CHAPTER 1

INTRODUCTION TO RENEWABLE ENERGY TECHNOLOGIES

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1.1 General introduction to renewable energy technologies

The sun is the only star of our solar system located at its center. The earth and other planets orbit the sun. Energy from the sun in the form of solar radiation supports almost all life on earth via photosynthesis and drives the earth's climate and weather.

About 74% of the sun's mass is hydrogen, 25% is helium, and the rest is made up of trace quantities of heavier elements. The sun has a surface temperature of approximately 5500 K, giving it a white color, which, because of atmospheric scattering, appears yellow. The sun generates its energy by nuclear fusion of hydrogen nuclei to helium. Sunlight is the main source of energy to the surface of the earth that can be harnessed via a variety of natural and synthetic processes. The most important is photosynthesis, used by plants to capture the energy of solar radiation and convert it to chemical form. Generally, photosynthesis is the synthesis of glucose from sunlight, carbon dioxide, and water, with oxygen as a waste product. It is arguably the most important known biochemical pathway, and nearly all life on earth depends on it.

Basically all the forms of energy in the world as we know it are solar in origin. Oil, coal, natural gas, and wood were originally produced by photosynthetic processes, followed by complex chemical reactions in which decaying vegetation was subjected to very high temperatures and pressures over a long period of time. Even the energy of the wind and tide has a solar origin, since they are caused by differences in temperature in various regions of the earth.

Since prehistory, the sun has dried and preserved humankind's food. It has also evaporated seawater to yield salt. Since humans began to reason, they have recognized the sun as a motive power behind every natural phenomenon. This is why many of the prehistoric tribes considered the sun as a god. Many scripts of ancient Egypt say that the Great Pyramid, one of humankind's greatest engineering achievements, was built as a stairway to the sun (Anderson, 1977).

From prehistoric times, people realized that a good use of solar energy is beneficial. The Greek historian Xenophon in his "memorabilia" records some of the teachings of the Greek philosopher Socrates (470–399 BC) regarding the correct orientation of dwellings to have houses that were cool in summer and warm in winter.

The greatest advantage of solar energy compared with other forms of energy is that it is clean and can be supplied without environmental pollution. Over the past century, fossil fuels provided most of our energy, because these were much cheaper and more convenient than energy from alternative energy sources, and until recently, environmental pollution has been of little concern.

Twelve autumn days of 1973, after the Egyptian army stormed across the Suez Canal on October 12, changed the economic relation of fuel and energy as, for the first time, an international crisis was created over the threat of the "oil weapon" being used as part of Arab strategy. Both the price and the political weapon issues were quickly materialized when the six Gulf members of the Organization of Petroleum Exporting Countries (OPEC) met in Kuwait and abandoned the idea of holding any more price consultations with the oil companies, announcing at the same time that they were raising the price of their crude oil by 70%.

The rapid increase in oil demand occurred mainly because increasing quantities of oil, produced at very low cost, became available during the 1950s and 1960s from the Middle East and North Africa. For the consuming countries, imported oil was cheap compared with indigenously produced energy from solid fuels.

The proven world oil reserves are equal to 1341 billion barrels (2009), the world coal reserves are 948,000 million tons (2008), and the world natural gas reserves are 178.3 trillion m^3 (2009). The current production rate is equal to 87.4 million barrels per day for oil, 21.9 million tons per day for coal and 9.05 billion m^3 per day for natural gas. Therefore, the main problem is that proven reserves of oil and gas, at current rates of consumption, would be adequate to meet demand for only another 42 and 54 years, respectively. The reserves for coal are in a better situation; they would be adequate for at least the next 120 years.

If we try to see the implications of these limited reserves, we are faced with a situation in which the price of fuels will accelerate as the reserves are decreased. Considering that the price of oil has become firmly established as the price leader for all fuel prices, the conclusion is that energy prices will increase continuously over the next decades. In addition, there is growing concern about the environmental pollution caused by burning fossil fuels. This issue is examined in Section 1.3.

The sun's energy has been used by both nature and humankind throughout time in thousands of ways, from growing food to drying clothes; it has also been deliberately harnessed to perform a number of other jobs. Solar energy is used to heat and cool buildings (both actively and passively), heat water for domestic and industrial uses, heat swimming pools, power refrigerators, operate engines and pumps, desalinate water for drinking purposes, generate electricity, for chemistry applications, and many more operations. The objective of this book is to present various types of systems used to harness solar energy, their engineering details, and ways to design them, together with some examples and case studies.

1.2 Energy demand and renewable energy

Many alternative energy sources can be used instead of fossil fuels. The decision as to what type of energy source should be utilized in each case must be made on the basis of economic, environmental, and safety considerations. Because of the desirable environmental and safety aspects it is widely believed that solar energy should be utilized instead of other alternative energy forms because it can be provided sustainably without harming the environment.

If the world economy expands to meet the expectations of countries around the globe, energy demand is likely to increase, even if laborious efforts are made to increase the energy use efficiency. It is now generally believed that renewable energy technologies can meet much of the growing demand at prices that are equal to or lower than those usually forecast for conventional energy. By the middle of the twenty-first century, renewable sources of energy could account for three-fifths of the world's electricity market and two-fifths of the market for fuels used directly.[1] Moreover, making a transition to a renewable energy-intensive economy would provide environmental and other benefits not measured in standard economic terms. It is envisaged that by 2050 global carbon dioxide (CO_2) emissions would be reduced to 75% of their levels in 1985, provided that energy efficiency and renewables are widely adopted. In addition, such benefits could be achieved at no additional cost, because renewable energy is expected to be competitive with conventional energy (Johanson et al., 1993).

This promising outlook for renewables reflects impressive technical gains made during the past two decades as renewable energy systems benefited from developments in electronics, biotechnology, material sciences, and in other areas. For example, fuel cells developed originally for the space program opened the door to the use of hydrogen as a non-polluting fuel for transportation.

Moreover, because the size of most renewable energy equipment is small, renewable energy technologies can advance at a faster pace than conventional technologies. While large energy facilities require extensive construction in the field, most renewable energy equipment can be constructed in factories, where it is easier to apply modern manufacturing techniques that facilitate cost reduction. This is a decisive parameter that the renewable energy industry must consider in an attempt to reduce cost and increase the reliability of manufactured goods. The small scale of the equipment also makes the time required from initial design to operation short; therefore, any improvements can be easily identified and incorporated quickly into modified designs or processes.

According to the renewable energy-intensive scenario, the contribution of intermittent renewables by the middle of this century could be as high as 30% (Johanson et al., 1993). A high rate of penetration by intermittent renewables without energy storage would be facilitated by emphasis on advanced natural gas-fired turbine power-generating systems. Such power-generating systems—characterized by low capital cost, high thermodynamic efficiency, and the flexibility to vary electrical output quickly in response to changes in the output of intermittent power-generating systems—would make it possible to backup the intermittent renewables at low cost, with little, if any, need for energy storage.

The key elements of a renewable energy-intensive future are likely to have the following key characteristics (Johanson et al., 1993):

1. There would be a diversity of energy sources, the relative abundance of which would vary from region to region. For example, electricity could be provided by various combinations of hydroelectric power, intermittent renewable power sources (wind, solar thermal electric, and photovoltaic (PV)), biomass,[2] and geothermal sources. Fuels could be provided by methanol, ethanol, hydrogen, and methane (biogas) derived from biomass, supplemented with hydrogen derived electrolytically from intermittent renewables.

[1]This is according to a renewable energy-intensive scenario that would satisfy energy demands associated with an eightfold increase in economic output for the world by the middle of the twenty-first century. In the scenario considered, world energy demand continues to grow in spite of a rapid increase in energy efficiency.

[2]The term *biomass* refers to any plant matter used directly as fuel or converted into fluid fuel or electricity. Biomass can be produced from a wide variety of sources such as wastes of agricultural and forest product operations as well as wood, sugarcane, and other plants grown specifically as energy crops.

2. Emphasis would be given to the efficient mixing of renewable and conventional energy supplies. This can be achieved with the introduction of energy carriers such as methanol and hydrogen. It is also possible to extract more useful energy from such renewable resources as hydropower and biomass, which are limited by environmental or land-use constraints. Most methanol exports could originate in sub-Saharan Africa and Latin America, where vast degraded areas are suitable for revegetation that will not be needed for cropland. Growing biomass on such lands for methanol or hydrogen production could provide a powerful economic driver for restoring these lands. Solar-electric hydrogen exports could come from the regions in North Africa and the Middle East that have good insolation.
3. Biomass would be widely used. Biomass would be grown sustainably and converted efficiently to electricity and liquid and gaseous fuels using modern technology without contributing to deforestation.
4. Intermittent renewables would provide a large quantity of the total electricity requirements cost-effectively, without the need for new electrical storage technologies.
5. Natural gas would play a major role in supporting the growth of a renewable energy industry. Natural gas-fired turbines, which have low capital costs and can quickly adjust their electrical output, can provide excellent backup for intermittent renewables on electric power grids. Natural gas would also help launch a biomass-based methanol industry.
6. A renewables-intensive energy future would introduce new choices and competition in energy markets. Growing trade in renewable fuels and natural gas would diversify the mix of suppliers and the products traded, which would increase competition and reduce the possibility of rapid price fluctuations and supply disruptions. This could also lead eventually to a stabilization of world energy prices with the creation of new opportunities for energy suppliers.
7. Most electricity produced from renewable sources would be fed into large electrical grids and marketed by electric utilities, without the need for electrical storage.

A renewable energy-intensive future is technically feasible, and the prospects are very good that a wide range of renewable energy technologies will become competitive with conventional sources of energy in a few years' time. However, to achieve such penetration of renewables, existing market conditions need to change. If the following problems are not addressed, renewable energy will enter the market relatively slowly:

- Private companies are unlikely to make the investments necessary to develop renewable technologies because the benefits are distant and not easily captured.
- Private firms will not invest in large volumes of commercially available renewable energy technologies because renewable energy costs will usually not be significantly lower than the costs of conventional energy.
- The private sector will not invest in commercially available technologies to the extent justified by the external benefits that would arise from their widespread deployment.

Fortunately, the policies needed to achieve the goals of increasing efficiency and expanding renewable energy markets are fully consistent with programs needed to encourage innovation and productivity growth throughout the economy. Given the right policy environment, energy industries will adopt innovations, driven by the same competitive pressures that revitalized other major manufacturing businesses around the world. Electric utilities have already shifted from being protected monopolies, enjoying economies of scale in large generating plants, to being competitive managers of investment portfolios that combine a diverse set of technologies, ranging from advanced generation, transmission, distribution, and storage equipment to efficient energy-using devices on customers' premises.

Capturing the potential for renewables requires new policy initiatives. The following policy initiatives are proposed by Johanson et al. (1993) to encourage innovation and investment in renewable technologies:

1. Subsidies that artificially reduce the price of fuels that compete with renewables should be removed or renewable energy technologies should be given equivalent incentives.
2. Taxes, regulations, and other policy instruments should ensure that consumer decisions are based on the full cost of energy, including environmental and other external costs not reflected in market prices.
3. Government support for research, development, and demonstration of renewable energy technologies should be increased to reflect the critical roles renewable energy technologies can play in meeting energy and environmental objectives.
4. Government regulations of electric utilities should be carefully reviewed to ensure that investments in new generating equipment are consistent with a renewables-intensive future and that utilities are involved in programs to demonstrate new renewable energy technologies.
5. Policies designed to encourage the development of the biofuels industry must be closely coordinated with both national agricultural development programs and efforts to restore degraded lands.
6. National institutions should be created or strengthened to implement renewable energy programs.
7. International development funds available for the energy sector should be increasingly directed to renewables.
8. A strong international institution should be created to assist and coordinate national and regional programs for increased use of renewables, support the assessment of energy options, and support centers of excellence in specialized areas of renewable energy research.

The integrating theme for all such initiatives, however, should be an energy policy aimed at promoting sustainable development. It will not be possible to provide the energy needed to bring a decent standard of living to the world's poor or sustain the economic well-being of the industrialized countries in environmentally acceptable ways if the use of present energy sources continues. The path to a sustainable society requires more efficient energy use and a shift to a variety of renewable energy sources. Generally, the central challenge to policy makers in the next few decades is to develop economic policies that simultaneously satisfy both socioeconomic developmental and environmental challenges.

Such policies could be implemented in many ways. The preferred policy instruments will vary with the level of the initiative (local, national, or international) and the region. On a regional level, the preferred options will reflect differences in endowments of renewable resources, stages of economic development, and cultural characteristics. Here the region can be an entire continent. One example of this is the declaration of the European Union (EU) for the promotion of renewable energies as a key measure to ensure that Europe meets its climate change targets under the Kyoto Protocol.

According to the decision, central to the European Commission's (EC) action to ensure that the EU and member states meet their Kyoto targets is the European Climate Change Programme launched in

2000. Under this umbrella, the Commission, member states, and stakeholders identified and developed a range of cost-effective measures to reduce emissions.

To date, 35 measures have been implemented, including the EU Emissions Trading Scheme and legislative initiatives to promote renewable energy sources for electricity production, to expand the use of biofuels in road transport, and to improve the energy performance of buildings. Previously, the EC proposed an integrated package of measures to establish a new energy policy for Europe that would increase actions to fight climate change and boost energy security and competitiveness in Europe, and the proposals put the EU on course toward becoming a low-carbon economy. The new package sets a range of ambitious targets to be met by 2020, including improvement of energy efficiency by 20%, increasing the market share of renewables to 20%, and increasing the share of biofuels in transport fuels to 10%. On greenhouse gas (GHG) emissions, the EC proposes that, as part of a new global agreement to prevent climate change from reaching dangerous levels, developed countries should reduce their emissions by an average of 30% from 1990 levels.

As a concrete first step toward this reduction, the EU would make a firm independent commitment to cut its emissions by at least 20% even before a global agreement is reached and irrespective of what others do.

Many scenarios describe how renewable energy will develop in coming years. In a renewable energy-intensive scenario, global consumption of renewable resources reaches a level equivalent to 318 EJ (exa, $E = 10^{18}$) per annum (a) of fossil fuels by 2050—a rate comparable with the 1985 total world energy consumption, which was equal to 323 EJ. Although this figure seems to be very large, it is less than 0.01% of the 3.8 million EJ of solar energy reaching the earth's surface each year. The total electric energy produced from intermittent renewable sources ($\sim$34 EJ/a) would be less than 0.003% of the sunlight that falls on land and less than 0.1% of the energy available from wind. The amount of energy targeted for recovery from biomass could reach 206 EJ/a by 2050, which is also small compared with the rate (3800 EJ/a) at which plants convert solar energy to biomass. The production levels considered are therefore not likely to be constrained by resource availability. A number of other practical considerations, however, do limit the renewable resources that can be used. The renewable energy-intensive scenario considers that biomass would be produced sustainably, not harvested in virgin forests. About 60% of the biomass supply would come from plantations established on degraded land or excess agricultural land and the rest from residues of agricultural or forestry operations. Finally, the amounts of wind, solar thermal, and PV power that can be economically integrated into electric generating systems are very sensitive to patterns of electricity demand and weather conditions. The marginal value of these intermittent electricity sources typically declines as their share of the total electric market increases.

By making efficient use of energy and expanding the use of renewable technologies, the world can expect to have adequate supplies of fossil fuels well into the twenty-first century. However, in some instances regional declines in fossil fuel production can be expected because of resource constraints. Oil production outside the Middle East would decline slowly under the renewables-intensive scenario, so that one-third of the estimated ultimately recoverable conventional resources will remain in the ground in 2050. Under this scenario, the total world conventional oil resources would decline from about 9900 EJ in 1988 to 4300 EJ in 2050. Although remaining conventional natural gas resources are comparable with those for conventional oil, with an adequate investment in pipelines and other infrastructure components, natural gas could be a major energy source for many years.

The next section reviews some of the most important environmental consequences of using conventional forms of energy. This is followed by a review of renewable energy technologies not included in this book.

1.3 Energy-related environmental problems

Energy is considered a prime agent in the generation of wealth and a significant factor in economic development. The importance of energy in economic development is recognized universally and historical data verify that there is a strong relationship between the availability of energy and economic activity. Although in the early 1970s, after the oil crisis, the concern was on the cost of energy, during the past two decades the risk and reality of environmental degradation have become more apparent. The growing evidence of environmental problems is due to a combination of several factors since the environmental impact of human activities has grown dramatically. This is due to the increase of the world population, energy consumption, and industrial activity. Achieving solutions to the environmental problems that humanity faces today requires long-term potential actions for sustainable development. In this respect, renewable energy resources appear to be one of the most efficient and effective solutions.

A few years ago, most environmental analysis and legal control instruments concentrated on conventional pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulates, and carbon monoxide (CO). Recently, however, environmental concern has extended to the control of hazardous air pollutants, which are usually toxic chemical substances harmful even in small doses, as well as to other globally significant pollutants such as carbon dioxide (CO_2). Additionally, developments in industrial processes and structures have led to new environmental problems. Carbon dioxide as a GHG plays a vital role in global warming. Studies show that it is responsible for about two-thirds of the enhanced greenhouse effect. A significant contribution to the CO_2 emitted to the atmosphere is attributed to fossil fuel combustion (EPA, 2007).

The United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro, Brazil, in June 1992, addressed the challenges of achieving worldwide sustainable development. The goal of sustainable development cannot be realized without major changes in the world's energy system. Accordingly, Agenda 21, which was adopted by UNCED, called for "new policies or programs, as appropriate, to increase the contribution of environmentally safe and sound and cost-effective energy systems, particularly new and renewable ones, through less polluting and more efficient energy production, transmission, distribution, and use".

The division for sustainable development of the United Nations Department of Economics and Social Affairs defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Agenda 21, the *Rio Declaration on Environment and Development*, was adopted by 178 governments. This is a comprehensive plan of action to be taken globally, nationally, and locally by organizations of the United Nations system, governments, and major groups in every area in which there are human impacts on the environment (United Nations, 1992). Many factors can help to achieve sustainable development. Today, one of the main factors that must be considered is energy and one of the most important issues is the requirement for a supply of energy that is fully sustainable (Rosen, 1996; Dincer and Rosen, 1998). A secure supply of energy is generally agreed to be a necessary but not a sufficient requirement for development within a society. Furthermore, for a sustainable development within a society, it is required that a sustainable supply of energy and an effective and efficient utilization of energy resources are secure. Such a supply in the long term should be readily available at reasonable cost, sustainable, and able to be utilized for all the required tasks without causing negative societal impacts. This is the reason why there is a close connection between renewable sources of energy and sustainable development.

Sustainable development is a serious policy concept. In addition to the definition just given, it can be considered as a development that must not carry the seeds of destruction, because such a development is unsustainable. The concept of sustainability has its origin in fisheries and forest management in which prevailing management practices, such as overfishing or single-species cultivation, work for limited time, then yield diminishing results and eventually endanger the resource. Therefore, sustainable management practices should not aim for maximum yield in the short run but for smaller yields that can be sustained over time.

Pollution depends on energy consumption. In 2011, the world daily oil consumption is 87.4 million barrels. Despite the well-known consequences of fossil fuel combustion on the environment, this is expected to increase to 123 million barrels per day by the year 2025 (Worldwatch, 2007). A large number of factors are significant in the determination of the future level of energy consumption and production. Such factors include population growth, economic performance, consumer tastes, and technological developments. Furthermore, government policies concerning energy and developments in the world energy markets certainly play a key role in the future level and pattern of energy production and consumption (Dincer, 1999).

In 1984, 25% of the world population consumed 70% of the total energy supply, while the remaining 75% of the population was left with 30%. If the total population were to have the same consumption per inhabitant as the Organization for Economic Cooperation and Development member countries have on average, it would result in an increase in the 1984 world energy demand from 10 TW (tera, $T = 10^{12}$) to approximately 30 TW. An expected increase in the population from 4.7 billion in 1984 to 8.2 billion in 2020 would raise the figure to 50 TW.

The total primary energy demand in the world increased from 5536 GTOE[3] in 1971 to 11,235 GTOE in 2007, representing an average annual increase of about 2%. It is important, however, to note that the average worldwide growth from 2001 to 2004 was 3.7%, with the increase from 2003 to 2004 being 4.3%. The rate of growth is rising mainly due to the very rapid growth in Pacific Asia, which recorded an average increase from 2001 to 2004 of 8.6%.

The major sectors using primary energy sources include electrical power, transportation, heating, and industry. The International Energy Agency data shows that the electricity demand almost tripled from 1971 to 2002. This is because electricity is a very convenient form of energy to transport and use. Although primary energy use in all sectors has increased, their relative shares have decreased, except for transportation and electricity. The relative share of primary energy for electricity production in the world increased from about 20% in 1971 to about 30% in 2002 as electricity became the preferred form of energy for all applications.

Fueled by high increases in China and India, worldwide energy consumption may continue to increase at rates between 3% and 5% for at least a few more years. However, such high rates of increase cannot continue for too long. Even at a 2% increase per year, the primary energy demand of 2002

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[3] TOE = Tons of oil equivalent = 41.868 GJ (giga, $G = 10^9$).

would double by 2037 and triple by 2057. With such high energy demand expected 50 years from now, it is important to look at all the available strategies to fulfill the future demand, especially for electricity and transportation.

At present, 95% of all energy for transportation comes from oil. Therefore, the available oil resources and their production rates and prices greatly influence the future changes in transportation. An obvious replacement for oil would be biofuels such as ethanol, methanol, biodiesel, and biogases. It is believed that hydrogen is another alternative because, if it could be produced economically from renewable energy sources, it could provide a clean transportation alternative for the future.

Natural gas will be used at rapidly increasing rates to make up for the shortfall in oil production; however, it may not last much longer than oil itself at higher rates of consumption. Coal is the largest fossil resource available and the most problematic due to environmental concerns. All indications show that coal use will continue to grow for power production around the world because of expected increases in China, India, Australia, and other countries. This, however, would be unsustainable, from the environmental point of view, unless advanced clean coal technologies with carbon sequestration are deployed.

Another parameter to be considered is the world population. This is expected to double by the middle of this century and as economic development will certainly continue to grow, the global demand for energy is expected to increase. For example, the most populous country, China, increased its primary energy consumption by 15% from 2003 to 2004. Today, much evidence exists to suggest that the future of our planet and the generations to come will be negatively affected if humans keep degrading the environment. Currently, three environmental problems are internationally known: acid precipitation, the stratospheric ozone depletion, and global climate change. These issues are analyzed in more detail in the following subsections.

1.3.1 Acid rain

Acid rain is a form of pollution depletion in which SO_2 and NO_x produced by the combustion of fossil fuels are transported over great distances through the atmosphere, where they react with water molecules to produce acids deposited via precipitation on the earth, causing damage to ecosystems that are exceedingly vulnerable to excessive acidity. Therefore, it is obvious that the solution to the issue of acid rain deposition requires an appropriate control of SO_2 and NO_x pollutants. These pollutants cause both regional and transboundary problems of acid precipitation.

Recently, attention also has been given to other substances, such as volatile organic compounds (VOCs), chlorides, ozone, and trace metals that may participate in a complex set of chemical transformations in the atmosphere, resulting in acid precipitation and the formation of other regional air pollutants.

It is well known that some energy-related activities are the major sources of acid precipitation. Additionally, VOCs are generated by a variety of sources and comprise a large number of diverse compounds. Obviously, the more energy we expend, the more we contribute to acid precipitation; therefore, the easiest way to reduce acid precipitation is by reducing energy consumption.

1.3.2 Ozone layer depletion

The ozone present in the stratosphere, at altitudes between 12 and 25 km, plays a natural equilibrium-maintaining role for the earth through absorption of ultraviolet (UV) radiation (240–320 nm) and absorption of infrared radiation (Dincer, 1998). A global environmental problem is the depletion of the stratospheric ozone layer, which is caused by the emissions of chlorofluorocarbons (CFCs), halons (chlorinated and brominated organic compounds), and NO_x. Ozone depletion can lead to increased levels of damaging UV radiation reaching the ground, causing increased rates of skin cancer and eye damage to humans, and is harmful to many biological species. It should be noted that energy-related activities are only partially (directly or indirectly) responsible for the emissions that lead to stratospheric ozone depletion. The most significant role in ozone depletion is played by the CFCs, which are mainly used in air-conditioning and refrigerating equipment as refrigerants, and NO_x emissions, which are produced by the fossil fuel and biomass combustion processes, natural denitrification, and nitrogen fertilizers.

In 1998, the size of the ozone hole over Antarctica was 25 million km^2 whereas in 2012 it is 18 million km^2. It was about 3 million km^2 in 1993 (Worldwatch, 2007). Researchers expect the Antarctic ozone hole to remain severe in the next 10–20 years, followed by a period of slow healing. Full recovery is predicted to occur in 2050; however, the rate of recovery is affected by the climate change (Dincer, 1999).

1.3.3 Global climate change

The term *greenhouse effect* has generally been used for the role of the whole atmosphere (mainly water vapor and clouds) in keeping the surface of the earth warm. Recently, however, it has been increasingly associated with the contribution of CO_2, which is estimated to contribute about 50% to the anthropogenic greenhouse effect. Additionally, several other gases, such as CH_4, CFCs, halons, N_2O, ozone, and peroxyacetylnitrate (also called *GHGs*), produced by the industrial and domestic activities can contribute to this effect, resulting in a rise of the earth's temperature. Increasing atmospheric concentrations of GHGs increase the amount of heat trapped (or decrease the heat radiated from the earth's surface), thereby raising the surface temperature of the earth. According to Colonbo (1992), the earth's surface temperature has increased by about 0.6 °C over the past century, and as a consequence the sea level is estimated to have risen by perhaps 20 cm. These changes can have a wide range of effects on human activities all over the world. The role of various GHGs is summarized by Dincer and Rosen (1998).

According to the EU, climate change is happening. There is an overwhelming consensus among the world's leading climate scientists that global warming is being caused mainly by carbon dioxide and other GHGs emitted by human activities, chiefly the combustion of fossil fuels and deforestation.

A reproduction of the climate over the past 420,000 years was made recently using data from the Vostok ice core in Antarctica. An ice core is a core sample from the accumulation of snow and ice over many years that has recrystallized and trapped air bubbles from previous time periods. The composition of these ice cores, especially the presence of hydrogen and oxygen isotopes, provides a picture of the climate at the time. The data extracted from this ice core provide a continuous record of temperature and atmospheric composition. Two parameters of interest are the concentration of CO_2 in the atmosphere and the temperature. These are shown in Figure 1.1, considering 1950 as the reference year. As can be seen, the two parameters follow a similar trend and have a periodicity of about 100,000 years. If one considers, however, the present (December 2012) CO_2 level, which is 392.92 ppm (www.co2now.org), the highest ever recorded, one can understand the implication that this would have on the temperature of the planet.

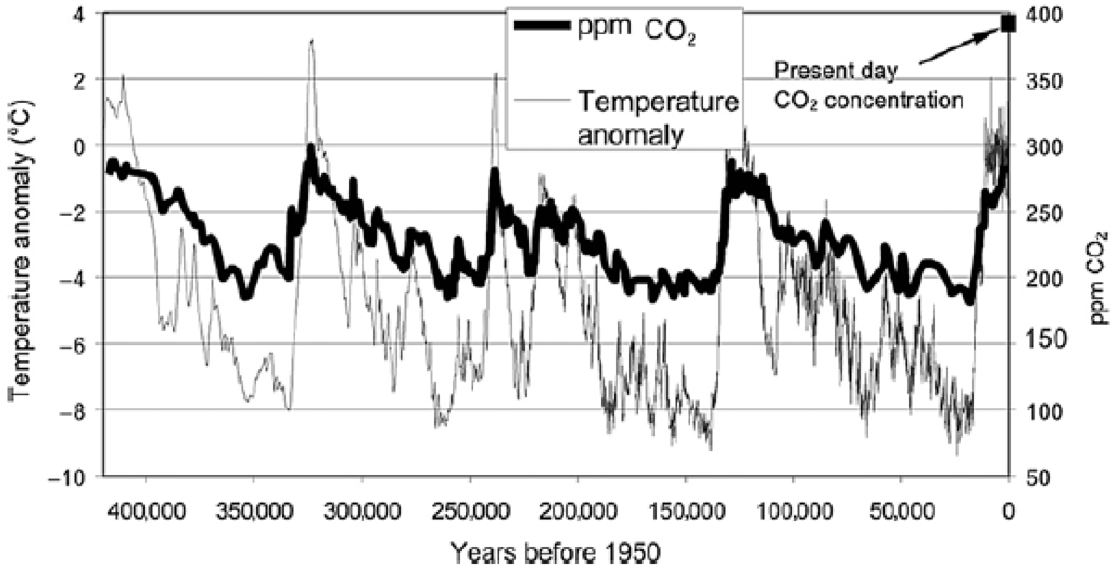

FIGURE 1.1

Temperature and CO_2 concentration from the Vostok ice core.

Humans, through many of their economic and other activities, contribute to the increase of the atmospheric concentrations of various GHGs. For example, CO_2 releases from fossil fuel combustion, methane emissions from increased human activities, and CFC releases contribute to the greenhouse effect. Predictions show that if atmospheric concentrations of GHGs, mainly due to fossil fuel combustion, continue to increase at the present rates, the earth's temperature may increase by another 2–4 °C in the next century. If this prediction is realized, the sea level could rise by 30–60 cm before the end of this century (Colonbo, 1992). The impacts of such sea level increase can easily be understood and include flooding of coastal settlements, displacement of fertile zones for agriculture to higher latitudes, and decrease in availability of freshwater for irrigation and other essential uses. Thus, such consequences could put in danger the survival of entire populations.

1.3.4 Nuclear energy

Nuclear energy, although non-polluting, presents a number of potential hazards during the production stage and mainly for the disposal of radioactive waste. Nuclear power environmental effects include the effects on air, water, ground, and the biosphere (people, plants, and animals). Nowadays, in many countries, laws govern any radioactive releases from nuclear power plants. In this section some of the most serious environmental problems associated with electricity produced from nuclear energy are described. These include only the effects related to nuclear energy and not the emissions of other substances due to the normal thermodynamic cycle.

The first item to consider is radioactive gases that may be removed from the systems supporting the reactor cooling system. The removed gases are compressed and stored. The gases are periodically sampled and can be released only when the radioactivity is less than an acceptable level, according to certain standards. Releases of this nature are done very infrequently. Usually, all potential paths where radioactive materials could be released to the environment are monitored by radiation monitors (Virtual Nuclear Tourist, 2007).

Nuclear plant liquid releases are slightly radioactive. Very low levels of leakage may be allowed from the reactor cooling system to the secondary cooling system of the steam generator. However, in any case where radioactive water may be released to the environment, it must be stored and radioactivity levels reduced, through ion exchange processes, to levels below those allowed by the regulations.

Within the nuclear plant, a number of systems may contain radioactive fluids. Those liquids must be stored, cleaned, sampled, and verified to be below acceptable levels before release. As in the gaseous release case, radiation detectors monitor release paths and isolate them (close valves) if radiation levels exceed a preset set point (Virtual Nuclear Tourist, 2007).

Nuclear-related mining effects are similar to those of other industries and include generation of tailings and water pollution. Uranium milling plants process naturally radioactive materials. Radioactive airborne emissions and local land contamination were evidenced until stricter environmental rules aided in forcing cleanup of these sites.

As with other industries, operations at nuclear plants result in waste; some of it, however, is radioactive. Solid radioactive materials leave the plant by only two paths:

- Radioactive waste (e.g. clothes, rags, wood) is compacted and placed in drums. These drums must be thoroughly dewatered. The drums are often checked at the receiving location by regulatory agencies. Special landfills must be used.
- Spent resin may be very radioactive and is shipped in specially designed containers.

Generally, waste is distinguished into two categories: low-level waste (LLW) and high-level waste (HLW). LLW is shipped from nuclear plants and includes such solid waste as contaminated clothing, exhausted resins, or other materials that cannot be reused or recycled. Most anti-contamination clothing is washed and reused; however, eventually, as with regular clothing, it wears out. In some cases, incineration or super-compaction may be used to reduce the amount of waste that has to be stored in the special landfills.

HLW is considered to include the fuel assemblies, rods, and waste separated from the spent fuel after removal from the reactor. Currently the spent fuel is stored at the nuclear power plant sites in storage pools or in large metal casks. To ship the spent fuel, special transport casks have been developed and tested.

Originally, the intent had been that the spent fuel would be reprocessed. The limited amount of highly radioactive waste (also called HLW) was to be placed in glass rods surrounded by metal with low long-term corrosion or degradation properties. The intent was to store those rods in specially designed vaults where the rods could be recovered for the first 50–100 years and then made irretrievable for up to 10,000 years. Various underground locations can be used for this purpose, such as salt domes, granite formations, and basalt formations. The objective is to have a geologically stable location with minimal chance for groundwater intrusion. The intent had been to recover the plutonium and unused uranium fuel and then reuse it in either breeder or thermal reactors as mixed oxide fuel. Currently, France, Great Britain, and Japan are using this process (Virtual Nuclear Tourist, 2007).

1.3.5 Renewable energy technologies

Renewable energy technologies produce marketable energy by converting natural phenomena into useful forms of energy. These technologies use the sun's energy and its direct and indirect effects on the earth (solar radiation, wind, falling water, and various plants; i.e., biomass), gravitational forces (tides), and the heat of the earth's core (geothermal) as the resources from which energy is produced. These resources have massive energy potential; however, they are generally diffused and not fully accessible, and most of them are intermittent and have distinct regional variabilities. These characteristics give rise to difficult, but solvable, technical and economical challenges. Nowadays, significant progress is made by improving the collection and conversion efficiencies, lowering the initial and maintenance costs, and increasing the reliability and applicability of renewable energy systems.

Worldwide research and development in the field of renewable energy resources and systems has been carried out during the past two decades. Energy conversion systems that are based on renewable energy technologies appeared to be cost-effective compared with the projected high cost of oil. Furthermore, renewable energy systems can have a beneficial impact on the environmental, economic, and political issues of the world. At the end of 2001 the total installed capacity of renewable energy systems was equivalent to 9% of the total electricity generation (Sayigh, 2001). As was seen before, by applying the renewable energy-intensive scenario, the global consumption of renewable sources by 2050 would reach 318 EJ (Johanson et al., 1993).

The benefits arising from the installation and operation of renewable energy systems can be distinguished into three categories: energy saving, generation of new working posts, and decrease in environmental pollution.

The energy-saving benefit derives from the reduction in consumption of the electricity and diesel used conventionally to provide energy. This benefit can be directly translated into monetary units according to the corresponding production or avoiding capital expenditure for the purchase of imported fossil fuels.

Another factor of considerable importance in many countries is the ability of renewable energy technologies to generate jobs. The penetration of a new technology leads to the development of new production activities, contributing to the production, market distribution, and operation of the pertinent equipment. Specifically for the case of solar energy collectors, job creation is mainly related to the construction and installation of the collectors. The latter is a decentralized process, since it requires the installation of equipment in every building or for every individual consumer.

The most important benefit of renewable energy systems is the decrease in environmental pollution. This is achieved by the reduction of air emissions due to the substitution of electricity and conventional fuels. The most important effects of air pollutants on the human and natural environment are their impact on the public health, agriculture, and on ecosystems. It is relatively simple to measure the financial impact of these effects when they relate to tradable goods, such as the agricultural crops; however, when it comes to non-tradable goods, such as human health and ecosystems, things become more complicated. It should be noted that the level of the environmental impact and therefore the social pollution cost largely depend on the geographical location of the emission sources. Contrary to the conventional air pollutants, the social cost of CO_2 does not vary with the geographical characteristics of the source, as each unit of CO_2 contributes equally to the climate change thread and the resulting cost.

All renewable energy sources combined account for only 22.5% share of electricity production in the world (2010), with hydroelectric power providing almost 90% of this amount. However, as the renewable energy technologies mature and become even more cost competitive in the future, they will be in a position to replace a major fraction of fossil fuels for electricity generation. Therefore, substituting fossil fuels with renewable energy for electricity generation must be an important part of any strategy of reducing CO_2 emissions into the atmosphere and combating global climate change.

In this book, emphasis is given to solar thermal systems. Solar thermal systems are non-polluting and offer significant protection of the environment. The reduction of GHG pollution is the main advantage of utilizing solar energy. Therefore, solar thermal systems should be employed whenever possible to achieve a sustainable future.

The benefits of renewable energy systems can be summarized as follows (Johanson et al., 1993):

- *Social and economic development*. Production of renewable energy, particularly biomass, can provide economic development and employment opportunities, especially in rural areas, that otherwise have limited opportunities for economic growth. Renewable energy can thus help reduce poverty in rural areas and reduce pressure for urban migration.
- *Land restoration*. Growing biomass for energy on degraded lands can provide the incentive and financing needed to restore lands rendered nearly useless by previous agricultural or forestry practices. Although lands farmed for energy would not be restored to their original condition, the recovery of these lands for biomass plantations would support rural development, prevent erosion, and provide a better habitat for wildlife than at present.
- *Reduced air pollution*. Renewable energy technologies, such as methanol or hydrogen for fuel cell vehicles, produce virtually none of the emissions associated with urban air pollution and acid deposition, without the need for costly additional controls.
- *Abatement of global warming*. Renewable energy use does not produce carbon dioxide or other greenhouse emissions that contribute to global warming. Even the use of biomass fuels does not contribute to global warming, since the carbon dioxide released when biomass is burned equals the amount absorbed from the atmosphere by plants as they are grown for biomass fuel.
- *Fuel supply diversity*. There would be substantial interregional energy trade in a renewable energy-intensive future, involving a diversity of energy carriers and suppliers. Energy importers would be able to choose from among more producers and fuel types than they do today and thus would be less vulnerable to monopoly price manipulation or unexpected disruptions of supply. Such competition would make wide swings in energy prices less likely, leading eventually to stabilization of the world oil price. The growth in world energy trade would also provide new opportunities for energy suppliers. Especially promising are the prospects for trade in alcohol fuels, such as methanol, derived from biomass and hydrogen.
- *Reducing the risks of nuclear weapons proliferation*. Competitive renewable resources could reduce incentives to build a large world infrastructure in support of nuclear energy, thus avoiding major increases in the production, transportation, and storage of plutonium and other radioactive materials that could be diverted to nuclear weapons production.

Solar systems, including solar thermal and PVs, offer environmental advantages over electricity generation using conventional energy sources. The benefits arising from the installation and operation of solar energy systems fall into two main categories: environmental and socioeconomical issues.

From an environmental viewpoint, the use of solar energy technologies has several positive implications that include (Abu-Zour and Riffat, 2006):

- Reduction of the emission of the GHGs (mainly CO_2 and NO_x) and of toxic gas emissions (SO_2, particulates),

- Reclamation of degraded land,
- Reduced requirement for transmission lines within the electricity grid, and
- Improvement in the quality of water resources.

The socioeconomic benefits of solar technologies include:

- Increased regional and national energy independence,
- Creation of employment opportunities,
- Restructuring of energy markets due to penetration of a new technology and the growth of new production activities,
- Diversification and security (stability) of energy supply,
- Acceleration of electrification of rural communities in isolated areas, and
- Saving foreign currency.

It is worth noting that no artificial project can completely avoid some impact to the environment. The negative environmental aspects of solar energy systems include:

- Pollution stemming from production, installation, maintenance, and demolition of the systems,
- Noise during construction,
- Land displacement, and
- Visual intrusion.

These adverse impacts present difficult but solvable technical challenges.

The amount of sunlight striking the earth's atmosphere continuously is 1.75×10^5 TW. Considering a 60% transmittance through the atmospheric cloud cover, 1.05×10^5 TW reaches the earth's surface continuously. If the irradiance on only 1% of the earth's surface could be converted into electric energy with a 10% efficiency, it would provide a resource base of 105 TW, while the total global energy needs for 2050 are projected to be about 25–30 TW. The present state of solar energy technologies is such that single solar cell efficiencies have reached more than 20%, with concentrating PVs at about 40%, and solar thermal systems provide efficiencies of 40–60%.

Solar PV panels have come down in cost from about \$30/W to about \$0.8/W in the past three decades. At \$0.8/W panel cost, the overall system cost is around \$2.5-5/W (depending on the size of the installation), which is still too high for the average consumer. However, solar PV is already cost-effective in many off-grid applications. With net metering and governmental incentives, such as feed-in laws and other policies, even grid-connected applications such as building-integrated PV have become cost-effective. As a result, the worldwide growth in PV production has averaged more than 30% per year during the past 5 years.

Solar thermal power using concentrating solar collectors was the first solar technology that demonstrated its grid power potential. A total of 354 MWe solar thermal power plants have been operating continuously in California since 1985. Progress in solar thermal power stalled after that time because of poor policy and lack of R&D. However, the past 5 years have seen a resurgence of interest in this area, and a number of solar thermal power plants around the world are constructed and more are under construction. The cost of power from these plants (which so far is in the range of \$0.12–\$0.16/kWh) has the potential to go down to \$0.05/kWh with scale-up and creation of a mass market. An advantage of solar thermal power is that thermal energy can be stored efficiently and fuels such as natural gas or biogas may be used as backup to ensure continuous operation.