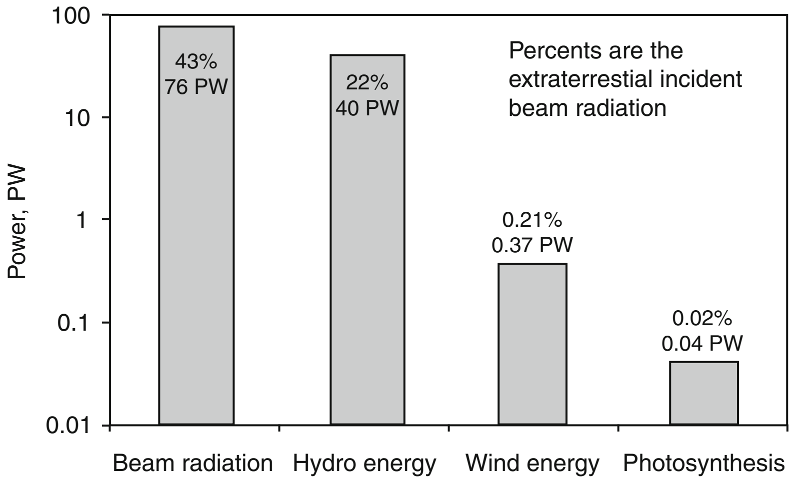

Fig. 2.3 The distribution of solar energy source absorbed by the earth [data from Tiwari and Ghosal (2007)]

is in the infrared spectrum). The radiation emitted by the land and ocean surface amounts to about 16% of the incident solar radiation. Only 10% of this quantity reaches the extraterrestrial space, the rest being absorbed by clouds and by the greenhouse gases present in the atmosphere or reflected back by the clouds. Basically, the atmosphere is heated by the earth's surface through infrared radiation, conduction, and water evaporation. The clouds emit infrared radiation in the extraterrestrial space of an amount that is 20% of the total incident radiation of 174 PW, while 40% is the infrared emission associated with atmospheric water vapor, ozone, and carbon dioxide.

Figure 2.2 shows that the amount of reflected radiation (both short- and long wave) is, from left to right (6 + 17 + 7 + 10 + 20 + 40)% = 100%, that is, the same as the incident solar radiation (of 174 PW). This fact is not in contradiction with the model introduced by Fig. 2.1. The equality of the energy fluxes that enter and leave the terrestrial system is a condition of having an average constant temperature on the earth. In any other situation, the earth's temperature will increase or decrease until an equilibrium is achieved. Figure 2.1 details the mechanism by which the earth's climate is driven by the solar and background radiations in a similar manner as a heat engine is driven by a temperature differential at the source and sink. The work generated by the heat engine presented in Fig. 2.1 is in fact completely destroyed, that is, converted back into heat, which is eventually released outside the terrestrial atmosphere. Thus, overall, the earth does not gain any energy, but it needs to keep its temperature constant.

A series of processes are driven by the incident solar energy on the earth. A breakdown of solar energy use in various natural processes is shown in Fig. 2.3. An amount of 76 PW representing 43% of the incident extraterrestrial solar radiation is the so-called beam radiation, which heats the earth's surface (the land and the ocean).

This energy can be harvested by engineered systems and used for various purposes. Here are some technologies that typically can be used for converting beam radiation into other forms of energy:

- Ocean thermal energy conversion (OTEC) uses the difference in temperature between the ocean surface and the deep waters to drive a heat engine that produces electricity or synthetic fuels (e.g., ammonia can be produced by OTEC energy using nitrogen from air and hydrogen from water).
- Solar ponds are pools of saltwater whose surface is exposed to solar radiation. A gradient of temperature is formed in the pond due to stratification; the temperature at the pool bottom reaches up to 90°C. The harvested energy can be used for either space or process heating, desalinization, or electrical power generation.
- Solar-driven heat engines can concentrate the solar radiation to obtain high-temperature sources and convert the associated heat into electricity and lower grade process or space heating, which is cogeneration.
- Photovoltaic technology transforms the incident solar radiation directly into electricity.
- Other applications such as process heating, house and space heating, water heating, cooking, steam generation, and desalinization are possible.

All these energy conversion technologies represent forms of renewable energy conversion. Supposing, for example, that all the 76 PW associated with beam radiation is converted into electricity with 20% efficiency. The result is 15 PW of electrical power; this figure can be compared with the average world energy consumption rate of 0.015 PW; that is, the direct beam radiation energy if fully harvested can generate 1,000 times more electricity than the world total energy consumption rate. This comparison gives us an idea about the abundance of solar energy, which appears to be an inexhaustible source.

Moreover, 22% of the incident extraterrestrial solar radiation, amounting to 40 PW, is consumed by the hydrological cycle. The water cycle can be regarded as a natural way of storing solar energy in the form of potential energy of water. Solar energy heats water in seas, oceans, and lakes, which results in evaporation. Solar energy also heats snow in colder regions that sublimates, forming water vapor directly. Water vapor is also generated by plants and animal transpiration and by humid soils through evaporation. The vapor rises into the air and forms clouds where the temperature is lower to allow condensation. Precipitation in the form of rain and snow is formed. Through this assembly of processes, important amounts of water are transported from the plains to the heights and thus hydro energy is formed. Dam and accumulation lakes can be constructed to generate hydroelectricity.

Other forms of solar energy are wind (0.37 PW or 0.21%) and photosynthesis (0.04 PW or 0.02%). Photosynthesis is a means of storing solar energy in the form of chemicals. For example, glucose and ATP (adenosine triphosphate) are substances synthesized by plants from photosynthesis in order to store energy. Basically, wind energy can be harvested with various kinds of wind turbines, while the energy of plants can be retrieved in the form of biomass energy. Moreover, fossilized biomass has been converted in underground reservoirs into fossil fuels such as natural gas, coal, and petroleum of various kinds.

It is instructive to know the intensity of the incident beam radiation at the earth's surface. This value can be determined based on the solar constant, which is defined as the extraterrestrial solar radiation intensity per unit of surface and has the average value of 1,367 W/m^2. However, 30% of this radiation is reflected back into extraterrestrial space due to the albedo factor, which leaves 957 W/m^2. If one denotes the earth's radius by R, the incident radiation is the projected area of the earth's sphere, πR^2; however, the radiation distributes on average over the whole earth's surface, which is the area of the earth's sphere, $4\pi R^2$. In conclusion, the average intensity of solar beam radiation is on the order of 957/4 = 240 W/m^2.

2.3.2 *Geothermal Energy*

Geothermal energy manifests in the form of heat and has its source in the earth's core, where some nuclear reactions are assumed to occur. The earth's core temperature is estimated to be ~5,000 K, and due to rock conductivity the temperature at about 4 km below the earth's surface can reach ~90°C. The intensity of geothermal heat is comparatively low with respect to solar energy intensity, namely ~0.1 W/m^2 versus ~240 W/m^2 for geothermal solar, respectively (see Blackwell et al. 1991). However, at places where geysers, hot springs, hot rocks, or volcanoes exist, there is a much larger local potential for geothermal energy. The total estimated amount of geothermal energy is on the order of 10^{16} PJ (where 1 PJ is 10^{15} J). The geothermal heat flows from the earth's core to the surface at a rate of about 44 TW (where 1 TW is 10^{12} W), which is more than double the world's energy consumption rate of ~15 TW. However, since this heat is too diffuse (~0.1 W/m^2), it cannot be recovered unless a geographic location (i.e., geothermal site) shows a higher intensity geothermal resource. A simple calculation yields that at the consumption rate of 44 TW the geothermal heat will be exhausted after ~10^{12} years.

2.3.3 *Tidal Energy*

Tidal energy is the unique form of energy derived from the combined effect of the planet's spinning motion and the gravitational forces associated with the earth–moon and earth–sun systems. Because the most important effect is due to the gravitational forces of the moon, this kind of energy is sometimes called "lunar energy." Tidal energy is another kind of hydropower, in the sense that the energy is transmitted through water movement. However, hydro energy is originated by the hydrological cycle, while the nature of the tides is different (viz. gravitational).

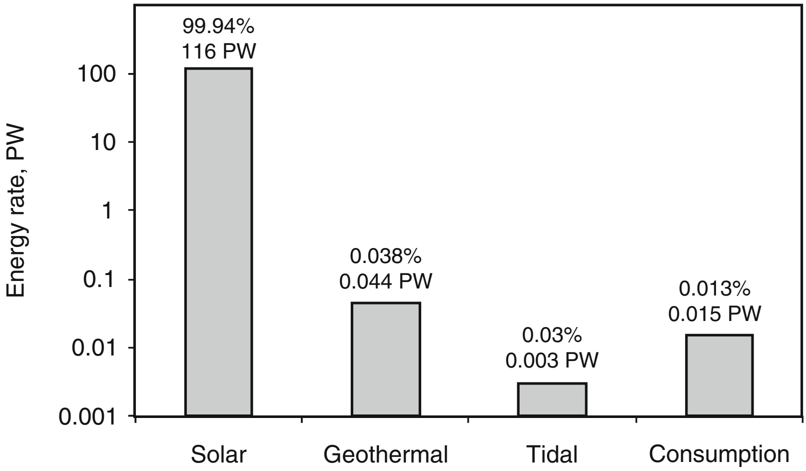

Fig. 2.4 The energy rate of the essential renewable sources and the rate of world energy consumption [data from Tiwari and Ghosal (2007)]

Figure 2.4 compares the average rate of energy consumption in the world with the rate at which the three kinds of fundamental sources may be available. The rate at which solar energy is available can be calculated from Fig. 2.3 as 76 + 40 + 0.37 + 0.04 = 116.41 PW; the rate of geothermal energy (total) available is 0.044 PW, while the rate of retrievable tidal energy is 0.003 PW. Figure 2.4 has been constructed based on these numbers and the rate of world energy consumption of 0.015 PW.

2.4 Biomass Energy

Biomass is a word derived from biological mass; thus biomass energy suggests a form of energy derived from living systems. In general, biomass energy refers to the energy embedded in materials such as wood and other crops that can be combusted or converted into synthetic fuels. The photosynthesis process can be written in a simplified manner as follows:

$$6CO_2 + 6H_2O \xrightarrow{\text{LIGHT}} C_6H_{12}O_6 + 6O_2,$$

where the products are glucose and oxygen. Some 2.8 MJ of light energy per mole of synthesized glucose is needed, and the efficiency of the photosynthesis process can be assumed to be 0.5% to 1%. On average, 1 square meter of the earth's surface is hit with incoming solar radiation of 240 W for 8 hours per day; that is, one can consider the incident radiation energy to be 2.5 kWh per day per square meter, or say 1,000 kWh per year per square meter. Assuming that 0.8% from this incident energy is transformed into glucose by plants, one gets the equivalent of 8 kWh per

Table 2.1 Energy content of biomass sources

Biomass type	GJ/kg	GJ/m^3	Biomass type	GJ/kg	GJ/m^3
Green wood	6	7	Dry dung	16	4
Dry wood	15	9	Fresh grass	4	3
Oven dry wood	18	9	Straw	15	2
Charcoal	30	9	Sugar cane	17	10
Paper	17	9	Domestic refuse	9	2

square meter per year of solar energy stored in glucose, which is the equivalent of 10 mol or 1.8 kg of glucose that can be produced per square meter per year.

The above figure is approximate, and assumes that the biomass is the same as glucose from the energy point of view. In fact, various kinds of biomass have different energy content. The energy content of the main kinds of biomass is listed in Table 2.1.

2.5 Fossil Fuels

It has been mentioned above that through photosynthesis, over long periods of time, all carbonaceous fuels including coal, petroleum, and natural gas were formed. In general, the energy of fossil fuel is used through direct combustion; therefore, this form of energy is mainly thermal. However, it is also possible to produce synthetic fuels from fossil fuels, such as hydrogen, ethanol, diesel, methane, or ammonia. There are three main kinds of fossil fuels, namely coal, petroleum, and natural gas; these will be discussed in this section.

2.5.1 Coal

Coal mainly comprises organic substances derived from plants that form sediments that also embed other mineral inclusions. There are various types of coal, each with its specific calorific heat (see, e.g., Goswami and Kreith 2008). The main component of coal is carbon. Coal plays a vital role in power generation, steam production, and steel manufacturing processes. However, it has a limited role in residential, commercial, and transportation applications. The calorific value of coal and its carbon content is presented in Table 2.2.

In Fig. 2.5, the evolution of coal production in the last three decades is presented, while in Fig. 2.6 the distribution of coal reserves in the world is shown.

2.5.2 Petroleum

Petroleum (also called crude oil) is a naturally occurring hydrocarbon-based liquid or solid (e.g., bitumen forms) found in underground rock formations. The main

Table 2.2 Parameters of various kinds of coal

Coal type	Carbon content by weight	Heat content (kJ/kg)
Lignite	~70%	<28,500
Gas coal	~83%	<35,000
Fat coal	~88%	<35,400
Forge coal	~90%	<35,400
Nonbaking coal	~91%	<35,400
Anthracite	>92%	<35,300

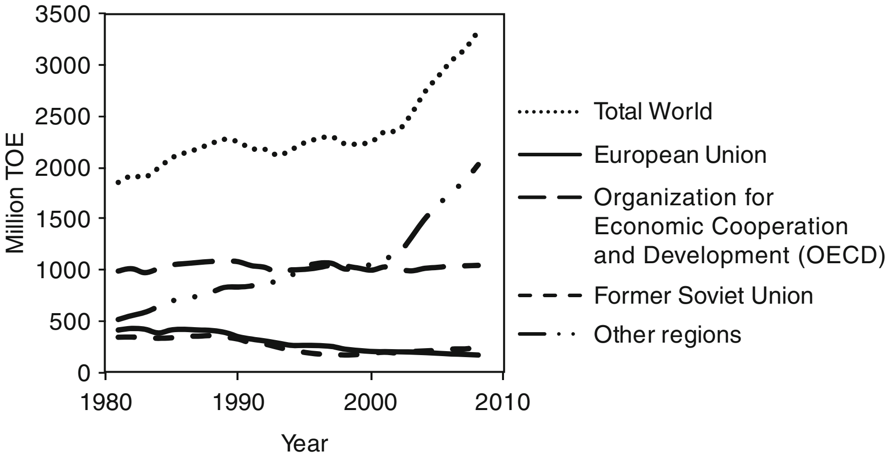

Fig. 2.5 Historical coal production in millions of tons of oil equivalent (TOE) [data from BP (2008)]

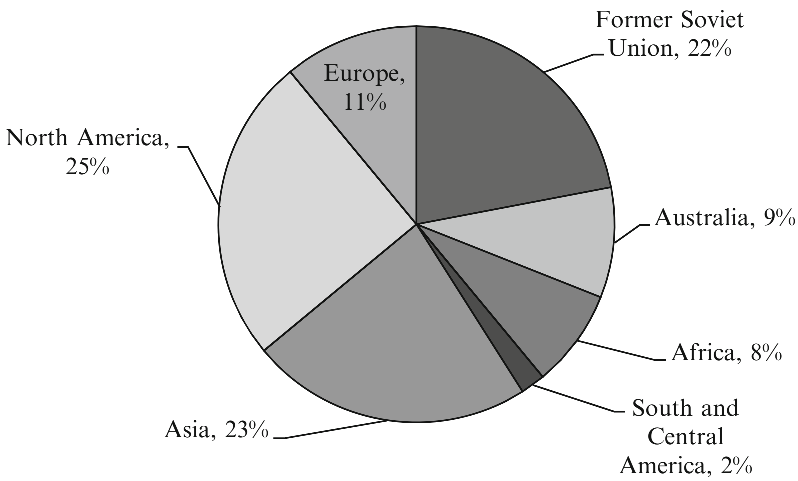

Fig. 2.6 Approximation of distribution of coal reserves in the world [data from BP (2008)]

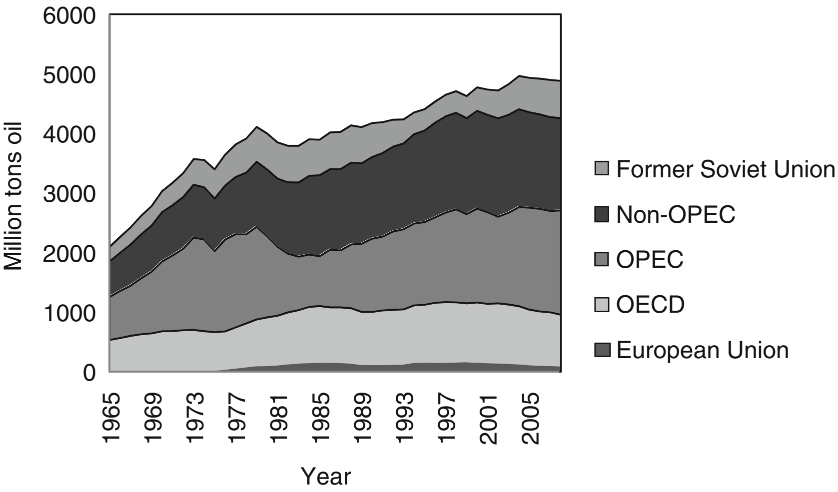

Fig. 2.7 Trend of oil production in the last 50 years [data from BP (2008)]

hydrocarbons included in petroleum are alkanes, cycloalkanes and aromatics, asphaltics, naphthalenes, and parafins. Out of the total world oil reserves, 30% is conventional oil, 15% heavy oil, and 25% extra heavy oil, and 30% of petroleum is found in the form of bitumen and oil sands. Petroleum is the number one primary source for producing transportation fuels. In Fig. 2.7, the trend of oil production for the last 50 years is shown.

2.5.3 Natural Gas

Fossil natural gas contains mainly methane and occurs naturally in oil fields, natural gas fields, and coal beds. Russia has the largest proven resource of natural gas of 47 PNm^3 (where PNm^3 stands for peta ore 10^{12} normal cubic meters). World production of natural gas accounts for 20% of world energy production, and its production is projected to double by 2025 (see, e.g., Goswami and Kreith 2008). The historical trend of natural gas production in the world is presented in Fig. 2.8.

2.6 Nuclear Energy

Nuclear energy in the form of electricity and heat is obtained through controlled nuclear fission reactions. About 15% of the world's electrical energy production originates from nuclear energy. Also, nuclear energy is used for propulsion of naval vessels. More than 400 nuclear power plants are operational worldwide at present, with an installed capacity of over 370 GWe (where GWe is giga watt electric).

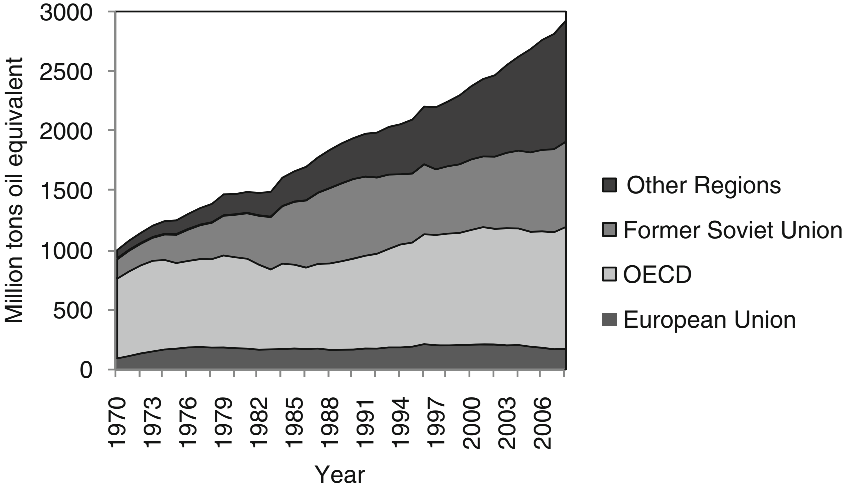

Fig. 2.8 Historical trend of natural gas production in the world [data from BP (2008)]

The conventional resource of nuclear energy is represented by uranium. The main chemical form of the uranium in the ore is U_3O_8, from which 1 ton produces 0.85 tons of uranium, which consists mainly of ^{238}U and only 0.71% ^{235}U. Therefore, one calculates that 1 ton of ore contains 5.9 kg or 1.38×10^{25} atoms of ^{235}U, which in a nuclear reactor could produce ~180 MeV of fission energy that can be converted into 40 GWh of electrical energy. The resulting fission residues are radioactive products with great potential as high specific-energy sources. For comparison purpose, one can note that 1 ton of coal produces 2.8 MWh of electrical energy, that is, 14,000 times less than the nuclear fission reaction. In Fig. 2.9, the trend of electricity production by nuclear power plants from 1965 until the present is presented.

2.7 Proven Fuel Reserves

It is recognized that fossil and nuclear fuel will be depleted, since they are finite resources. For example, the proved reserves of petroleum, natural gas, coal, and nuclear fuels are presented in Fig. 2.10. Considering this prediction and the rate of production in 2008 (BP 2008), the exploitable oil resources will last the least amount of time (about 42 years).

Regarding nuclear fuels, the total reserves were estimated based on Price and Blaise (2002) and include all conventional resources (uranium, plutonium, and thorium) plus the estimated reserves that are not possible to exploit with today's technology, comprising uranium found in phosphate-based minerals and uranium recovered from seawater.

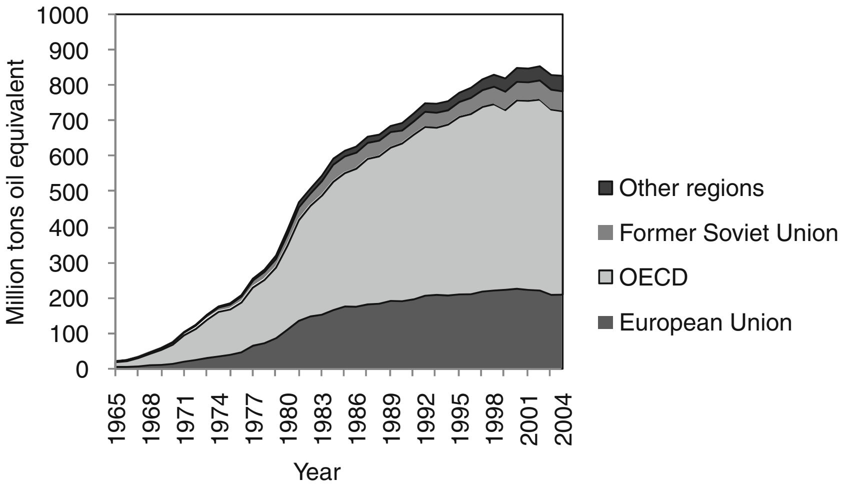

Fig. 2.9 Historical trend of nuclear electricity production [data from BP (2008)]

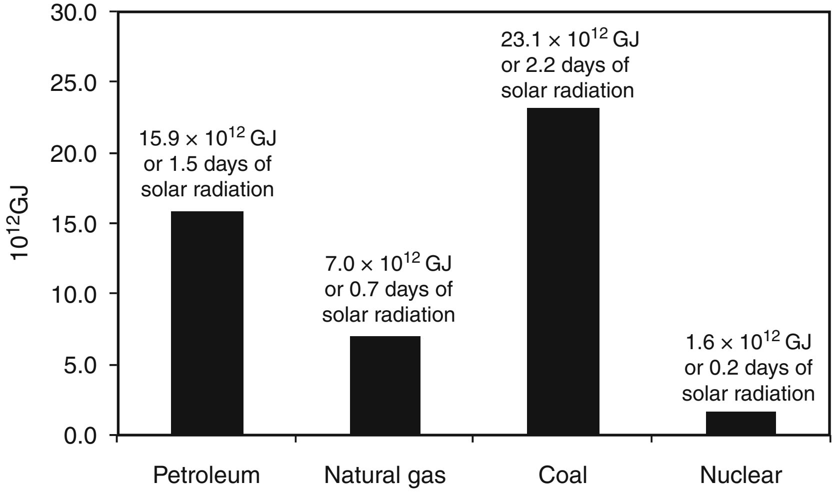

Fig. 2.10 Proved global fossil fuel reserves in year 2008 [data from BP (2008)]

An indicator denoted as R/P is introduced in Fig. 2.11 and represents the reserves versus production ratio, which is calculated by dividing the reserves remaining at the end of any year by the production in that year. The R/P ratio, measured in "years," gives an estimate of how long the respective resource will last. According to the R/P ratio in 2008, coal lasts the longest among the three main fossil fuels (133 years).

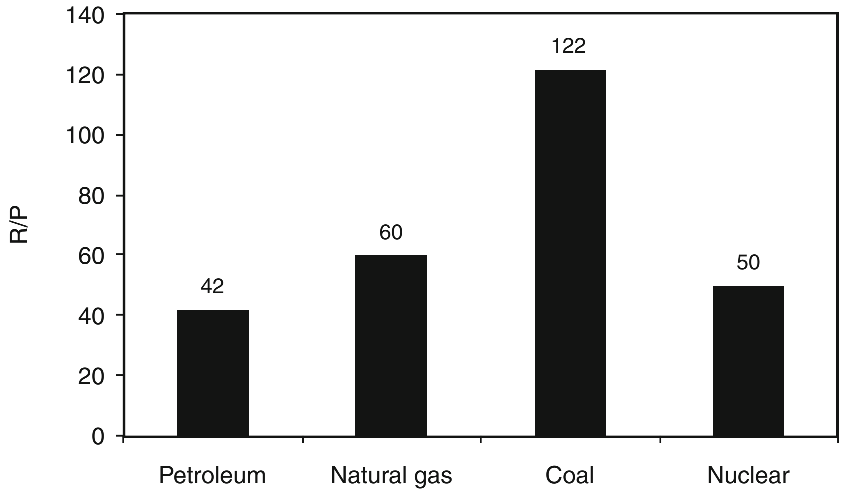

Fig. 2.11 Global fossil fuels reserves versus production ratio (R/P) in year 2008 [data from BP (2008)]

One notes that in Fig. 2.10 the resource reserves were indicated in two units: the amount of the energy resource in GJ, and the number of years needed to accumulate the equivalent energy from solar radiation incident on the earth's surface. Assuming that solar energy can be fully captured, in 2 years it will amount to the equivalent of the proven reserves of oil (see Fig. 2.10). Thus, the energy content accumulated in nearly 11 years is equivalent to that of the proved reserves of oil, natural gas, and coal combined.

Most of the world's energy supply, accounting for 86%, is currently based on fossil fuels including petroleum (36%), coal (27%), and natural gas (23%) (EIA 2008). This situation is obviously the historical consequence of the fact that, over many centuries, fossil fuels were (and still are) a profitable business.

Energy production and consumption represent important figures and are reported yearly by specialized energy agencies. These statistical data are useful for predicting the energy demand in future years. In Fig. 2.12, the world fossil energy production and consumption based on data from BP (2008) are presented. It is very interesting to note that in 2008 petroleum and coal consumption exceeded the production, meaning that reserves accumulated in previous years were used.

Other important statistics refers to the regional distribution of fossil production and consumption in a specific year. For 2008, this is shown in percents of the total corresponding figure for world production and consumption, respectively, in Figs. 2.13 to 2.15. These plots indicate the potential for export and the need for import for the respective regions. For example, Fig. 2.13 suggests that Middle East countries exported about 25% of the world's petroleum production in 2008, but they did not produce or consume coal at all.

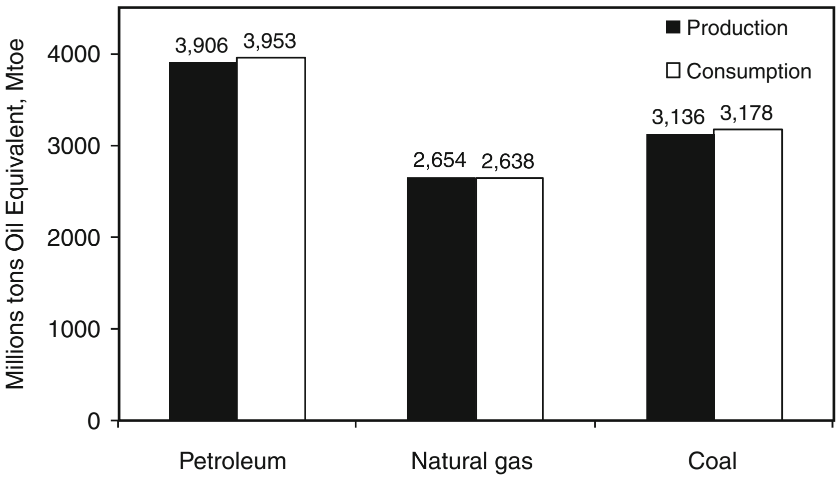

Fig. 2.12 World fossil fuel energy production and consumption in 2008 [data from BP (2008)]

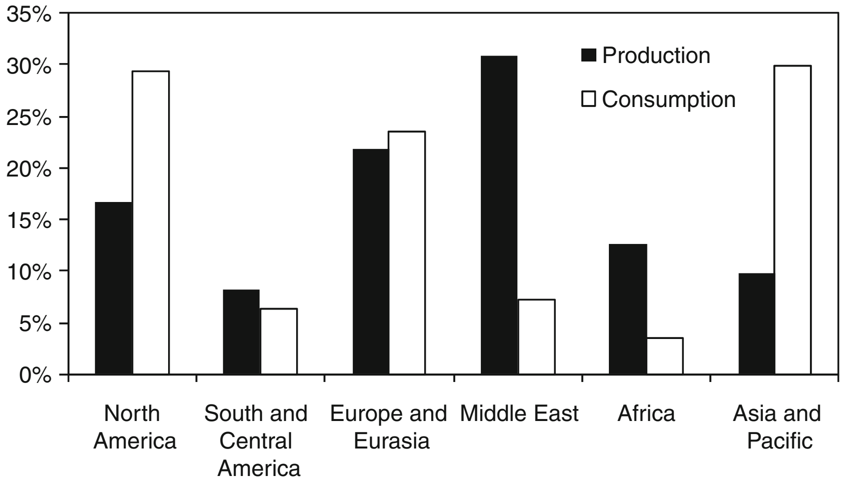

Fig. 2.13 Regional petroleum production and consumption in 2008 [data from BP (2008)]

2.8 Historical Trends and World Energy Prospects

Projections of fossil fuel and green energy consumption are important for local and global applications, and can play an important role in future energy policies, strategies, investments, and programs. It is also important to determine the transition period to a green energy economy and to plan fossil fuel or green energy budget allocations for local and industrial investments.

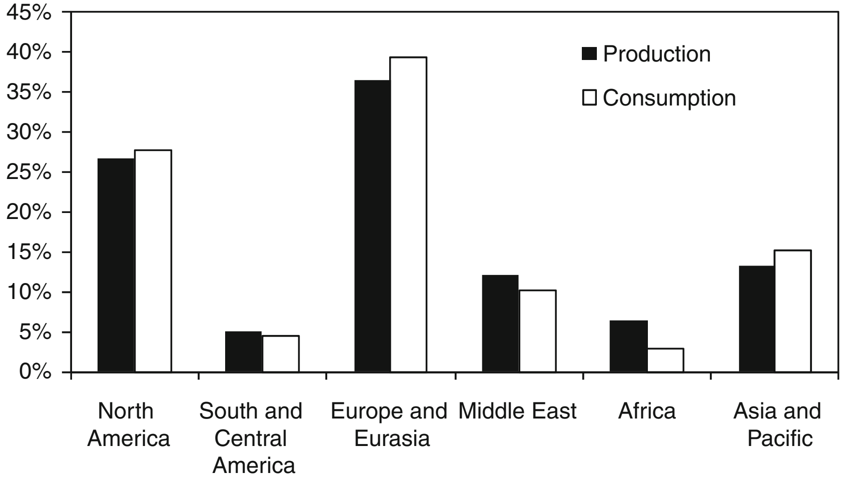

Fig. 2.14 Regional natural gas production and consumption in 2008 [data from BP (2008)]

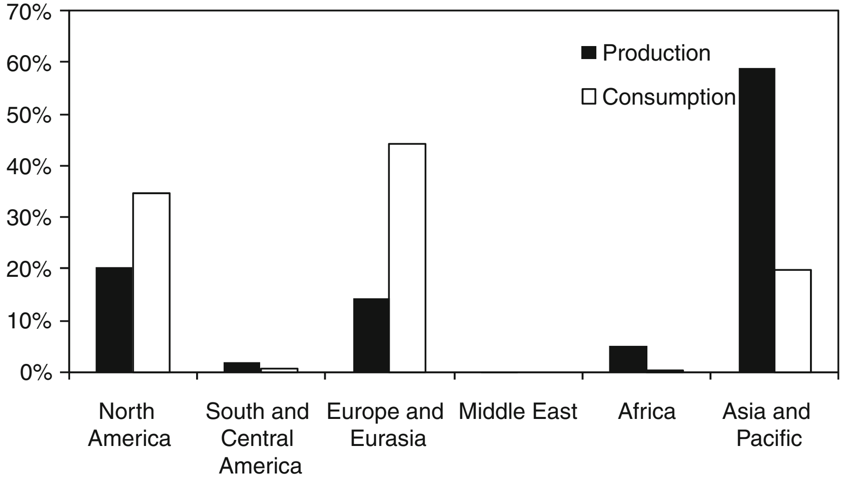

Fig. 2.15 Regional coal production and consumption in 2008 [data from BP (2008)]

Figure 2.16 illustrates the importance of predicting energy use patterns and planning. Better energy policies, strategies, and projections can facilitate the introduction of green energy–based environmental benefits in several ways. One is that energy consumption is better controlled. Also, the environmental impacts of energy sources and technologies such as greenhouse gas emissions and pollution are reduced. In addition, energy planning can contribute to innovative implementations of green energy technologies so as to achieve improved sustainability and global stability, particularly during a transition to a green energy–based economy.

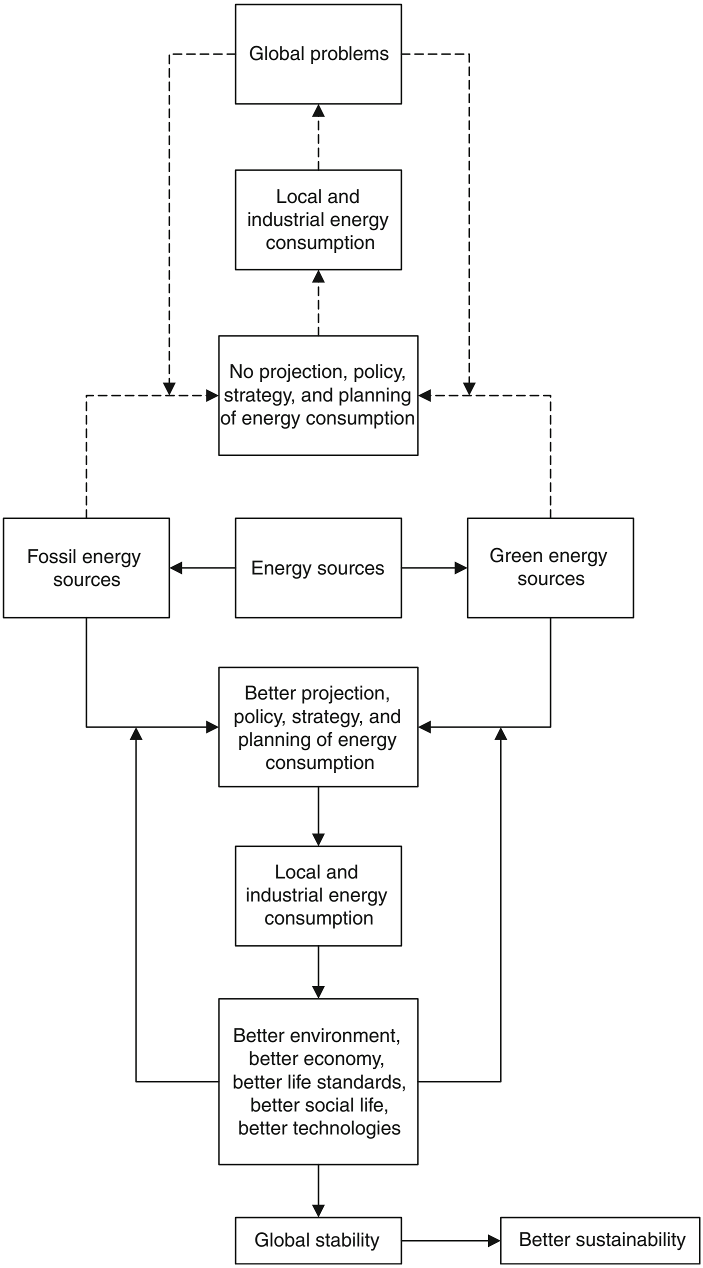

Fig. 2.16 The importance of energy forecast and planning programs. The *top half of the diagram* indicates the results of little or no planning, while the *bottom half* presents the outcomes when careful planning is applied [modified from Ermis et al. (2007)]

Predictions of the world energy consumption for the short term (couple of years) can be made based on linear or polynomial extrapolation, as first estimates. However, predictions over future decades must apply more advanced methods, because energy consumption is affected by a multitude of factors, including population growth, evolution of the gross domestic product of countries, potential conflicts, economic crises, and catastrophic events. An important method for forecasting energy consumption is artificial neural network (ANN) modeling. Although many investigations involving the ANN approach have been reported, limited studies are available in the open literature on predicting energy consumption for different applications. A review of the available studies on this subject is given by Ermis et al. (2007).

A neural network is an informatics algorithm that simulates the human brain's thinking, which can be instructed to respond to a number of events. During the instruction period, the artificial neural network algorithm adjusts and reconfigures the neurons connections. The network can be trained with past and present data, including significant historical events. The network can be validated using known data points. Here we show as an example the results by Ermis et al. (2007) regarding the predictions of world energy consumption, which includes fossil fuels and green energy for the period up to 2050. The artificial neural network used by Ermis et al. (2007) to predict the subsequent results has been trained using published statistical data for the last 40 years.

The world coal consumption curve equation derived via ANN depends on the actual and projected coal consumption data and can be expressed in EJ (exajoule, or 10^{18} J) as follows (Ermis et al. 2007):

$$E_{\mathrm{coal}}(\mathrm{EJ}) = 125.6667\left[1+\exp\left[-\left(\frac{Y-1{,}968.0551}{24.2314}\right)\right]\right]^{-1} \text{and } (R^2 = 0.99998), \quad (2.1)$$

where E_{coal} denotes world coal consumption in EJ and Y the year, and R is the mean square error. The results are also summarized in Fig. 2.17 and compared with linear predictions and predictions by Workbook (2005). It is expected that coal consumption will increase by 17.86% from 2005 to 2050, 11.22% from 2005 to 2025, and 5.97% from 2025 to 2050.

The world oil consumption curve equation derived via ANN depends on the actual and projected oil consumption data and can be expressed as follows (Ermis et al. 2007):

$$E_{\mathrm{oil}}(\mathrm{EJ}) = 184.5575\left[1+\exp\left[-\left(\frac{Y-1{,}987.7137}{10.2282}\right)\right]\right]^{-1} \text{and } (R^2 = 0.99947), \quad (2.2)$$

where E_{oil} denotes world oil consumption in EJ.

The corresponding results are also presented in Fig. 2.18. Due to rapid technological developments, transportation applications, and secondary fuel production based on oil reserves, it is expected that world oil consumption will probably increase as long as green energy sources such as solar, hydropower, wind, biomass,

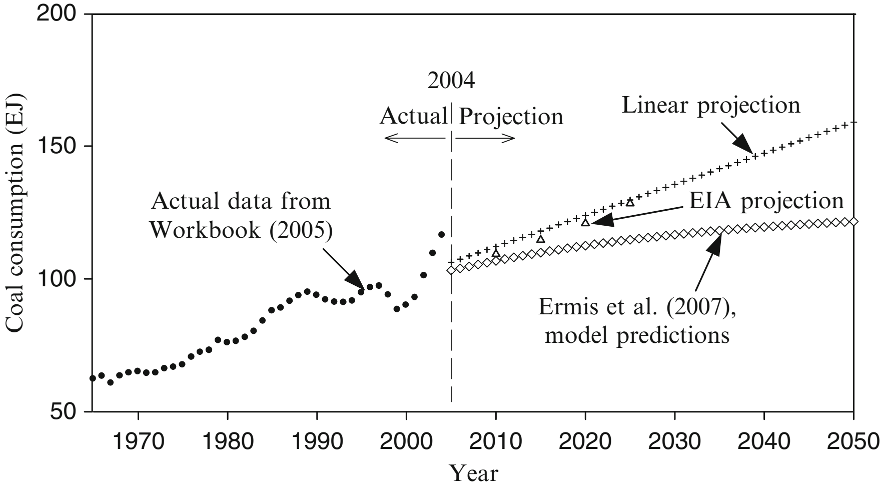

Fig. 2.17 Variation in world coal consumption with time [modified from Ermis et al. (2007)]

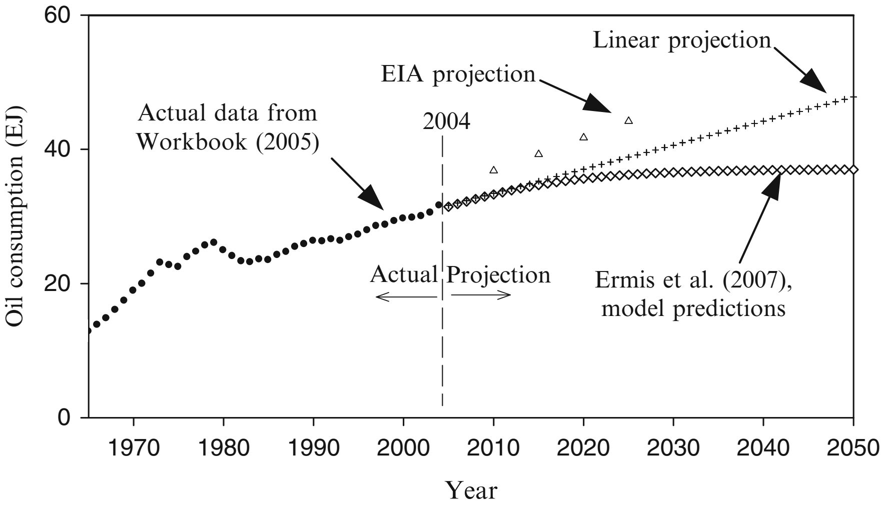

Fig. 2.18 Historical variation and future projection of world oil consumption [data from Ermis et al. (2007)]

nuclear, and hydrogen are not implemented to reduce the oil demand and consumption all over the world.

Oil consumption is expected to increase by 17.61% from 2005 to 2050, 15.14% from 2005 to 2025, and 2.14% from 2025 to 2050. After 2025, world oil consumption will probably remain stable. This stabilization in oil consumption indicates that, in the future, other green energy sources or natural gas will be mostly used to compensate for the world oil deficit.

The world natural gas consumption curve equation derived via ANN depends on the actual and projected natural gas consumption data and can be expressed as follows (Ermis et al. 2007):

$$E_{ng}(\mathrm{EJ}) = 186.5923\left[1+\exp\left[-\left(\frac{Y-1,984.2525}{27.0821}\right)\right]\right]^{-1} \text{and } (R^2 = 0.99965), \quad (2.3)$$

where E_{ng} denotes world natural gas consumption in EJ. As illustrated also in Fig. 2.19, the consumption of natural gas, which causes less greenhouse gas emissions than other fossil fuels, is expected to rise by 59.81% from 2005 to 2050, 31.89% from 2005 to 2025, and 21.16% from 2025 to 2050.

It is expected that rapid increases in technological developments, transportation applications, industrial and local energy demands, and secondary fuel production and power generation from natural gas will probably increase world natural gas consumption in the future. Thus, natural gas will probably be considered another alternate fuel for reducing greenhouse gas emissions.

Global demand for energy services is expected to increase by as much as one order of magnitude by 2050, while primary energy demands are expected to increase by 1.5 to 3 times. Trying to predict the evolution of the world energy market, policy makers studied various long- and short-term scenarios. Relevant work in this respect

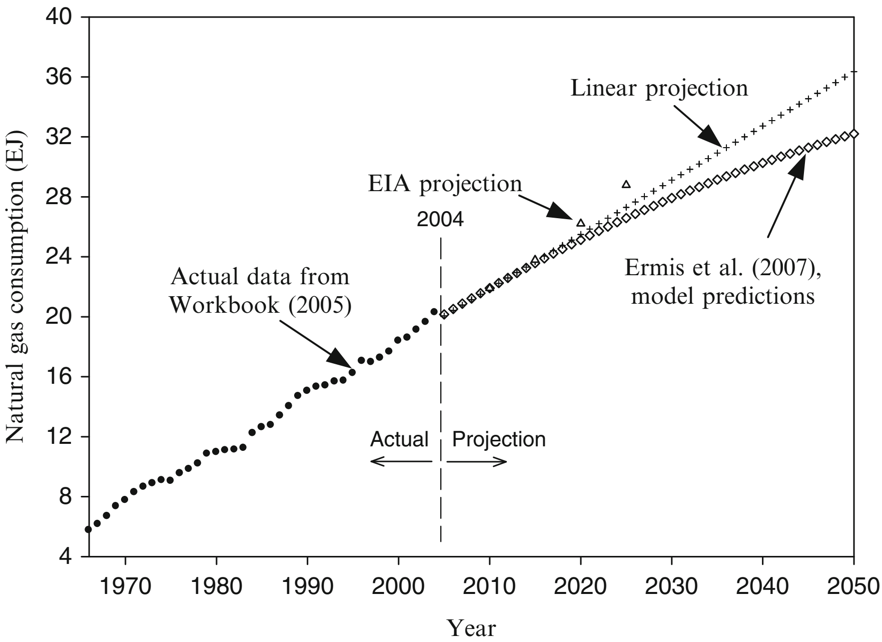

Fig. 2.19 Historical variation and future projection of world natural gas consumption [data from Ermis et al. (2007)]

has been pursued by the European Commission (EC 2006), which predicts the world energy technology outlook through 2050.

In this report, the geopolitical context, CO_2 emission profile, oil, gas, and coal production profiles, H_2-technology development, population growth, predicted energy demand, and other factors are accounted for to propose three scenarios for energy technology development up to 2050.

In the reference case (RC) scenario, a minimum degree of political initiative is assumed in all countries toward sustainable development. In the second scenario, called the carbon constraint case (CCC), severe limits in CO_2 emissions are assumed up to 2050. In the third scenario, called the H_2-case, it is assumed that a firm political decision is made in most countries toward the development of a hydrogen economy, and therefore major breakthroughs will be possible. We compiled the data from EC (2006) and give in the following paragraphs a summary, with a special focus on sustainable energy issues.

The data from Fig. 2.20 correlate the evolution of electricity consumption per capita in the three scenarios with global population growth. At present, developing countries, with a population of around four billion, represent some 77% of the world's population but use only a quarter of its global energy budget. Demographers generally predict that the total population will top eight billion by 2050. Roughly three-quarters of these people will live in developing countries. Energy service supplies for the developing world must grow considerably to meet the extra demands expected from these countries and to ensure that their economic development is not constrained. It can be seen that, while the population increases 1.4 times, the electricity consumption per capita increases ~2.6 times. In the same time, it is noted from EC (2006) that the gross domestic product (GDP) augments ~2.7 times.

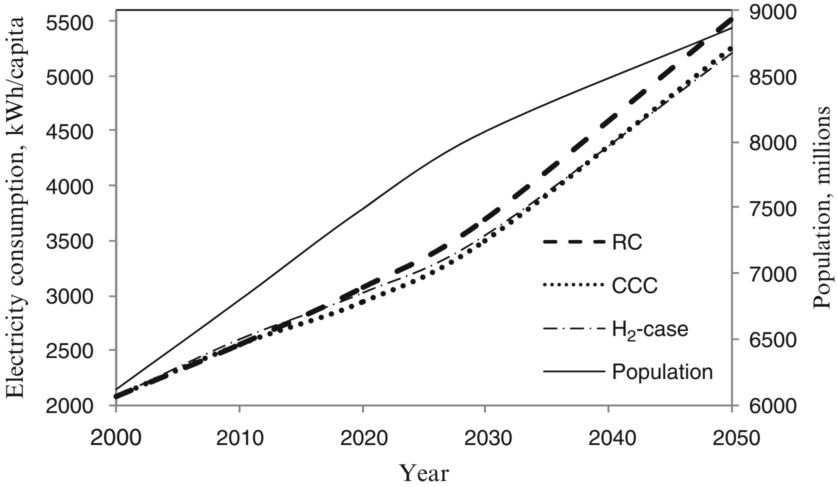

Fig. 2.20 Correlation between electricity consumption and world population for three development scenarios of energy technology (*RC* reference case; *CCC* carbon constraint case; *H_2-case* hydrogen economy case) [data from EC (2006)]

Based on Ermis et al. (2007) the world green energy consumption can be expressed as follows:

$$E_{ge}(\text{EJ}) = 105.493\left[1+\exp\left[-\left(\frac{Y-1{,}999.642}{26.387}\right)\right]\right]^{-1} \text{ and } (R^2 = 0.99976), \quad (2.4)$$

where E_{ge} denotes world green energy consumption in EJ. Green energy use is projected to be the fastest growing component of world primary energy consumption according to the ANN projection by Ermis et al. (2007). This prediction is compared with other sources in Fig. 2.21.

The green energy consumption is projected to increase by 59.84% from 2005 to 2050, 32.29% from 2005 to 2025, and 20.81% from 2025 to 2050. If utilization of green energy resources and technologies is encouraged, it can be expected that countries may maximize the benefits of green energy sources and technologies, while minimizing the global unrest and other problems associated with the use of fossil fuel energy sources.

The predicted primary energy production in 2050 will increase more than two times (from 60,000 to 125,000 GJ) with respect to the year 2000. This is illustrated in Fig. 2.22 together with the respective energy shares among various kinds of energy. The share of renewables (including hydro, geothermal, biomass, wastes, wind, and solar) increases from 14% to 19% with a prominent augmentation of solar and wind production (from 0.1% in 2000 to 4.6% in 2050, respectively).

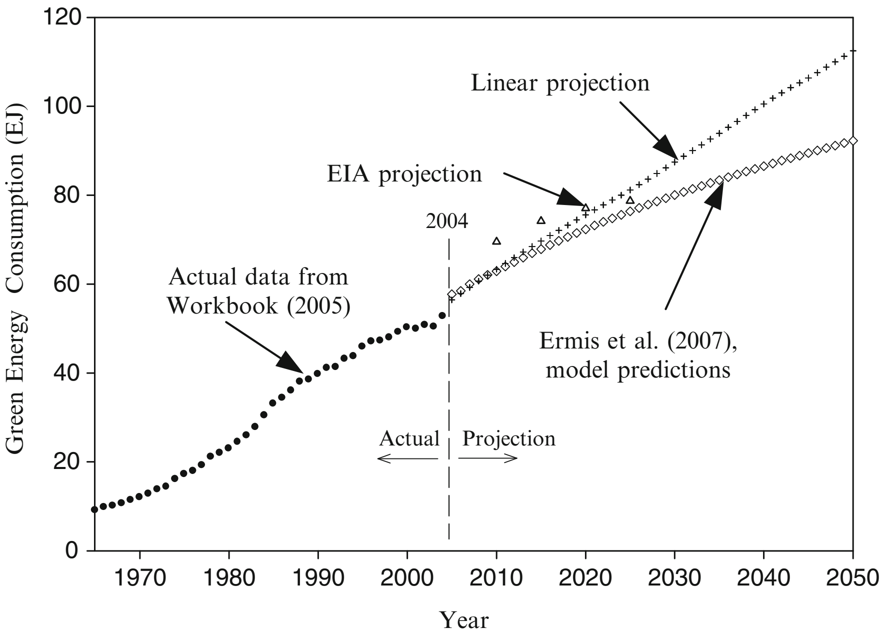

Fig. 2.21 Historical variation and future projection of green energy consumption [data from Ermis et al. (2007)]

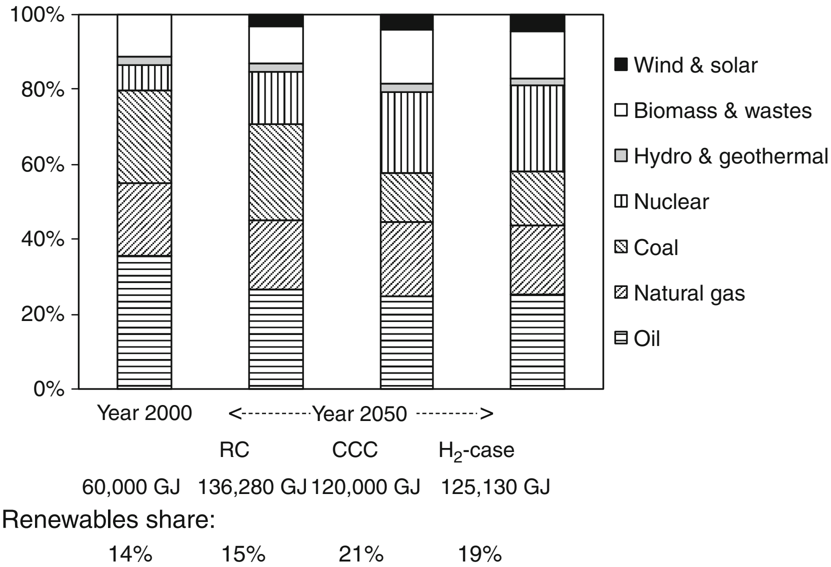

Fig. 2.22 The predicted primary energy production in the year 2050 in three scenarios in comparison with the year 2000 case (*RC* reference case; *CCC* carbon constraint case; *H_2-case* hydrogen economy case) [data from EC (2006)]

The predicted evolution of world primary energy consumption is indicated in Fig. 2.23; the associated prediction equation by Ermis et al. (2007) is as follows:

$$E_{\mathrm{wpc}}(\mathrm{EJ}) = 589.024\left[1 + \exp\left[-\left(\frac{Y - 1{,}984.253}{22.721}\right)\right]\right]^{-1} \text{and } (R^2 = 0.99965), \quad (2.5)$$

where E_{wpc} denotes world primary energy consumption in EJ.

The primary energy consumption, according to Eq. (2.5) and Fig. 2.23, has two components, namely the fossil fuel and the green energy components. The components of world primary energy consumption are also indicated in Fig. 2.23.

The fossil fuel prices are highly influenced by major political events; in fact, that complicates their prediction. For this reason, it is important to adopt a fair/realistic scenario of future political and economical events prior to any attempt to estimate oil/gas/coal price evolution. There are several serious institutions concerned with fuel price predictions for short as well as for longer terms. For example, the Natural Resources of Canada (NRC 2005) issues periodic reviews and outlooks with a range of prediction of about 15 years in the future; it is expected that the Canadian fuel price will increase by 20% in nominal value by 2020. A recent review is by the Energy Information Administration of the United States (EIA 2008) forecasting over a period up to 2030. In a so-called high-price scenario, the oil price is predicted to increase by ~60% in real value with respect to the 2008 value, while in a

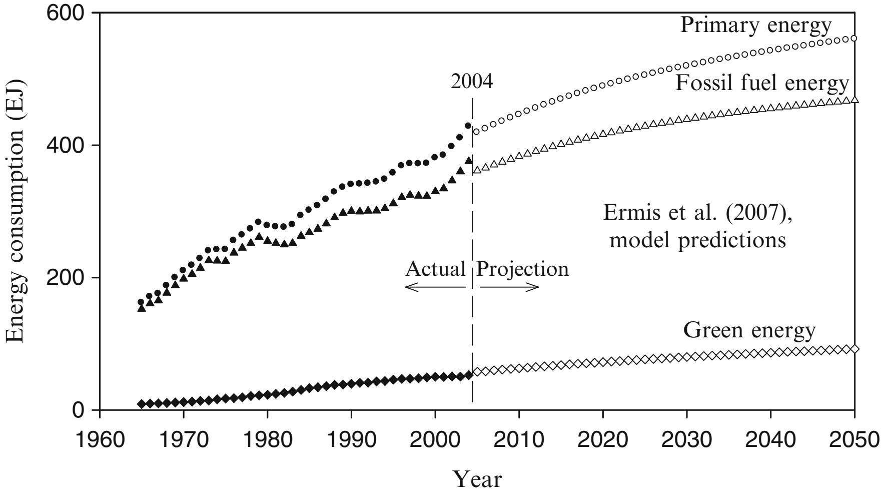

Fig. 2.23 Variation of world primary energy, fossil, and green energy consumption with time [data from Ermis et al. (2007)]

low-price scenario it might decrease by ~30%. Periodic oil market reports are prepared also by the International Energy Agency [IEA (2006, 2008)].

The World Energy Council (WEC 2007) elaborated four scenarios on world energy up to the year 2050. These scenarios account for low to high international cooperation and integration on energy policy and high and low engagements of governments in energy issues. However, the analysis does not give explicit fossil price estimations. In its report of 2006, the European Commission elaborated the world energy outlook up to 2050 and predicted the extreme limits of fuel price increases (EC 2006). The predictions are given according to the above-discussed RC and CCC scenarios.

A plot showing the past recorded prices and the future prediction of oil and natural gas prices is presented in Fig. 2.24. In order to obtain this plot, historical data from BP (2008) has been used for oil price records since 1870. For the modern era, these prices correspond to the world average, but for the 1800s and early 1900s they are the U.S. estimates. Historical natural gas annual records were obtained from the U.S. Department of Energy for the period 1930 to 2000 (EIA 2000). Recent trends in coal prices were taken from Pincock (2004) and converted into real currency, namely US$ 2008.

In Fig. 2.24, two lines for future price prediction of oil are marked; the upper line corresponds to the CCC scenario, while the lower corresponds to the RC case. For the natural gas price prediction (dashed line), the profiles for the CCC and RC scenarios cross by the year 2020. The coal price records in recent years are also indicated on the plot, to suggest that, in general, the price of coal is a little lower than that of oil and natural gas, per unit of energy content.

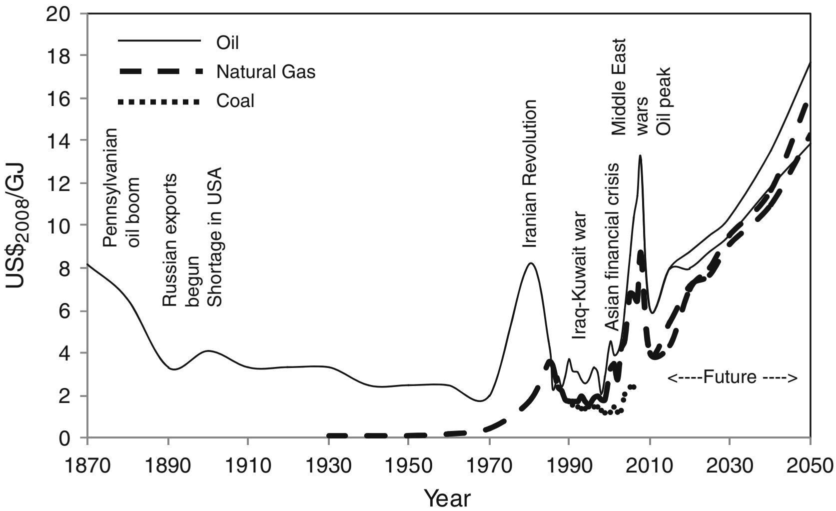

Fig. 2.24 Historical and predicted fossil fuel prices (average values for world) [data from BP (2008), EIA (2000), Pincock (2004)]

The continuous increase of fuel's real value is mainly a consequence of fuel shortage. No major political events (e.g., major wars or conflicts) are assumed in the predictions by EC (2006), even though this assumption has a certain degree of uncertainty. To observe the impact of political, economic, and social incidents on fossil fuel prices, the most influential events are added to the chart in Fig. 2.24.

One notices, for instance, the great influence of the Iranian revolution and that of the believed oil peak. The oil peak is the point in time when the maximum rate of global petroleum extraction is reached, after which the rate of production enters terminal decline. This concept has foundation in the recorded data from the oil exploitation industry and has been expressed mathematically by Hubbert (1956). The oil peak was predicted to occur by 2010.

2.9 Environmental Impact of Energy Generation and Utilization

Environmental problems associated with energy use span a spectrum of pollutant emissions, hazards, and accidents, as well as the degradation of environmental quality and natural ecosystems. Over the past few decades, energy-related environmental concerns have expanded from primarily local or regional issues, to the international and global nature of major energy-related environmental problems. Particularly in developing or newly industrialized countries, where energy consumption growth rates are typically extremely high and where environmental management has not yet been fully incorporated into the infrastructure, environmental problems are becoming apparent or already exist. Nevertheless, industrialized countries are at present mainly responsible for air pollution, ozone depletion, and carbon emissions because of the small contribution of the developing countries.

In the 1970s, concerns about energy use mainly focused on the relationship between energy and economics. At that time, the linkage between energy and the environment did not receive much attention. An institutional structure to deal with environmental problems emerged after the 1970s in most countries. Since the late 1970s, governments have adopted a number of laws on environmental and management policies that were supposed to be the basis of central government decisions relating to economic development and environmental impact. As environmental concerns, such as pollution, ozone depletion, and global climate change, became major issues in the 1980s, interest in the link between energy utilization and the environment became more pronounced (especially in the late 1980s and early 1990s). More recently, some researchers have suggested that the impact of energy resource utilization on the environment is best addressed by considering exergy. The exergy of a quantity of energy or a substance is a measure of its usefulness or potential to cause change, and it appears to be an effective measure of the potential of a substance to impact the environment. Although many studies have been performed on energy and the environment, limited work has been reported on the link between exergy and environment concepts (Rosen and Dincer 1996).

The environmental impact of energy use is reduced by increasing the efficiency of energy-resource utilization (often referred to as energy conservation), and by substituting more environmentally benign energy resources for damaging ones.

During recent decades the environmental impact of human activities has grown dramatically because of increases in the world population, resource consumption, and industrial activity. Throughout the 1970s, most environmental analysis and legal control instruments concentrated on conventional pollutants such as SO_2, NO_x, volatile organic compounds (VOCs, which are gases emitted by various materials and which may have adverse health effects), particulates, and carbon monoxide (CO). Recently, environmental concern has extended to hazardous air pollutants, which are usually toxic chemical substances that are harmful in small doses, as well as to globally significant pollutants such as CO_2. The pollutants referred to above have a variety of effects on the biosphere (Hollander and Brown 1992).

Carbon monoxide is a significant pollutant of urban air, in which it arises mostly from the incomplete combustion of automobile fuels, and poses a human health risk on inhalation. SO_2, a corrosive gas that is hazardous to human health and harmful to the natural environment, is emitted worldwide by natural processes such as volcanoes and sea spray, and by human activities, notably combustion of sulfur-containing fuels (mainly coal and fuel oil), smelting of nonferrous metal ores, oil refining, electricity generation, and pulp and paper manufacturing. SO_2 causes respiratory difficulties, damages plant foliage, and is a precursor of acid precipitation.

Nitrogen oxides (NO_x) are produced when combustion occurs at temperatures high enough for oxygen and nitrogen (mainly in air) to react, and can lead to respiratory problems, low-level ozone formation, and the creation of acids that can damage structures and natural systems. Controlling NO_x emissions is more

Table 2.3 Essential gaseous pollutants and the impacts

Gaseous pollutant	Greenhouse effect	Stratospheric ozone depletion	Acid precipitation	Smog
Carbon monoxide (CO)				
Carbon dioxide (CO_2)	+	+/–		
Methane (CH_4)	+	+/–		
Nitric oxide (NO) and nitrogen dioxide (NO_2)		+/–	+	+
Nitrous oxide (N_2O)	+	+/–		
Sulfur dioxide (SO_2)	–	+		
Chlorofluorocarbons (CFCs)	+	+		
Ozone (O_3)	+			+

"+" stands for a positive contribution, and "–" stands for variation with conditions and chemistry, which may not be a general contributor

challenging than controlling SO_2 because SO_2 emissions come overwhelmingly from large facilities such as power plants which are relatively easy to identify and control, while NO_x sources, most of which are motor vehicles, are smaller, more mobile, and much more numerous and varied. VOCs and petroleum and solvent vapors impede the formation of ozone. Efforts to reduce VOCs emissions have resulted in a 90% reduction in tailpipe emissions of unburned fuels in the U.S. since the 1970s through the use of catalytic converters (Hollander and Brown 1992). Particles in the air (fly ash, sea salt, dust, metals, liquid droplets, soot) come from a variety of natural and human-made sources. Particulates are emitted by factories, power plants, and vehicles, and are formed in the atmosphere by condensation or chemical transformation of emitted gases including SO_x, NO_x, and VOCs. Particulates cause a variety of health and environmental effects including acid precipitation, damage to plant life and human structures, loss of visibility, toxic or mutagenic effects on people, and possibly nonaccidental deaths.

Major areas of environmental concern are described in the following subsections. For each of these items, Table 2.3 presents the pollutants and hazards involved, as well as the cause-and-effect linkage among energy activities, pollutants, and environmental effects.

2.9.1 Global Warming (Greenhouse Gas) Effect

During the past several decades, there has been growing concern over the potential dangers associated with the accumulation of greenhouse gases (i.e., infrared-absorbing gases, such as CO_2) in the atmosphere. Such gases allow solar radiation to penetrate to the earth's surface while reabsorbing infrared radiation emanating from it. In conjunction with this, this environmental problem is also called either the *greenhouse effect* or *global warming*.

The greenhouse effect, also known as the global warming effect, is potentially the most important energy-related environmental problem. The increasing atmospheric concentration of greenhouse gases such as CO_2, CH_4, halons, N_2O, ozone, and peroxyacetylnitrate augments the atmosphere's ability to trap heat radiated from the earth's surface, thereby raising the surface temperature. The surface temperature increased about 0.6°C over the last century, and as a consequence the sea level is estimated to have risen by perhaps 20 cm. Further changes could have wide-ranging and catastrophic effects on human activities all over the world (e.g., increases in atmospheric concentrations of greenhouse gases in line with predicted fossil fuel consumption could cause the earth's temperature to increase in the next century by 2° to 4°C, causing seal levels to rise 30 to 60 cm by 2100, and such effects as flooding of coastal settlements, displacement of fertile zones for agriculture and food production toward higher latitudes, and a decreasing availability of fresh water. In Table 2.4, the role of various greenhouse gases is given.

Note that some dispute whether CO_2 levels are rising in the atmosphere, and that the quantitative linkage between atmospheric CO_2 levels and global climate change is not well understood. Since energy utilization is a major contributor to environmental degradation, decisions regarding energy policy alternatives require comprehensive environmental analysis.

A schematic representation of this global climate change problem is illustrated in Fig. 2.25. Humankind is contributing through many of its economic and other activities to the increase in the atmospheric concentrations of various greenhouse gases. For example, CO_2 releases from fossil fuel combustion, methane emissions from increased human activity, CFC releases, and deforestation all contribute to the greenhouse effect.

One of the most important aspects is thorough evaluation of the costs of reducing CO_2 emissions. From a developing-country perspective, the discussion of costs and benefits has to take into account the need for policies promoting rapid economic growth. Achieving such a balance between economic development and emissions abatement requires the adoption of domestic policies aimed at improving the efficiency of energy use and facilitating fuel switching, and the implementation of international policies enabling easier access to advanced technologies and external resources.

It is certain that atmospheric CO_2 levels will continue to increase significantly. The degree to which this occurs depends on the fixture levels of CO_2 production and

Table 2.4 Roles of different substances in the greenhouse effect

		Atmospheric concentration				
Substance	ARIRR[a]	Preindustrial (ppm)	Present (ppm)	Annual growth rate (%)	SGEHA[b] (%)	SGEIHA[c] (%)
CO_2	1	275	346	0.4	71	50 ± 5
CH_4	25	0.75	1.65	1	8	15 ± 5
N_2O	250	0.25	0.35	0.2	18	9 ± 2

Data from Aebischer et al. (1989)

[a]Ability to retain infrared radiation relative to CO_2

[b]Share in the greenhouse effect due to human activities (%)

[c]Share in the greenhouse effect increase due to human activities (%)

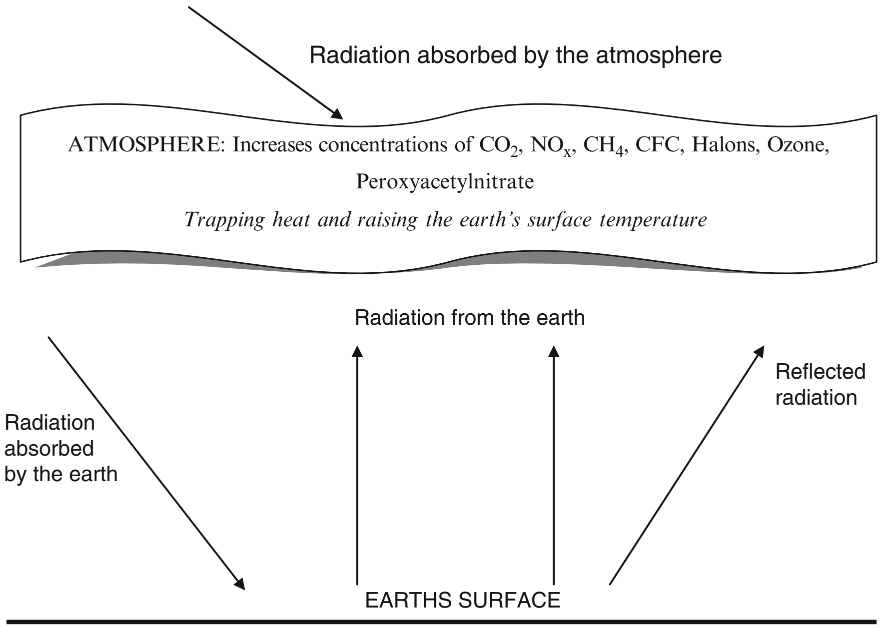

Fig. 2.25 A schematic illustration of the greenhouse effect

the fraction of that production that remains in the atmosphere. Given plausible projections of CO_2 production and a reasonable estimate that half the amount will remain in the atmosphere, indications are that sometime during the middle part of the 21st century the concentration of CO_2 will reach 600 ppm in the atmosphere (Speight 1996).

The arguments about the magnitude of the greenhouse effect have gone back and forth for some time. There are those who believe that the earth is doomed to a rise in temperature, and there are those who believe that we can go on polluting the atmosphere without consequence. Whatever the argument is, there is no doubt that the emissions are harmful and destroy the environment (Bradley et al. 1991). Of course, there are several contradictory reports and arguments published recently that make this field complicated to study. Furthermore, the environment should be considered to be an extremely limited resource, and discharge of chemicals into it should be subject to severe constraints. Nevertheless, in order to conduct a successful environmental study, we should have a clear outline and include the following significant steps:

- Definition of the main goals, both short and long term.
- Measurement or estimation of the data needed as accurately as possible.
- Evaluation of the measurements or estimations.
- Generation of new and reliable data and reporting of the results.

Many developed and developing countries, through several national and international institutes and agencies, have started taking actions to reduce (or eliminate)

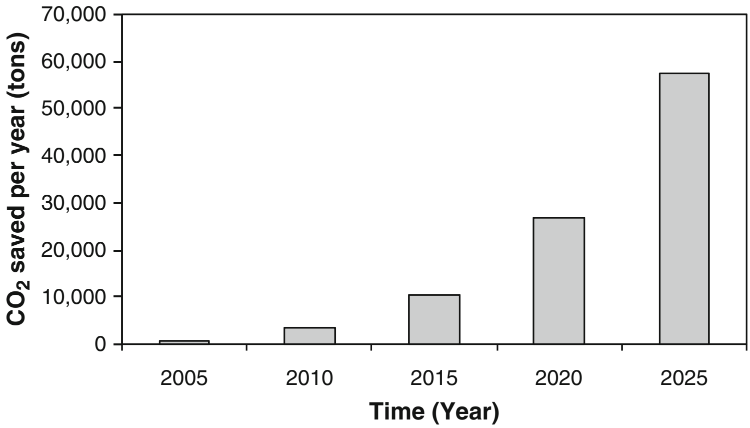

Fig. 2.26 Predicted CO_2 mitigation induced by solar power development in the world [data from Brackmann (2008)]

the pollutant emissions and to attain a sustainable supply of energy sources. In December 1997 the International Kyoto Conference on climate change came up with a list of 15 concrete proposals for curbing global greenhouse gas emissions. The list includes improving the fuel efficiency of automobiles, introducing solar power facilities, and planting forests to act as "green lungs" in densely populated areas.

It is expected that some countries will offer certain tax reductions for those businesses that promote renewable energy technologies, especially because these technologies are characterized by low or zero CO_2 emission. For example, Fig. 2.26 shows the evolution of the global CO_2 mitigation expected from the foreseen solar energy expansion. This figure is based on the data from Brackmann (2008) that predicts the trend of solar energy utilization in future years.

2.9.2 Acid Precipitation

The main sources of acid rain deposition are the emissions of SO_2 and NO_x, and such gases react with water and oxygen in the atmosphere and result in acids such as sulfuric and nitric acids (Dincer 1998) as shown in Fig. 2.27. Acids produced mainly from the combustion of fossil fuels, especially coal and oil, and the smelting of nonferrous ores can be transported long distances through the atmosphere and deposited on ecosystems.

Also, substances such as volatile organic compounds (VOCs), chlorides, ozone, and trace metals may participate in the complex set of chemical transformations in the atmosphere resulting in acid precipitation, the effects of which are as follows: acidification of lakes, streams, and ground waters, resulting in damage to fish and aquatic life; damage to forests and agricultural crops; and deterioration of materials, such as buildings, metal structures, and fabrics. A major source of acid-precipitation

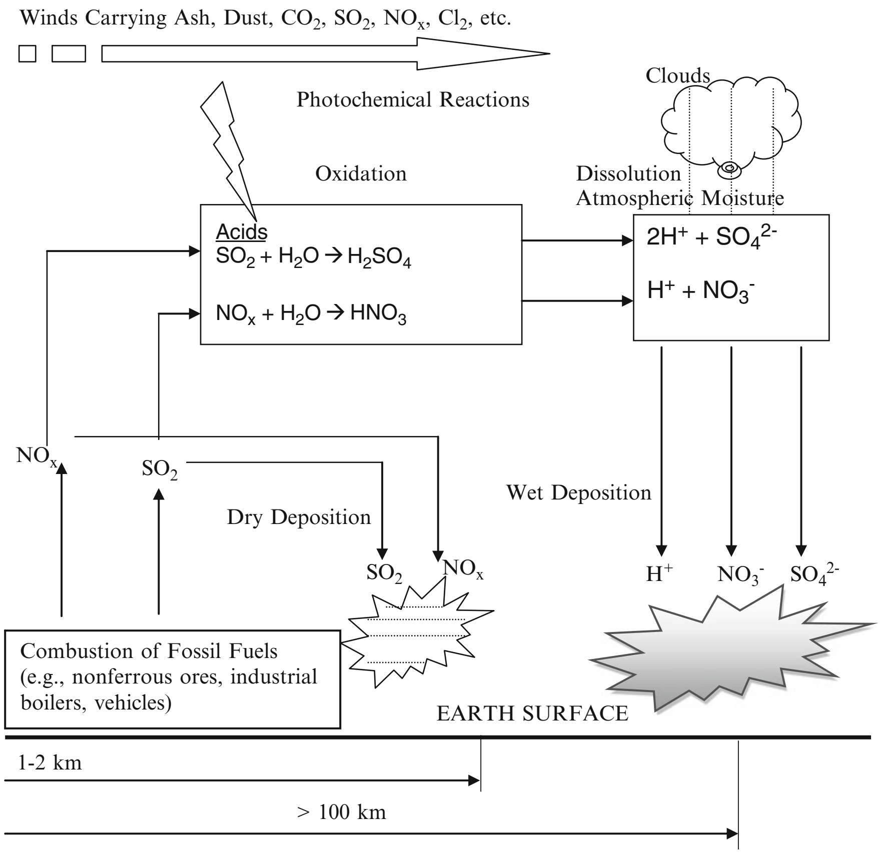

Fig. 2.27 Schematic illustration of the formation, distribution, and impact of acid rain

precursors are energy-related activities (e.g., electric power plants, residential heating, and industrial energy use account for 80% of SO_2 emissions, while road transport accounts for 48% of NO_x emissions in OECD countries).

Another source of acid precipitation is sour gas treatment, which produces H_2S that then reacts to form SO_2 when exposed to air. Road transport is also an important source of NO_x emissions. Most of the remaining NO_x emissions are due to fossil fuel combustion in stationary sources. Countries in which the energy-related activities mentioned here occur widely are likely to be significant contributors to acid precipitation (e.g., U.S., Russia, and China).

A major problem with acid rain is that its effects often occur in a different country than its source. There is a large variety of major evidence to show the damage of acid precipitation as follows:

- Acidification of lakes, streams, and ground waters
- Toxicity to plants from excessive acid concentration

- Corrosion of exposed structures
- Health hazards for fish and aquatic life
- Damage to forests and agricultural crops
- Deterioration of buildings and fabrics
- Harmful effect of sulfate aerosols on physical and optical properties of clouds

Some possible solutions include cleaning fossil fuels before combustion, burning them more cleanly by using fluidized bed technology for coal, using renewable energies, switching to a hydrogen economy, implementing thermal energy storage technologies, promoting efficient public transport, using more fuel-efficient vehicles, and so on.

2.9.3 Impact of Energy Efficiency

The implications of the limited nature of energy and other resources have led in part to significant efforts in energy-utilization efficiency improvement and resource recycling and reuse. For example, refuse and other solid wastes are now often used to supplement fuel supplies. Recycling (resource recovery) extends the lifetimes of many of the natural resources and is often profitable and usually beneficial environmentally. Energy efficiency and conservation can postpone shortages of energy resources, reduce environmental damage, and provide economic benefits. The efficient use of energy is of particular importance to developing countries, as it can forestall the need for very large capital investments.

In the early 1980s, several energy efficiency and conservation measures were applied, such as strict regulations and standards, particularly for cars and buildings; incentive schemes to stimulate energy conservation investments; energy auditing and reporting schemes, especially for energy-intensive industries; encouragement of the use of waste heat from power stations and from industries, such as the cogeneration of heat and electricity; and promotion of relevant research and development. More recently, environmental concerns have increased the usefulness of these and other measures.

Enormous potential exists through improvements in energy efficiency and conservation for decreasing total world energy consumption, and thereby the effects of energy consumption on the environment. Often, such improvements require a myriad of small changes in consumption patterns.

Despite this obstacle, energy efficiency measures can often be implemented quickly since there is a rapid stock turnover for such devices as light bulbs, cars, and refrigerators, unlike for power stations. Despite the high capital costs, many efficiency measures can result in considerable economic savings for both individual consumers and societies (e.g., the benefits of eliminating the need for a new power station through high electricity-utilization efficiency). Such savings are particularly attractive to developing countries that suffer from acute shortages of capital, since investment in new efficient technology is typically much cheaper than retrofitting old plants. It is therefore important that the expansion of developing country economies, especially the introduction of new industries, is based on the latest technology available, bypassing the inefficient and wasteful technologies that have been used in the industrialized countries.

Increased energy efficiency reduces energy-related environmental impacts such as those discussed in Section 2.9.4 (e.g., environmental damage due to the process of extracting energy resources from the ground, and the competition for water between hydropower and such other uses as agriculture and recreational activities, and associated damage to water quality). In addition, improved efficiency enhances the reliability of future energy supplies and improves the longevity of energy supplies. The potential for energy efficiency is significant during both energy production and consumption (e.g., the 30% of oil in a reservoir that is extracted from onshore wells could be improved upon using secondary recovery techniques, such as water flooding and thermal stimulation).

2.9.4 Other Environmental Impact Aspects

Much concern is focused on the risks and consequences of major environmental accidents, such as explosions and fires at oil/gas refineries, oil rigs, tanks, and pipelines; hydroelectric dam failures, causing flooding and landslides; nuclear accidents; and explosions in mines. Population concentrations often worsen the effects of major accidents in terms of human lives lost and injured or people displaced.

Significant concern exists about the quality and quantity of available water resources including groundwater, because of its role in the supply of drinking and irrigation water. Efforts are continually made to control energy-related pollution causes, such as geothermal fluids containing toxic chemicals; acid drainage from mines; coal wastes; effluents containing hazardous chemicals from power plants and refineries; and thermal pollution from the discharges of cooling systems of power plants.

Although much public concern has concentrated on maritime pollution from large accidental oil spills, the main source of maritime-based pollution remains shipping operations. Annually 1.1 million tons of oil are discharged as a result of regular shipping, and about 400,000 tons comes from tanker accidents (EC 2006).

Economic priorities often cause land particularly suited for sustaining agriculture, housing, or natural ecosystems to be lost. In the energy sector, concern has focused on mining sites and hydroelectric reservoirs; the large land surfaces that might be needed for the large-scale exploitation of renewable energy forms, such as solar power, wind power stations, or biomass production; the sites chosen for large, complex industrial processes, such as fuel refining or electric power generation, and the disposal of solid wastes including radioactive wastes.

Hazardous wastes pose special health and environment threats, and are mainly generated by the chemicals and metal industries. Nonhazardous wastes, such as bottom ash from power plants and air-pollution control residues, pose disposal problems regarding space and appropriate containment. The commercial use of some solid wastes as building industry products and transportation surfaces is limited by the size of the market.

About 90% of exposure to radiation is due to natural causes and 10% is human-made. Energy activities contribute about 25% of the total human-made radioactivity. Though fossil fuel combustion releases radionuclides, ongoing debate about energy-related radiation centers mainly on the nuclear fuel cycle and its various stages. Radon, which is released in uranium mining and milling, is one of the potential occupational hazards and may cause groundwater contamination. Nuclear waste disposal and facility decommissioning involve varying degrees of hazards depending on the characteristics of the wastes.

Hazardous air pollutants are usually emitted in smaller quantities than those that are the focus of ambient air quality concerns. Lead is the main hazardous air pollutant, and most of the world's lead pollution comes from the use of lead-based gasoline additives to increase octane ratings. Lead exposure may cause neurological damage. Since the 1970s many countries have taken steps to phase out these lead-based additives. Additionally, the number of suspected hazardous pollutants is very large, and knowledge of sources, emissions, and effects is still developing. The concern is both localized, effects where micropollutants are discharged, and regional for the toxic pollutants, such as cadmium, mercury, and polycyclic aromatic hydrocarbons (PAHs). Many energy-related activities emit hazardous air pollutants, such as hydrocarbons (such as benzene) emitted from oil and gas extraction and processing industries; hydrocarbon and dioxin emissions caused by the use and combustion of petrol and diesel oil for transport; small quantities of arsenic, mercury, beryllium, and radionuclides released during the combustion of coal and heavy fuel oil; and mercury, chlorinated dioxin, and furan emissions from municipal waste incinerators.

Air pollution is caused by emissions of toxic gases such as SO_x, NO_x, CO, VOCs, and particulate matter (e.g., fly ash and suspended particles). Excessive concentrations of these pollutants and of ozone have demonstrated health, welfare, and ecological effects felt locally and sometimes regionally. VOCs and NO_x are known to be responsible for photochemical smog. Air pollutants are emitted from a variety of stationary and mobile fuel consumption sources, and energy-related activities contribute significant quantities of all of these pollutants. Regulations on emissions are often used to reduce air pollution, and high chimney stacks are used to alleviate localized air pollution (i.e., transport pollutants elsewhere). Indoor air pollution is also of concern (e.g., CO, CO_2, and smoke from stoves and fireplaces; various gaseous oxides of nitrogen and sulfur from furnaces; stray natural gas and heating oil vapors; radon emitted by natural gas–burning appliances and the surrounding soil; cigarette smoke; formaldehyde from plywood and glues). Ventilation even in tightly sealed energy-efficient buildings can eliminate most indoor air quality concerns. Knowledge of indoor pollutant dose–response relationships is still incomplete.

2.10 Case Study

This example investigates the contributions to sustainable development that are possible through the provision of heat and electricity services via cogeneration, rather than via separate processes for heat production and electricity generation. Cogeneration is the more efficient of these two options for providing such services. The example is intended to be a simple yet practical and realistic illustration of one of the many ways in which increased energy efficiency can contribute to achieving sustainable development in a society.

In the example, the potential benefits are investigated of the simultaneous production of thermal and electrical energy (cogeneration) using the facilities of Ontario Hydro, the principal electrical utility in the province of Ontario, Canada. The main advantage of cogenerating thermal and electrical energy is that less input energy is consumed than would be required to produce the same products in separate processes; additional benefits of cogeneration often include reduced environmental emissions, and more economic, safe, and reliable operation.

This example is based on an investigation performed previously on the benefits of implementing cogeneration in countries and regions. Additional details to those provided here for the example are presented elsewhere (Rosen 1994; Hart and Rosen 1995). The benefits of implementing utility-based cogeneration are examined for the province, by evaluating the changes in energy consumption and environmental emissions when cogeneration is implemented, relative to a base-case year. The example considers the effects of cogeneration implementation on the electrical utility sector, the remainder of the province, and the overall province.

A high degree of cogeneration implementation is assumed. Specifically, an advanced utility-based cogeneration network supplies a large portion of these annual heat demands (i.e., 40% or 206 PJ of the heat demands of the residential, commercial, and institutional sectors, and 12% or 54 PJ of those for the industrial sector). Two main categories of heat demands are partly satisfied through cogeneration:

- Residential, commercial, and institutional processes, which require large quantities of heat at relatively low temperatures (e.g., for heating air and water). Utilization of cogenerated heat in these sectors sometimes involves district heating, where centrally supplied heat (often in the form of hot water or steam) is transported through a network of pipes to users throughout the region.
- Industrial processes, which require heat at a wide range of temperatures (e.g., for drying and boiling).

A detailed procedure described elsewhere (Rosen 1994; Hart and Rosen 1995) was used to determine the numerical values cited earlier in this subsection. Many factors relating to the usability and marketability of utility-cogenerated heat in these sectors were considered, including the following:

- The quantity, supply rate, and temperature of supplied heat must satisfy all demand requirements.

- Users and suppliers of heat must be located within a suitable distance of each other.
- Heat must be available when it is in demand, either by cogenerating when heat is demanded or storing the heat during periods between its generation and utilization.
- An overall infrastructure and all relevant technologies must exist for all cogeneration steps, including heat supply, distribution, storage, and utilization.
- The system must be able to accommodate actual variations in heat-demand parameters (quantity, temperature, etc.).
- The attitude of all parties involved (suppliers, distributors, users, etc.) must be positive.
- The economics for cogeneration options should be at least competitive with, and preferably superior to, the economics for other noncogeneration options.

Table 2.5 lists the base-case annual energy use data in the province in physical units (top section) and energy units (second section), followed by reductions in annual energy use for the example, expressed as a percentage of the corresponding base-case values. Similarly, Table 2.6 lists the base-case annual emissions to the environment for the province (top section) and percent reductions in these emissions.

Table 2.5 Base-case annual energy use in Ontario and percent reductions in base-case values for the cogeneration scenario

Base-case energy use (PJ)	Electricity	Gas and NGLs	Oil and petrol	Coal	Other	Uranium	Total
Utility sector	–	–	14	286	–	640	940
Province (excl. utility)	477	824	782	21	158	–	2,262
Province (total)	477	824	796	307	158	640	3,202
Base-case energy use (physical units)	**Electricity (TWh)**	**Gas and NGLs (teraliters)**	**Oil and petrol (gigaliters)**	**Coal (mega-tons)**	**Other (kilo-tons)**	**Uranium (tons)**	
Utility sector	–	–	0.33	10.4	–	1,040	
Province (excl. utility)	132	21.0	21.5	0.71	5,340	–	
Province (total)	132	21.0	21.8	11.1	5,340	1,040	
% Reductions in values							
Utility sector	–	–	0.0	47	–	35	82
Province (excl. Utility)	30	15	2.6	5.6	7.5	–	60.7
Province (total)	30	15	2.6	44	7.5	35	155.1

Note: Hydraulic energy use is not shown since it is free. The "other" energy category includes coke and coke oven gases, which are originally produced from coal, the energy value of uranium to be heated from fission delivered from the nuclear reactor to the power cycle. NGLs denote natural gas liquids. Total base-case annual energy use for the overall province (3,200 PJ) includes the shown primary energy forms, as well as the secondary from, electricity. PJ denotes petajoule (10^{15} J)

Table 2.6 Base-case annual emissions in Ontario and percent reductions in base-case values for the cogeneration scenario

Base-case emissions to the environment (PJ)	Pollution (10^{15} Bq)	Material emissions (kilotons)					Thermal VOC	Radiation spent	Uranium
		SO_2	No_x	CO_2	CO	Particulates			
Utility sector	321	92	32,000	4	11	0.5	1.04	591	11
Province (excl. utility)	1,060	526	132,000	3,500	837	755	–	–	–
Province (total)	1,380	618	164,000	3,504	849	775	1.04	591	11
% Reductions in values									
Utility sector	47	47	47	47	47	47	35	83	35
Province (excl. utility)	8.8	4.8	7.4	4.2	1.6	2.9	–	–	–
Province (total)	18	12	15	4.2	2.1	3	35	83	35

Note: VOCs denote volatile organic compounds. Thermal pollution is taken to be heat rejected to bodies of water, so as to cause appreciable temperature rises. Radioactive emissions from non–nuclear-energy sources, such as radioactivity in coal-station stack gases, have not been considered. PJ denotes (10^{15} J) and Bq denotes becquerel

The key points demonstrated are that energy use and environmental emissions decrease for the utility sector, the rest of the province, and the overall province; and provincial electricity generation requirements decrease. Specific implications of these findings are significant:

– Provincial annual electricity consumption decreases by as much as 30%, permitting provincial annual electrical generation to decrease correspondingly.
– For the electrical utility sector, annual coal use and coal-related emissions both decrease by up to 47%, while annual uranium use and related emissions both decrease by up to 35%.
– Excluding the electrical utility sector, the province's annual use of fossil fuels and the corresponding annual emissions both decrease by up to 15%.

This example demonstrates that the increased energy-utilization efficiency that can be achieved through cogeneration in a region or country can contribute to attaining sustainable development by doing the following:

– Reducing significantly the amounts of energy resources required to satisfy given energy demands
– Reducing significantly the environmental emissions (and related societal impacts) associated with satisfying the energy demands

It is noted that this is but one limited illustration of how increased energy efficiency can contribute to sustainable development. Numerous other areas in which increased energy efficiency can contribute exist in any society.

2.11 Concluding Remarks

In this chapter, a summary of some general introductory aspects of energy perspectives was presented. Predictions of energy consumption and population growth were correlated, and the environmental impact of energy use was discussed. One relevant case study was presented.

Nomenclature

E Energy consumption, EJ
Q Heat rate, W
R Mean square error
T Temperature, K
Y Year

Greek Letter

η Energy efficiency

Subscripts

ge	Green energy
H	Hot
L	Low
ng	Natural gas
S	Sun
wpc	World primary energy consumption

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Study Questions/Problems

2.1 What is the relationship among the use of renewable energy sources, environment, and sustainability?

2.2 What is the relationship among energy efficiency, environment, and sustainability?

2.3 Give a definition of sustainable energy engineering.

2.4 Enumerate and describe briefly the fundamental energy sources on earth.

2.5 Explain the nature of biomass energy.

2.6 Calculate the reaction enthalpy of glucose formation process by photosynthesis, according to the reaction $6CO_2 + 6H_2O \xrightarrow{\text{LIGHT}} C_6H_{12}O_6 + 6O_2$.

2.7 Calculate how many kilograms of green wood produce the same amount of energy as 1 kg of dry wood. Calculate how many cubic meters of green wood are equivalent in energy terms to 1 cubic meter of dry wood.

2.8 Make a prediction of world coal consumption by 2100, based on linear extrapolation of statistical data. Compare the linear prediction with that given by Eq. (2.1).

2.9 Explain the oil peak theory by Hubert.

2.10 What are the main environmental impacts of energy generation and utilization?

2.11 Explain the global warming effect.

2.12 Explain the acid precipitation formation and its environmental effect.

2.13 Comment on the energy efficiency impact on the environment.

2.14 Using the case study 2.10 as guideline, try to quantify the environmental benefit of cogeneration of power and heat within a geo-economic region.

2.15 Comment on the impact of distributed energy systems on sustainability.

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