Solar Energy Fundamentals and Modeling Techniques

Zekai Şen

Solar Energy Fundamentals and Modeling Techniques

Atmosphere, Environment, Climate Change and Renewable Energy

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Bismillahirrahmanirrahim

In the name of Allah the most merciful and the most beneficial

Preface

Atmospheric and environmental pollution as a result of extensive fossil fuel exploitation in almost all human activities has led to some undesirable phenomena that have not been experienced before in known human history. They are varied and include global warming, the greenhouse affect, climate change, ozone layer depletion, and acid rain. Since 1970 it has been understood scientifically by experiments and research that these phenomena are closely related to fossil fuel uses because they emit greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) which hinder the long-wave terrestrial radiation from escaping into space and, consequently, the earth troposphere becomes warmer. In order to avoid further impacts of these phenomena, the two main alternatives are either to improve the fossil fuel quality thus reducing their harmful emissions into the atmosphere or, more significantly, to replace fossil fuel usage as much as possible with environmentally friendly, clean, and renewable energy sources. Among these sources, solar energy comes at the top of the list due to its abundance and more even distribution in nature than other types of renewable energy such as wind, geothermal, hydropower, biomass, wave, and tidal energy sources. It must be the main and common purpose of humanity to develop a sustainable environment for future generations. In the long run, the known limits of fossil fuels compel the societies of the world to work jointly for their replacement gradually by renewable energies rather than by improving the quality of fossil sources.

Solar radiation is an integral part of different renewable energy resources, in general, and, in particular, it is the main and continuous input variable from the practically inexhaustible sun. Solar energy is expected to play a very significant role in the future especially in developing countries, but it also has potential in developed countries. The material presented in this book has been chosen to provide a comprehensive account of solar energy modeling methods. For this purpose, explanatory background material has been introduced with the intention that engineers and scientists can benefit from introductory preliminaries on the subject both from application and research points of view.

The main purpose of Chapter 1 is to present the relationship of energy sources to various human activities on social, economic and other aspects. The atmospheric environment and renewable energy aspects are covered in Chapter 2. Chapter 3 provides the basic astronomical variables, their definitions and uses in the calculation of the solar radiation (energy) assessment. These basic concepts, definitions, and derived astronomical equations furnish the foundations of the solar energy evaluation at any given location. Chapter 4 provides first the fundamental assumptions in the classic linear models with several modern alternatives. After the general review of available classic non-linear models, additional innovative non-linear models are presented in Chapter 5 with fundamental differences and distinctions. Fuzzy logic and genetic algorithm approaches are presented for the non-linear modeling of solar radiation from sunshine duration data. The main purpose of Chapter 6 is to present and develop regional models for any desired location from solar radiation measurement sites. The use of the geometric functions, inverse distance, inverse distance square, semivariogram, and cumulative semivariogram techniques are presented for solar radiation spatial estimation. Finally, Chapter 7 gives a summary of solar energy devices.

Applications of solar energy in terms of low- and high-temperature collectors are given with future research directions. Furthermore, photovoltaic devices are discussed for future electricity generation based on solar power site-exploitation and transmission by different means over long distances, such as fiber-optic cables. Another future use of solar energy is its combination with water and, as a consequence, electrolytic generation of hydrogen gas is expected to be another source of clean energy. The combination of solar energy and water for hydrogen gas production is called solar-hydrogen energy. Necessary research potentials and application possibilities are presented with sufficient background. New methodologies that are bound to be used in the future are mentioned and, finally, recommendations and suggestions for future research and application are presented, all with relevant literature reviews. I could not have completed this work without the support, patience, and assistance of my wife Fatma Şen.

İstanbul, Çubuklu

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Chapter 1
Energy and Climate Change

1.1 General

Energy and fresh water are the two major commodities that furnish the fundamentals of every human activity for a reasonable and sustainable quality of life. Energy is the fuel for growth, an essential requirement for economic and social development. Solar energy is the most ancient source and the root for almost all fossil and renewable types. Special devices have been used for benefiting from the solar and other renewable energy types since time immemorial. During the early civilizations water and wind power have been employed as the major energy sources for navigation, trade, and information dissemination. For instance, Ebul-İz Al-Jazari (1136–1206), as mentioned by Şen (2005), was the first scientist who developed various instruments for efficient energy use. Al-Jazari described the first reciprocating piston engine, suction pump, and valve, when he invented a two-cylinder reciprocating suction piston pump, which seems to have had a direct significance in the development of modern engineering. This pump is driven by a water wheel (water energy) that drives, through a system of gears, an oscillating slot-rod to which the rods of two pistons are attached. The pistons work in horizontally opposed cylinders, each provided with valve-operated suction and delivery pipes. His original drawing in Fig. 1.1a shows the haulage of water by using pistons, cylinders, and a crank moved by panels subject to wind power. In Fig. 1.1b the equivalent instrument design is achieved by Hill (1974).

Ebul-İz Al-Jazari's original *robotic* drawing is presented in Fig. 1.2. It works with water power through right and left nozzles, as in the figure, and accordingly the right and left hands of the human figure on the elephant move up and down.

In recent centuries the types and magnitudes of the energy requirements have increased in an unprecedented manner and mankind seeks for additional energy sources. Today, energy is a continuous driving power for future social and technological developments. Energy sources are vital and essential ingredients for all human transactions and without them human activity of all kinds and aspects cannot be progressive. Population growth at the present average rate of 2% also exerts extra pressure on limited energy sources.

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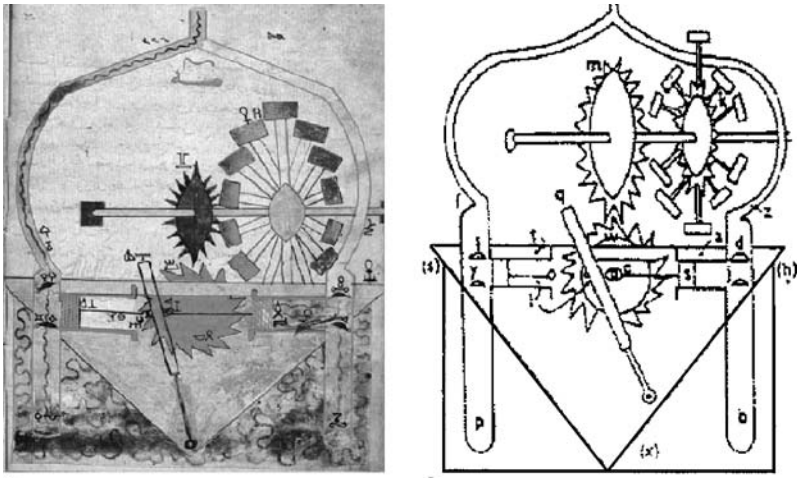

a b

Fig. 1.1 **a** Al-Jazari (1050). **b** Hill (1974)

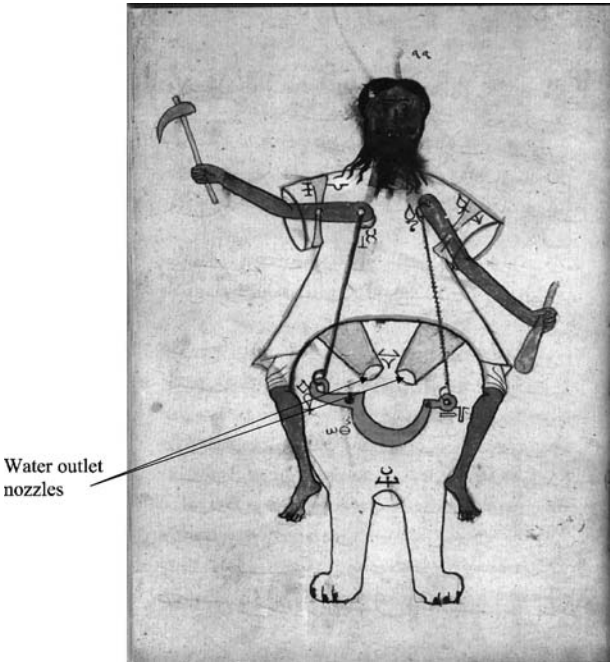

Fig. 1.2 Robotic from Al-Jazari

The *oil crises* of the 1970s have led to a surge in research and development of renewable and especially solar energy alternatives. These efforts were strongly correlated with the fluctuating market price of energy and suffered a serious setback as this price later plunged. The missing ingredient in such a process was a long-term perspective that hindered the research and development policy within the wider context of fossil and solar energy tradeoffs rather than reactions to temporary price fluctuations. The same events also gave rise to a rich literature on the optimal exploitation of natural resources, desirable rate of research, and development efforts to promote competitive technologies (Tsur and Zemel 1998). There is also a vast amount of literature on energy management in the light of atmospheric pollution and climate change processes (Clarke 1988; Edmonds and Reilly 1985, 1993; Hoel and Kvendokk 1996; Nordhaus 1993, 1997; Tsur and Zemel 1996; Weyant 1993).

The main purpose of this chapter is to present the relationship of energy sources to various human activities including social, economic, and other aspects.

1.2 Energy and Climate

In the past, natural weather events and climate phenomena were not considered to be interrelated with the energy sources, however during the last three decades their close interactions become obvious in the atmospheric composition, which drives the meteorological and climatologic phenomena. Fossil fuel use in the last 100 years has loaded the atmosphere with additional constituents and especially with carbon dioxide (CO_2), the increase of which beyond a certain limit influences atmospheric events (Chap. 2). Since the nineteenth century, through the advent of the industrial revolution, the increased emissions of various *greenhouse* gases (CO_2, CH_4, N_2O, *etc.*) into the atmosphere have raised their concentrations at an alarming rate, causing an abnormal increase in the earth's average temperature. Scientists have confirmed, with a high degree of certainty, that the recent trend in global average temperatures is not a normal phenomenon (Rozenzweig *et al.*, 2007). Its roots are to be found in the unprecedented industrial growth witnessed by the world economy, which is based on energy consumption.

Since climate modification is not possible, human beings must be careful in their use of energy sources and reduce the share of fossil fuels as much as possible by replacing their role with clean and environmentally friendly energy sources that are renewable, such as solar, wind, water, and biomass. In this manner, the extra loads on the atmosphere can be reduced to their natural levels and hence sustainability can be passed on to future generations.

Over the last century, the amount of CO_2 in the atmosphere has risen, driven in large part by the usage of *fossil fuels*, but also by other factors that are related to rising population and increasing consumption, such as land use change, *etc*. On the global scale, increase in the emission rates of greenhouse gases and in particular CO_2 represents a colossal threat to the world climate. Various theories and calculations in atmospheric research circles have already indicated that, over the last half century, there appeared a continuously increasing trend in the average temperature value up to 0.5 °C. If this trend continues in the future, it is expected that in some areas of the world, there will appear extreme events such as excessive rainfall and consequent floods, droughts, and also local imbalances in the natural climatic behavior giving rise to unusual local heat and cold. Such events will also affect the world food production rates. In addition, global temperatures could rise by a further 1 – 3.5 °C by the end of the twenty-first century, which may lead potentially to disruptive climate change in many places. By starting to manage the CO_2 emissions through renewable energy sources now, it may be possible to limit the effects of climate change to adaptable levels. This will require adapting the world's energy systems. Energy policy must help guarantee the future supply of energy and drive the necessary transition. International cooperation on the climate issue is a prerequisite for achieving cost-effective, fair, and sustainable solutions.

At present, the global energy challenge is to tackle the threat of climate change, to meet the rising demand for energy, and to safeguard security of energy supplies. *Renewable energy* and especially solar radiation are effective energy technologies that are ready for global deployment today on a scale that can help tackle climate change problems. Increase in the use of renewable energy reduces CO_2 emissions, cuts local air pollution, creates high-value jobs, curbs growing dependence of one country on imports of fossil energy (which often come from politically unstable regions), and prevents society a being hostage to finite energy resources.

In addition to *demand*-side impacts, *energy production* is also likely to be affected by climate change. Except for the impacts of extreme weather events, research evidence is more limited than for energy consumption, but climate change could affect energy production and supply as a result of the following (Wilbanks *et al.*, 2007):

1. If extreme weather events become more intense
2. If regions dependent on water supplies for hydropower and/or thermal power plant cooling face reductions in water supplies
3. If changed conditions affect facility siting decisions
4. If conditions change (positively or negatively) for biomass, wind power, or solar energyproductions

Climate change is likely to affect both energy use and energy production in many parts of the world. Some of the possible impacts are rather obvious. Where the climate warms due to climate change, less heating will be needed for industrial increase (Cartalis *et al.*, 2001), with changes varying by region and by season. Net energy demand on a national scale, however, will be influenced by the structure of energy supply. The main source of energy for cooling is electricity, while coal, oil, gas, biomass, and electricity are used for space heating. Regions with substantial requirements for both cooling and heating could find that net annual electricity demands increase while demands for other heating energy sources decline (Hadley *et al.*, 2006). Seasonal variation in total energy demand is also important. In some cases, due to infrastructure limitations, peak energy demand could go beyond the maximum capacity of the transmission systems. Tol (2002a,b) estimated the effects of climate change on the demand for global energy, extrapolating from a simple country-specific (UK) model that relates the energy used for heating or cooling to degree days, per capita income, and energy efficiency. According to Tol, by 2100 benefits (reduced heating) will be about 0.75% of gross domestic product

(GDP) and damages (increased cooling) will be approximately 0.45%, although it is possible that migration from heating-intensive to cooling-intensive regions could affect such comparisons in some areas (Wilbanks *et al.*, 2007).

Energy and climate are related concerning cooling during hot weather. Energy use has been and will continue to be affected by climate change, in part because air-conditioning, which is a major energy use particularly in developed countries, is climate-dependent. However, the extent to which temperature rise has affected energy use for space heating/cooling in buildings is uncertain. It is likely that certain adaptation strategies (*e.g.*, tighter building energy standards) have been (or would be) taken in response to climate change. The energy sector can adapt to *climate-change* vulnerabilities and impacts by anticipating possible impacts and taking steps to increase its resilience, *e.g.*, by diversifying energy supply sources, expanding its linkages with other regions, and investing in technological change to further expand its portfolio of options (Hewer 2006). Many energy sector strategies involve high capital costs, and social acceptance of climate-change response alternatives that might imply higher energy prices.

Climate change could have a negative impact on thermal power production since the availability of cooling water may be reduced at some locations because of climate-related decreases (Arnell *et al.*, 2005) or seasonal shifts in river runoff (Zierl and Bugmann 2005). The distribution of energy is also vulnerable to climate change. There is a small increase in line resistance with increasing mean temperatures coupled with negative effects on line sag and gas pipeline compressor efficiency due to higher maximum temperatures. All these combined effects add to the overall uncertainty of climate change impacts on power grids.

1.3 Energy and Society

Since the *energy crisis* in 1973 air pollution from combustion processes has caused serious damage and danger to forests, monuments, and human health in many countries, as has been documented by official studies and yearly statistics. Many environmental damages, including *acid rain* and their forest-damaging consequences, have incurred economic losses in the short term and especially in the long term. Hence, seemingly cheap energy may inflict comparatively very high expenses on society. Figure 1.3 shows three partners in such a social problem including material beneficiary, heat beneficiary, and, in between, the third party who has nothing to do with these two major players.

On the other hand, the climate change due to CO_2 emission into the atmosphere is another example of possible social costs from the use of energy, which is handed over to future generations by today's energy consumers. Again the major source of climate change is the combustion of unsuitable quality fossil fuels.

Today, the scale of development of any society is measured by a few parameters among which the used or the per capita energy amount holds the most significant rank. In fact, most industrialized countries require reliable, efficient, and readily

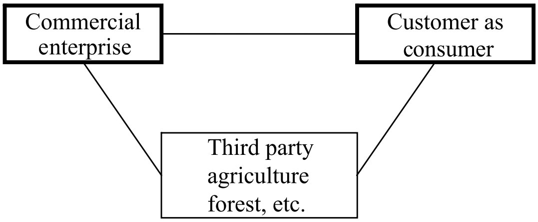

Fig. 1.3 Energy usage partners

available energy for their transportation, industrial, domestic, and military systems. This is particularly true for developing countries, especially those that do not possess reliable and sufficient energy sources.

Although an adequate supply of energy is a prerequisite of any modern society for economic growth, energy is also the main source of environmental and atmospheric pollution (Sect. 1.6). On the global scale, increasing emissions of air pollution are the main causes of greenhouse gases and climate change. If the trend of increasing CO_2 continues at the present rate, then major climatic disruptions and local imbalances in the hydrological as well as atmospheric cycles will be the consequences, which may lead to excessive rainfall or drought, in addition to excessive heat and cold. Such changes are already experienced and will also affect the world's potential for food production. The continued use of conventional energy resources in the future will adversely affect the natural environmental conditions and, consequently, social energy-related problems are expected to increase in the future. A new factor, however, which may alleviate the environmental and social problems of future energy policies, or even solve them, is the emerging new forms of renewable sources such as solar, wind, biomass, small hydro, wave, and geothermal energies, as well as the possibility of solar hydrogen energy.

The two major reasons for the increase in the energy consumption at all times are the steady population increase and the strive for better development and comfort. The world *population* is expected to almost double in the next 50 years, and such an increase in the population will take place mostly in the developing countries, because the developed countries are not expected to show any significant population increase. By 2050, energy demand could double or triple as population rises and developing countries expand their economies and overcome poverty.

The energy demand growth is partially linked to population growth, but may also result from larger per capita energy consumptions. The demand for and production of energy on a world scale are certain to increase in the foreseeable future. Of course, growth will definitely be greater in the developing countries than in the industrialized ones. Figure 1.4 shows the world population increase for a 100-year period with predictions up to 2050. It indicates an exponential growth trend with increasing rates in recent years such that values double with every passage of a fixed amount of time, which is the *doubling time*.

The recent rise in population is even more dramatic when one realizes that per capita consumption of energy is also rising thus compounding the effects. Economic growth and the population increase are the two major forces that will continue to

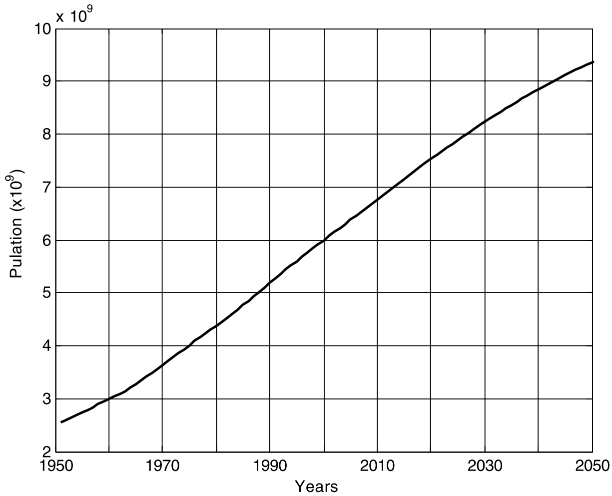

Fig. 1.4 Human population

cause increase in the energy demand during the coming decades. The future energy demand is shown in Table 1.1 for the next 30 years (Palz 1994).

The energy use of a society distinguishes its scale of development compared to others. A poor citizen in a less-developed country must rely on human and animal power. In contrast, developed countries consume large quantities of energy for transportation and industrial uses as well as heating and cooling of building spaces.

How long can the world population want these percentages to increase? The answer is not known with certainty. If the growth rate, G_r, is 1% per year then the doubling period, D_p, will be 69 years. Accordingly, the doubling periods, are presented for different growth rates in Fig. 1.5. It appears as a straight line on double-logarithmic paper, which implies that the model can be expressed mathematically in the form of a power function, as follows:

$$D_p = 69G_r^{-0.98} \,. \tag{1.1}$$

It is obvious that there is an inversely proportional relationship between the population growth rate and the doubling period.

Table 1.1 Future energy demand

1000 Moet	1990	2020	Increase (%)
Industrialized countries	4.1	4.6	12
Central and eastern Europe	1.7	1.8	5
Developing countries	2.9	6.9	137
World	8.7	13.3	52

Moet million oil equivalent ton (energy unit)

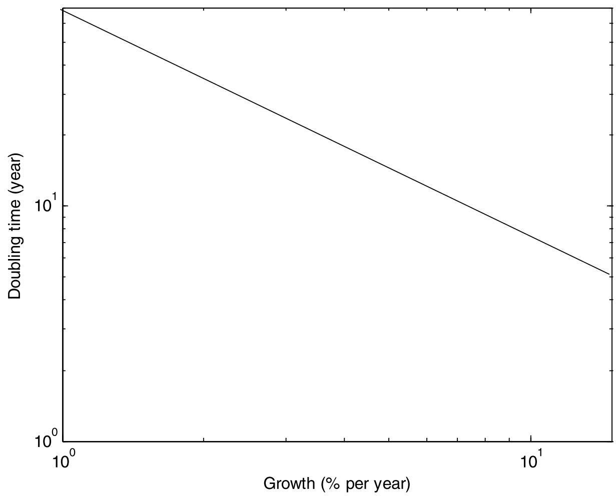

Fig. 1.5 Doubling time

Since energy cannot be created or destroyed and with the expected population increase, it is anticipated that there will be energy crises in the future, which may lead to an energy dilemma due to the finite amount of readily available fossil fuels. The population of human beings has increased in the last century by a factor of 6 but the energy consumption by a factor of 80. The worldwide average continuous power consumption today is 2 kW/person. In the USA the power consumption is on average 10 kW/person and in Europe about 5 kW/person and two billion people on earth do not consume any fossil fuels at all. The reserves of fossil fuels on earth are limited and predictions based on the continuation of the energy consumption development show that the demand will soon exceed the supply. The world's population increases at 1.3 – 2% per year so that it is expected to double within the next 60 years. According to the International Energy Agency (IEA 2000) the present population is about 6.5×10^9 and growing toward 12×10^9 in 2060. At the same time, developing countries want the same standard of living as developed countries. The world population is so large that there is an uncontrolled experiment taking place on the earth's environment. The developed countries are the major contributors to this uncontrolled experiment.

The poor, who make up half of the world's population and earn less than US$ 2 a day (UN-Habitat 2003), cannot afford adaptation mechanisms such as air-conditioning, heating, or climate-risk insurance (which is unavailable or significantly restricted in most developing countries). The poor depend on water, energy, transportation, and other public infrastructures which, when affected by climate-related disasters, are not immediately replaced (Freeman and Warner 2001).

Increases in the world population, demands on goods, technology, and the higher standard of comfort for human life all require more energy consumption and, accordingly, human beings started to ponder about additional alternative energy types.

Prior to the discovery of fossil fuels, coal and water played a vital role in such a search. For instance, transportation means such as the oceangoing vessels and early trains ran on steam power, which was the combination of coal and water vapor. After the discovery of oil reserves, steam power became outmoded. Hence, it seemed in the first instance that an unparalleled energy alternative had emerged for the service of mankind. Initially, it was considered an unlimited resource but with the passage of time, limitations in this alternative were understood not only in the quantitative sense but also in the *environmental and atmospheric pollution senses*. Society is affected by climate and hence energy in one of the three major ways:

1. Economic sectors that support a settlement are affected because of changes in productive capacity or changes in market demand for the goods and services produced there (energy demand). The importance of this impact depends in part on whether the settlement is rural (which generally means that it is dependent on one or two resource-based industries with much less energy consumption) or urban, in which case there usually is a broader array of alternative resources including energy resources consumption centers.
2. Some aspects of physical infrastructure (including energy transmission and distribution systems), buildings, urban services (including transportation systems), and specific industries (such as agro-industry and construction) may be directly affected. For example, buildings and infrastructure in deltaic areas may be affected by coastal and river flooding; urban energy demand may increase or decrease as a result of changed balances in space heating and space cooling (additional energy consumption); and coastal and mountain tourism may be affected by changes in seasonal temperature and precipitation patterns and sea-level rise. Concentration of population and infrastructure in urban areas can mean higher numbers of people and a higher value of physical capital at risk, although there also are many economies of scale and proximity in ensuring a well-managed infrastructure and service provision.
3. As a result of climate change society may be affected directly through extreme weather conditions leading to changes in health status and migration. Extreme weather episodes may lead to changes in deaths, injuries, or illness. Population movements caused by climate changes may affect the size and characteristics of settlement populations, which in turn changes the demand for urban services (including energy demand). The problems are somewhat different in the largest population centers (*e.g.*, those of more than 1 million people) and mid-sized to small-sized regional centers. The former are more likely to be destinations for migrants from rural areas and smaller settlements and cross-border areas, but larger settlements generally have much greater command over national resources. Thus, smaller settlements actually may be more vulnerable. Informal settlements surrounding large and medium-size cities in the developing world remain a cause for concern because they exhibit several current health and environmental hazards that could be exacerbated by global warming and have limited command over resources.

1.4 Energy and Industry

Industry is defined as including manufacturing, transport, energy supply and demand, mining, construction, and related informal production activities. Other sectors sometimes included in industrial classifications, such as wholesale and retail trade, communications, real estate and business activities are included in the categories of services and infrastructure. An example of an industrial sector particularly sensitive to climate change is energy (Hewer 2006). After the *industrial revolution* in the mid-eighteenth century human beings started to require more energy for consumption. Hence, non-renewable energy sources in the form of coal, oil, and wood began to deplete with time. As a result, in addition to the limited extent and environmental pollution potential, these energy sources will need to be replaced by renewable alternatives.

Global net energy demand is very likely to change (Tol 2002b) as demand for air-conditioning is highly likely to increase, whereas demand for heating is highly likely to decrease. The literature is not clear on what temperature is associated with minimum global energy demand, so it is uncertain whether warming will initially increase or decrease net global demand for energy relative to some projected baseline. However, as temperatures rise, net global demand for energy will eventually rise as well (Scheinder *et al.*, 2007).

Millennium goals were set solely by indicators of changes in energy use per unit of GDP and/or by total or per capita emissions of CO_2. Tracking indicators of protected areas for biological diversity, changes in forests, and access to water all appear in the goals, but they are not linked to *climate-change impacts* or adaptation; nor are they identified as part of a country's capacity to adapt to climate change (Yohe *et al.*, 2007).

With the unprecedented increase in the population, the industrial products, and the development of technology, human beings started to search for new and alternative ways of using more and more energy without harming or, perhaps, even destroying the natural environment. This is one of the greatest unsolved problems facing mankind in the near future. There is an unending debate that the key atmospheric energy source, *solar radiation*, should be harnessed more effectively and turned directly into heat energy to meet the growing demand for cheaper power supplies.

The net return from industrial material produced in a country is the reflection of energy consumption of the society in an efficient way. Otherwise, burning fossil fuels without economic industrial return may damage any society in the long run, especially with the appearance of renewable energy resources that are expected to be more economical, and therefore, exploitable in the long run. The extensive fossil fuel reservoirs available today are decreasing at an unprecedented rate and, hence, there are future *non-sustainability* alarms on this energy source. It is, therefore, necessary to diminish their exploitation rate, even starting from today, by partial replacements, especially through the *sustainable alternatives* such as solar energy.

The fossil fuel quantities that are consumed today are so great that even minor imbalances between supply and demand cause considerable *societal disruptions*. In order to get rid of such disruptions, at least for the time being, each country imports coal, and especially oil to cover the energy imbalances. The oil embargo by the Organization of Petroleum Exporting Countries (OPEC) in 1973, gave the first serious warning and alarm to industrialized countries that energy *self-sufficiency* is an essential part of any country concerned for its economic, social, and even cultural survival. In fact, the technological and industrial developments in the last 150 years rendered many countries to energy-dependent status.

Worldwide use of energy for several decades, especially in the industrial sectors, appeared to be increasing dramatically, but in the last decade, it has leveled off, and even dropped to a certain extent as shown in Fig. 1.6. In this graph, all forms of energy uses are represented in terms of the amount of coal that would provide the equivalent energy. Around the 1970s most of the predictions foresaw that energy demand would continue to accelerate causing expected severe energy shortages. However, just the opposite situation has developed, and today, there is a surplus of energy on the worldwide market that has resulted from economic downturn coupled with many-fold increases in the oil price during the last 20 years.

Fossil fuel reserves in the form of oil and *natural gas* are still adequate at present consumption rates for the next 50 years. However, with increasing amounts of renewable energy and discoveries of new reservoirs this span of time is expected to extend for almost a century from now onward.

Linkage systems, such as transportation and transmission for industry and settlements (*e.g.*, water, food supply, energy, information systems, and waste disposal), are important in delivering the ecosystem and other services needed to support human well-being, and can be subject to climate-related extreme events such as *floods*, landslides, fire, and severe storms.

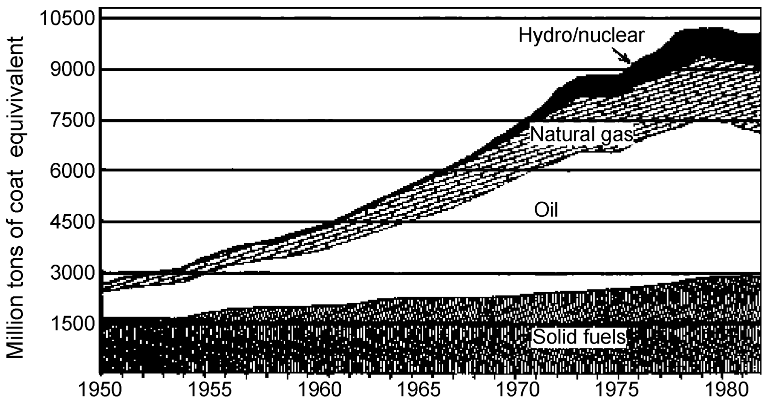

Fig. 1.6 Changes in annual energy consumption in the world (Dunn 1986)

1.5 Energy and the Economy

Continuance of *economic growth* and prosperity rely heavily on an adequate energy supply at reasonably low costs. On the other hand, energy is the main source of pollution in any country on its way to development. In general, conventional (non-renewable) energy resources are limited as compared to the present and foreseeable future energy consumptions of the world. As a whole electricity production based on fossil or nuclear fuels induces substantial social and environmental costs whereas it would appear that the use of renewable energy sources involves far less and lower costs. There are a number of different energy cost categories borne by third parties who ought to be taken into consideration in the comparison of different energy resources and technologies. Hohmeyer (1992) has given the following seven effective categories for consideration:

1. Impact on human health:
   a. Short-term impacts, such as injuries
   b. Long-term impacts, such as cancer
   c. Intergenerational impacts due to genetic damage
2. Environmental damage on:
   a. Flora, such as crops and forests
   b. Fauna, such as cattle and fish
   c. Global climate
   d. Materials
3. Long-term cost of resource depletion:
   a. Structural macro-economic impacts, such as employment effects
4. Subsidies for:
   a. Research and development
   b. Operation costs
   c. Infrastructure
   d. Evacuation in cases of accidents
5. Cost of an increased probability of wars due to:
   a. Securing energy resources (such as the Gulf War)
   b. Proliferation of nuclear weapons
6. Cost of radioactive contamination of production equipment and dwellings after major nuclear accidents
7. Psycho-social cost of:
   a. Serious illness and death
   b. Relocation of population

Adaptation strategies and implementation are strongly motivated by the cost of energy (Rosenzweig *et al.*, 2007). The nature of *adaptation* and *mitigation* decisions changes over time. For example, mitigation choices have begun with relatively easy measures such as adoption of low-cost supply and demand-side options in the energy sector (such as passive solar energy) (Levine *et al.*, 2007). Through successful investment in research and development, low-cost alternatives should become available in the energy sector, allowing for a transition to low-carbon venting pathways. Given the current composition of the energy sector, this is unlikely to happen overnight but rather through a series of decisions over time. Adaptation decisions have begun to address current *climatic risks* (*e.g.*, drought early-warning systems) and to be anticipatory or proactive (*e.g.*, land-use management). With increasing climate change, autonomous or reactive actions (*e.g.*, purchasing air-conditioning during or after a heat wave) are likely to increase. Decisions might also break trends, accelerate transitions, and mark substantive jumps from one development or technological pathway to another (Martens and Rotmans 2002; Raskin *et al.*, 2002a,b). Most studies, however, focus on technology options, costs, and competitiveness in energy markets and do not consider the implications for adaptation. For example, McDonald *et al.*(2006) use a global computed general equilibrium model and find that substituting switch grass for crude oil in the USA would reduce the GDP and increase the world price of cereals, but they do not investigate how this might affect the prospects for adaptation in the USA and for world agriculture. This limitation in scope characterizes virtually all bioenergy studies at the regional and sectorial scales, but substantial literature on adaptation-relevant impacts exists at the project level (Pal and Sharma 2001).

Other issues of particular concern include ensuring energy services, promoting agriculture and industrialization, promoting trade, and upgrading technologies. Sustainable *natural-resource management* is a key to sustained economic growth and poverty reduction. It calls for clean energy sources, and the nature and pattern of agriculture, industry, and trade should not unduly impinge on ecological health and resilience. Otherwise, the very basis of economic growth will be shattered through environmental degradation, more so as a consequence of climate change (Sachs 2005). Put another way by Swaminathan (2005), developing and employing "ecotechnologies" (based on an integration of traditional and frontier technologies including biotechnologies, renewable energy, and modern management techniques) is a critical ingredient rooted in the principles of economics, gender, social equity, and employment generation with due emphasis given to climate change (Yohe *et al.*, 2007).

1.6 Energy and the Atmospheric Environment

Even though the natural circulation in the atmosphere provides scavenging effects, continuous and long-term loading of atmosphere might lead to undesirable and dangerous situations in the future. Therefore, close inspection and control should be directed toward various phenomena in the atmosphere. Among these there are more applied and detailed research needs in order to appreciate the meteorological events in the troposphere, ozone depletion in the stratosphere, pollution in the lower troposphere and trans-boundary between the troposphere and hydro-lithosphere, energy, transport and industrial pollutants generation and movement, effects of acid rain, waste water leakage into the surface, and especially ground water resources.

For success in these areas, it is necessary to have sound scientific basic research with its proper applications. The basic data for these activities can be obtained from extensive climatic, meteorological, hydrological, and hydro-geological observation network establishments with spatial and temporal monitoring of the uncontrollable variables. Ever greater cooperation is needed in detecting and predicting atmospheric changes, and assessing consequential environmental and socio-economic impacts, identifying dangerous pollution levels and greenhouse gases. New and especially renewable energy sources are required for controlling emissions of greenhouse gases. Consumption of fossil fuels in industry as well as transportation gives rise to significant atmospheric emissions. The major points in energy use are the protection of the environment, human health, and the hydrosphere. Any undesirable changes in the atmospheric conditions may endanger forests, hydrosphere ecosystems, and economic activities such as agriculture. The ozone layer within the stratosphere is being depleted by reactive chlorine and bromine from human-made *chlorofluorocarbons* (CFCs) and related substances. Unfortunately, levels of these substances in the atmosphere increase continuously signaling future dangers if necessary precautions are not taken into consideration.

It has been stated by Dunn (1986) that several problems have arisen from the increased use of energy, *e.g.*, *oil spillages* resulting from accidents during tanker transportation. Burning of various energy resources, especially fossil fuels, has caused a global-scale CO_2 rise. If the necessary precautions are not considered in the long run, this gas in the atmosphere could exceed the natural levels and may lead to climatic change. Another problem is large-scale air pollution in large cities especially during cold seasons. The use of fossil fuels in automobiles produces exhaust gases that also give rise to air pollution as well as increasing the surface ozone concentration which is dangerous for human health and the environment. Air pollution leads to acid rain that causes pollution of surface and groundwater resources which are the major water supply reservoirs for big cities.

In order to reduce all these unwanted and damaging effects, it is consciously desirable to shift toward the use of environmentally friendly and clean *renewable energy* resources, and especially, the solar energy alternatives. It seems that for the next few decades, the use of conventional energy resources such as oil, coal, and natural gas will continue, perhaps at reduced rates because of some replacement by renewable sources. It is essential to take the necessary measures and developments toward more exploitation of solar and other renewable energy alternatives by the advancement in research and technology. Efforts will also be needed in conversion and moving toward a less energy demanding way of life.

The use of energy is not without penalty, in that energy exploitation gives rise to many undesirable degradation effects in the surrounding environment and in life. It is, therefore, necessary to reduce the *environmental impacts* down to a minimum level with the optimum energy saving and management. If the energy consumption continues at the current level with the present energy sources, which are mainly of fossil types, then the prospects for the future cannot be expected to be sustainable or without negative impacts. It has been understood by all the nations since the 1970s that the energy usage and types must be changed toward more clean and environmentally friendly sources so as to reduce both *environmental* and *atmospheric pollutions*. *Sustainable future* development depends largely on the pollution potential of the energy sources. The criterion of sustainable development can be defined as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs. *Sustainable development* within a society demands a sustainable supply of energy and an effective and efficient utilization of energy resources. In this regard, *solar energy* provides a potential alternative for future prospective development. The major areas of environmental problems have been classified by Dincer (2000) as follows:

1. Major environmental accidents
2. Water pollution
3. Maritime pollution
4. Land use and siting impact
5. Radiation and radioactivity
6. Solid waste disposal
7. Hazardous air pollution
8. Ambient air quality
9. Acid rain
10. Stratospheric ozone depletion
11. Global climate change leading to greenhouse effect

The last three items are the most widely discussed issues all over the world. The main gaseous pollutants and their impacts on the environment are presented in Table 1.2.

Unfortunately, energy is the main source of pollution in any country on its way to development. It is now well known that the sulfur dioxide (SO_2) emission from fossil fuels is the main cause of *acid rain* as a result of which more than half the forests in the Northern Europe have already been damaged. In order to decrease degradation effects on the environment and the atmosphere, technological developments have been sought since the 1973 oil crisis. It has been recently realized that

Table 1.2 Main gaseous pollutants

Gaseous pollutants	Greenhouse effect	Stratospheric ozone depletion	Acid precipitation
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)	−	+	
Chlorofluorocarbon(CFCs)	+	+	
Ozone (O_3)	+	+	

Plus and minus signs indicate proportional and inversely proportional effects whereas ± implies either effect depending on circumstances renewable energy sources and systems can have a beneficial impact on the following essential technical, environmental, and political issues of the world. These are:

1. Major environmental problems such as acid rain, *stratospheric ozone* depletion, *greenhouse* effect, and smog
2. Environmental degradation
3. Depletion of the world's non-renewable conventional sources such as coal, oil, and natural gas
4. Increasing energy use in the developing countries
5. World population increase

In most regions, climate change would alter the probability of certain weather conditions. The only effect for which average change would be important is *sea-level rise*, under which there could be increased risk of *inundation* in coastal settlements from average (higher) sea levels. Human settlements for the most part would have to adapt to more or less frequent or intense rain conditions or more or less frequent mild winters and hot summers, although individual day weather may be well within the range of current weather variability and thus not require exceptionally costly adaptation measures. The larger, more costly impacts of climate change on human settlements would occur through increased (or decreased) probability of extreme weather events that overwhelm the designed resiliency of human systems.

Much of the urban center managements as well as the governance structures that direct and oversee them are related to reducing *environmental hazards*, including those posed by extreme weather events and other natural hazards. Most regulations and management practices related to buildings, land use, waste management, and transportation have important environmental aspects. Local capacity to limit environmental hazards or their health consequences in any settlement generally implies local capacity to adapt to climate change, unless adaptation implies particularly expensive infrastructure investment.

An increasing number of urban centers are developing more comprehensive plans to manage the environmental implications of urban development. Many techniques can contribute to better *environmental planning* and *management* including market-based tools for pollution control, demand management and waste reduction, mixed-use zoning and transport planning (with appropriate provision for pedestrians and cyclists), environmental impact assessments, capacity studies, strategic environmental plans, environmental audit procedures, and state-of-the-environment reports (Haughton 1999). Many cities have used a combination of these techniques in developing "Local Agenda 21s," which deal with a list of urban problems that could closely interact with climate change and energy consumption in the future. Examples of these problems include the following points (WRI 1996):

1. Transport and road infrastructure systems that are inappropriate to the settlement's topography (could be damaged by landslides or flooding with climate change)
2. Dwellings that are located in high-risk locations for floods, landslides, air and water pollution, or disease (vulnerable to flood or landslides; disease vectors more likely)

3. Industrial contamination of rivers, lakes, wetlands, or coastal zones (vulnerable to flooding)
4. Degradation of landscape (interaction with climate change to produce flash floods or desertification)
5. Shortage of green spaces and public recreation areas (enhanced heat island effects)
6. Lack of education, training, or effective institutional cooperation in environmental management (lack of adaptive capacity)

1.7 Energy and the Future

The world demand for energy is expected to increase steadily until 2030 according to many scenarios. Global primary energy demand is projected to increase by 1.7% per year from 2000 to 2030, reaching an annual level of 15.3×10^9 tons of oil equivalent (toe). The projected growth is, nevertheless, slower than the growth over the past 30 years, which ran at 2.1% per year. The global oil demand is expected to increase by about 1.6% per year from 75×10^6 barrels per day to 120×10^6 barrels per day. The transportation sector will take almost three quarters of this amount. Oil will remain the fuel of choice in transportation (IEA 2002).

The energy sources sought in the long term are hoped to have the following important points for a safer and more pleasant environment in the future:

1. Diversity of various alternative energy resources both conventional (non-renewable) and renewable, with a steadily increasing trend in the use of renewable resources and a steadily decreasing trend over time in the non-renewable resources usage.
2. Quantities must be abundant and sustainable in the long term.
3. Acceptable cost limits and prices compatible with strong economic growth.
4. Energy supply options must be politically reliable.
5. Friendly energy resources for the environment and climate change.
6. Renewable domestic resources that help to reduce the important energy alternatives.
7. They can support small to medium scale local industries.

The renewable energies are expected to play an active role in the future energy share because they satisfy the following prerequisites:

1. They are environmentally clean, friendly, and do not produce greenhouse gases.
2. They should have sufficient resources for larger scale utilization. For instance, the solar energy resources are almost evenly distributed all over the world with maximum possible generatable amounts increasing toward the equator.
3. The intermittent nature of solar and wind energy should be alleviated by improving the storage possibilities.

4. The cost effectiveness of the renewable sources is one of the most important issues that must be tackled in a reduction direction. However, new renewable energies are now, by and large, becoming cost competitive with conventional forms of energy.

In order to care for the future generations, energy conservation and savings are very essential. Toward this end one has to consider the following points:

1. Conservation and more efficient use of energy. Since the first energy crisis, this has been the most cost-effective mode of operation. It is much cheaper to save a barrel of oil than to discover new oil.
2. Reduce demand to zero growth rate and begin a steady-state society.
3. Redefine the size of the system and colonize the planets and space. For instance, the resources of the solar system are infinite and our galaxy contains over 100 billion stars.

Because the earth's resources are finite for the population, a change to a *sustainable society* depends primarily on renewable energy and this becomes imperative over a long time scale. The following *adaptation* and *mitigation* policies must be enhanced in every society:

1. Practice conservation and efficiency
2. Increase the use of *renewable energy*
3. Continue dependence on natural gas
4. Continue the use of coal, but include all social costs (externalities)

Regional and local polices must be the same. Efficiency can be improved in all major sectors including residential, commercial, industrial, transportation, and even the primary electrical utility industry. The most gains can be accomplished in the transportation, residential, and commercial sectors. National, state, and even local building codes will improve energy efficiency in buildings. Finally, there are a number of things that each individual can do in conservation and energy efficiency.

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