Cambridge University Press
978-1-107-02848-7 — Renewable Energy Engineering
Nicholas Jenkins , Janaka Ekanayake
Excerpt
More Information

1 Energy in the Modern World

INTRODUCTION

An adequate supply of energy is essential for the working of any modern society. Energy is needed for cooking food, heating or cooling, lighting, materials processing and for transport. At present most energy comes from fossil fuels. Primary energy from fossil fuels – coal, oil and gas – is used either directly or converted into electricity. An increasing quantity of electrical energy is consumed in the operation of computers and communication equipment.

Over the past 25 years, the world demand for energy, supplied mainly from fossil fuels, has grown continuously at a rate of increase of around 2½% per year. This increase in consumption cannot be sustained indefinitely both because of depletion of reserves and, more urgently, because of the environmental impact of burning fossil fuels. The reserves of coal, oil and gas that are now being used were laid down over millions of years and have been exploited for less than three centuries. At some time in the future the costs of the extraction of oil and gas will become so high as to limit their use. There is clear agreement among climate scientists that burning fossil fuels and the consequent emission of CO_2 into the atmosphere is leading to damaging climate change. Most governments are making strenuous efforts to improve the efficiency with which energy is used and to control demand. However, attempts to control demand for energy have had only limited success. As the world population rises and societies grow richer their consumption of energy increases.

The use of renewable energy has an important part to play in the future supply of energy and in the transition to a more sustainable economy, but renewable energy brings its own challenges. In general, the initial capital cost of renewable energy schemes is high and their output depends completely on the resource and so varies with the strength of the sun and wind.

This book examines the various renewable sources of energy and how they can be used effectively. It focuses on those technologies that can make a significant contribution to energy supply over the next 30 years or so and pays particular attention to the renewable energy resource. Without a good energy resource it is impossible to develop a cost-effective renewable energy scheme.

This introductory chapter starts with a review of energy use in the modern world and demonstrates clearly the scale of the challenge that the world faces if it is to move to a sustainable energy system. The implications of the simple equation describing exponential growth are described. Section 1.2 addresses the important question of how to limit demand for energy and how Discounted Cash Flow analysis is used for the financial evaluation of energy efficiency measures. The final section describes the need for renewable energy both as reserves of oil and gas are depleted and as the environmental impact of burning fossil fuel grows.

1.1 ENERGY USE IN THE MODERN WORLD

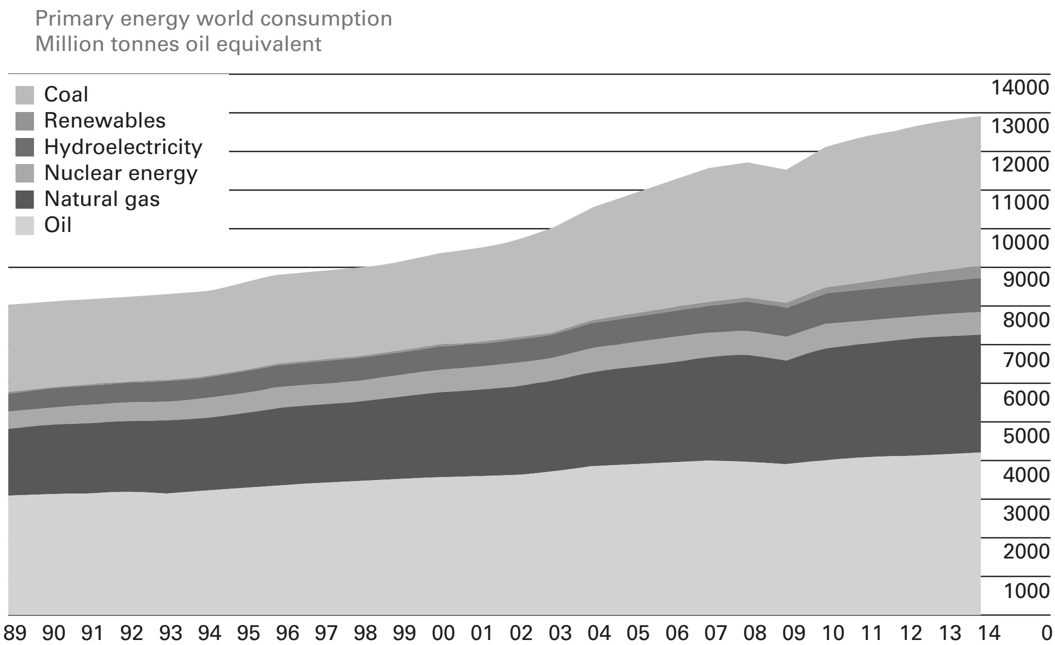

Figure 1.1 World consumption of primary energy over 25 years in million tonnes of oil equivalent (mtoe). *Source:* BP Statistical Review of World Energy, 2015.
(For the colour version, please refer to the plate section.)

Figure 1.1 shows the worldwide consumption of primary energy over 25 years from 1989 to 2014. World energy consumption has increased steadily over this period with only occasional variations in the rate of increase due to changes in levels of economic activity. There was a pause in the rate of increase of energy consumption in 2009–10 caused by the economic crisis in western countries. Primary energy supply is mainly from fossil fuels: oil, gas and coal. It may be seen that oil remains the most widely used fuel, but with a considerable fraction of world energy being produced from coal and an increasing share from natural gas. The use of nuclear and hydro plants to generate electricity has remained substantially constant in recent times. The data show a small but rapidly growing contribution from other forms of renewable energy: biomass, wind and solar. These renewable sources of energy supplied approximately 2.5% of all traded energy and around 6% of electricity produced in 2014.

Figure 1.1 shows only those energy sources that are traded commercially and so does not include traditional biomass. Wood and other biomass fuels are particularly important in some areas of developing countries where they are used for cooking. Shortages of wood, with the consequent high prices, are a major problem for some poor rural communities.

World energy consumption is increasing as the world's population grows, but also as a number of countries industrialise and raise the standard of living of their populations. The world's population has increased from around 5000 million to more than 7000 million over the 25 years from 1989 to 2014 (Figure 1.2). It is expected that the world's population will stabilise at between 10 000–12 000 million sometime this century.

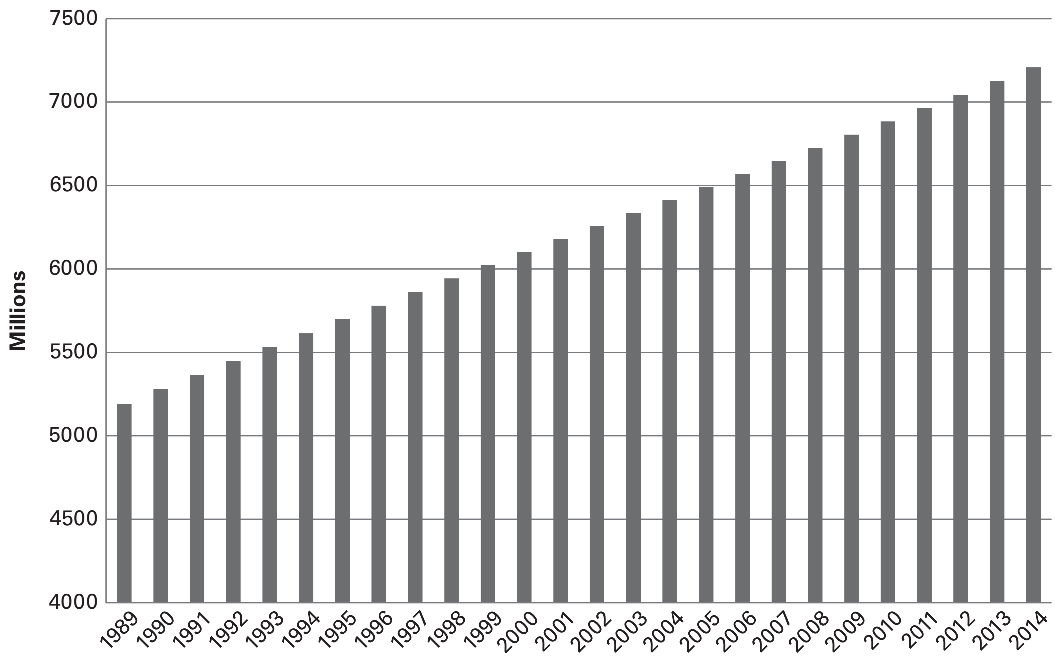

Figure 1.2 World population over 25 years.
Source of data: World Bank.

There are dramatic differences in the annual per capita quantity of energy used in different regions of the world. In North America annual primary energy use per capita is around 7000 kg of oil equivalent while the European average is around 3500 kg of oil equivalent. In certain parts of the world, e.g. Sub-Saharan Africa, each individual uses an average of only around 700 kg of oil equivalent each year. Across the world the average annual use of primary energy is 1800 kg of oil equivalent per capita.

Units used to quantify energy

Joule (J): This is the SI unit of energy

kilowatt-hour (kWh): This is the usual unit of electricity production or consumption. 1 kWh is equal to 3.6×10^6 J. However, larger generators produce many thousands of kWh represented in MWh, GWh and TWh. The relationships between these are:

1 MWh = 1000 kWh
1 GWh = 1000 MWh
1 TWh = 1000 GWh

tonne of oil equivalent: When discussing energy, it is often convenient to use a single unit. With this unit, energy from different fuels is converted into energy produced by burning one tonne of oil. The heat content of one tonne of crude oil depends on the origin of the oil but is generally taken as 41.87 GJ. The following conversions are usually used:

Box continued

Heat value of 1 tonne of coal = 29.3 GJ = 0.7 tonnes of oil equivalent
1 MWh of electrical energy = $3.6 \times 10^6 \times 1000$ J = 3.6 GJ = 0.086 tonnes of oil equivalent
1 kg of oil equivalent is equal to 11.64 kWh

In these conversions of electrical generation to the tonne of oil equivalent it is assumed that the efficiency of the thermal power plant is 100%. If the efficiency of the plant is 38%, a realistic figure for single cycle thermal generators, then 1 kg of oil equivalent is equal to 11.64×0.38 kWh = 4.42 kWh.

Figure 1.3 shows that the per capita annual energy use in certain countries, e.g. UK and USA, is reducing as manufacturing industry relocates to areas of the world where production costs are lower. The economic recession from 2009 in western countries and warmer winters has also led to a short-term reduction in energy use. However, other countries, including some with large populations, e.g. Brazil, India and China, are industrialising rapidly and increasing their per capita consumption of energy. A growing population with an increasing per capita use of energy obviously leads to rising national energy use.

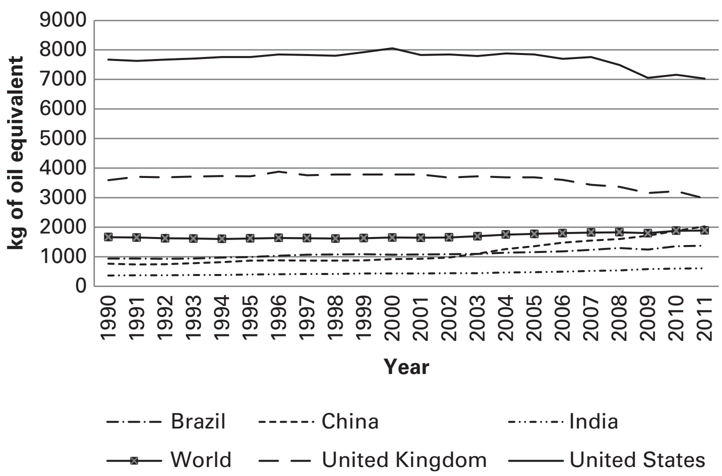

Figure 1.3 Annual energy consumption per capita.
Source of data: International Energy Agency.

Thus the worldwide increase in the use of energy is caused both by increasing population and per capita energy use. This is illustrated by Example 1.1.

Example 1.1 – Increase of Energy Use

Calculate the percentage increase in energy consumption of a country if its population increases by 25% and the per capita energy consumption increases from 2000 kg of oil equivalent to 4000 kg oil equivalent.

Solution

The population before increase is P and with a 25% increase the new population is $1.25P$.

The initial energy consumption is $2000P$ kg oil equivalent. When the per capita energy consumption increases to 4000 oil equivalent then the new energy consumption = $1.25P \times 4000 = 5000P$ kg oil equivalent.

The % increase of energy consumption = $[(5000P - 2000P)/2000P] \times 100 = 150\%$.

The use of energy is correlated with indicators of human well-being such as life expectancy and infant mortality. These indicators are shown in Figures 1.4 and 1.5, as scatter plots with regression lines, for over 100 countries of the world. In general, life expectancy increases with energy use and infant mortality reduces. Of course it does not follow that by increasing energy use alone greater life expectancy or lower infant mortality results. Rather Figures 1.4 and 1.5 indicate that richer societies with better human health use more energy.

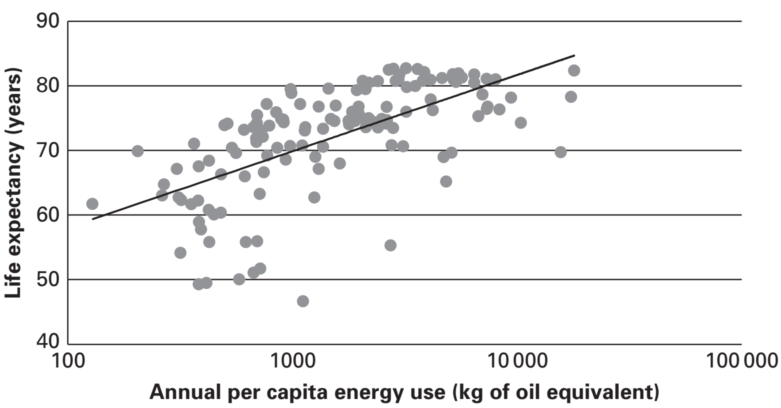

Figure 1.4 Energy use versus life expectancy of 100 countries. *Source of data:* International Energy Agency and World Bank.

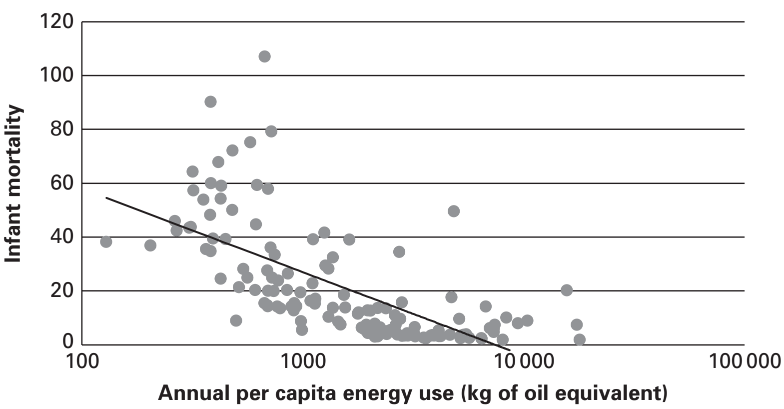

Figure 1.5 Energy use versus infant mortality of 100 countries in 2009. Infant mortality is the number of children dying before the age of one, per 1000 live births. *Source of data:* International Energy Agency and World Bank.

1.1.1 Exponential Growth

Over the past 25 years world energy consumption has grown continuously at around 2½% per year and continues to do so. The apparently rather small rate of increase does not, at first sight, give cause for great concern. However, this is an exponential rate of increase described by the equation

$$E_n = E(1 + r_e)^n \tag{1.1}$$

where

E_n is energy use in year n
E is energy use at present
r_e is rate of increase of use of energy
n is number of years.

Equation 1.1 shows that over 25 years a rate of growth of 2½% per year results in an increase in energy use by a factor of 1.85. If this rate of growth of energy use is maintained then world energy consumption will increase from its present value of around 13 000 mtoe (million tonnes of oil equivalent) to more than 24 000 mtoe over the next 25 years.

An alternative representation of exponential growth is the doubling time. This is the time in years for an exponentially increasing quantity to double; it is shown in Table 1.1. The doubling time may be estimated approximately by dividing 72 by the rate of increase in per cent.

In summary, it can be stated that worldwide primary energy use is increasing at a long-term rate of almost 2½% per year. This rate implies a doubling of primary energy use every 30 years. The increase in energy use is driven partly by rising world population and partly by the progress of countries in increasing the standard of living and so improving the health of their populations.

Table 1.1 **Doubling time of exponential increase**

Rate of increase (% per year)	Approximate doubling time (years)
0.1	720
0.5	144
1	72
2	36
3	24
5	14

Example 1.2 – Exponential Growth

Use of natural gas is expected to increase, at least partly due to the exploitation of unconventional (shale) gas. In 2011 the worldwide use of gas as a primary energy source was 3×10^9 toe/year (see Figure 1.1). Construct a table showing the use of gas over the next 50 years if the rate of increase varies between 1% and 4% per year.

Cambridge University Press
978-1-107-02848-7 — Renewable Energy Engineering
Nicholas Jenkins , Janaka Ekanayake
Excerpt
More Information

Solution

Using Equation 1.1 with a present gas consumption of 3×10^9 toe/year.

Table 1.2 **Use of gas over 50 years, 10^9 tonnes of oil equivalent**

	Rate of increase %/year			
Years of increase	**1**	**2**	**3**	**4**
5	3.15	3.31	3.48	3.65
10	3.31	3.66	4.03	4.44
20	3.66	4.46	5.42	6.57
30	4.04	5.43	7.28	9.73
50	4.93	8.07	13.15	21.32

It may be seen that an annual rate of increase of 2% over a period of 30 years leads to an almost doubling of use from 3×10^9 to 5.43×10^9 toe while a 4% per annum increase over 50 years results in a seven times increase in gas use to 21.32×10^9 toe.

1.2 LIMITING ENERGY USE

The doubling of worldwide energy use over the next 30 years that can be anticipated simply from continuation of the historical rate of increase will place great strain on the energy resources and ecosystems of the planet. The obvious first response is to reduce energy use or at least limit its rate of increase and the governments of most countries that consume significant quantities of energy have active programmes to improve the effectiveness with which energy is used. These can be considered in two aspects: *energy efficiency* and *energy conservation*.

1.2.1 Energy Efficiency

Energy efficiency is achieving the same goals and maintaining the same levels of comfort and services but with the use of less energy. A recent example of a successful energy efficiency measure is the switch from incandescent to low energy light bulbs that has now been mandated throughout Europe. This change in the way energy is used was made possible by the development of new lighting technology, compact fluorescent (CF) and light emitting diode (LED) lamps, together with new product standards that effectively banned the sale of incandescent bulbs. Low energy lights produce the same level of light as incandescent bulbs while using only 15%–30% of the electrical energy (Table 1.3). The same outcome, i.e. the same level of light, is

Table 1.3 **Light output and power consumption of different lamps**

Light output (lumens)	Power consumption Incandescent lamp (W)	Compact fluorescent lamp (W)	Light emitting diode lamp (W)
400–500	40	7–11	4–5
650–900	60	13–18	6–8
1100–1750	75	18–22	9–13
>1800	100	23–30	16–20
>2700	150	30–55	25–28

achieved with greater energy efficiency. Another good example of a successful energy efficiency measure was the regulation made in the UK that all new domestic central heating gas boilers had to be high efficiency condensing units. These produce the same level of heat as the older non-condensing boilers but consume less gas.

Around 40% of the primary energy used in the USA is within buildings. The energy is used for space heating, cooling and ventilation together with lighting and electrical appliances. Studies show that this energy use could be reduced by up to 30% with no reduction in the performance of the building if suitable improvements in energy efficiency were made by using technology that is presently available. The cost of improving the insulation of buildings and installing advanced building service technology would be balanced by savings in the use of energy over the coming years. The same level of comfort and services within the buildings would be maintained.

Improving the energy efficiency of buildings is, at first sight, a technical question of using higher efficiency equipment and limiting energy losses, e.g. reducing heat loss through the fabric of a building. It might be thought that if an economic case can be developed that shows a benefit then it might be assumed that the appropriate modifications to buildings and equipment would be made. The energy and financial savings would then follow. However, experience has shown that improving energy efficiency is, in practice, much more complex than a simple engineering and economic appraisal would indicate. There is a considerable body of literature that attempts to explain why people are reluctant to implement energy efficiency measures that, at first sight, give them obvious financial benefit. Examples of the well-documented difficulties of implementing energy efficiency programmes include the following.

- For many individuals, the decision when buying certain goods, e.g. a car, does not include any assessment of its future energy use. Many modern cars have engines much more powerful than are necessary for their simple transportation function and hence have lower fuel efficiency than is necessary to transport the driver and passengers.

- The landlord–tenant problem refers to the situation where the cost of implementing energy efficiency measures in a building falls on the landlord but the reduced energy bills would benefit the tenant. The landlord is then reluctant to make the initial investment. Similarly, designers and builders of new dwellings or offices may be more concerned with reducing initial capital cost (which they bear) rather than achieving long-term low energy performance (which benefits the building user).
- Individuals are more concerned with immediate expenditure than with benefits that accrue in the future. This is sometimes described as individuals having a high personal discount rate.
- Organisations may be limited in the amount of capital they can raise. Hence even if an investment in energy efficiency shows an attractive payback in, say, three years, the organisation may be unable to fund the initial changes that are required. This is a particular problem in public buildings that often operate with maintenance budgets over only one year.
- Improving the efficiency of existing buildings is likely to involve disruption to the occupants, who may then delay making what is otherwise an economically rational improvement.

Energy efficiency in industry can be improved greatly by using variable speed drives. A large number of the motors used in industrial drivers are fixed speed and oversized. The output of a pump or fan is controlled by throttling the air or fluid flow rather than reducing the power consumed. The control of motor speed using a variable speed drive (VSD) allows the motor to operate at high efficiency under varying duty cycles and loading conditions. The largest gains can be obtained from centrifugal machinery such as fans and pumps where the flow is proportional to speed. However, many industrial plants continue to use over-sized, fixed speed pump or fan motors with the output air or fluid throttled and considerable energy wasted.

1.2.2 Economic Appraisal of Energy Efficiency Measures

Energy efficiency measures typically require an initial investment that is then recovered by savings in energy costs that are made over a number of years.

The simplest way to evaluate an energy efficiency project is to calculate the Payback Period:

$$\text{Payback Period} = \frac{\text{Capital cost}}{\text{Annual cost saving}}$$

However, most people and organisations have a *time preference for money* and they would rather receive money today not next year, and would prefer to pay out money next year in preference to today. This makes an energy efficiency measure that has an initial expenditure but in which the benefits accrue only in later years more difficult to justify. Financial analysis recognising the time value of money is known as Discounted Cash Flow (DCF) appraisal and is discussed in Section 9.2.1.

The mechanics of DCF analysis are simple and the calculation may be implemented easily on a spreadsheet; the main functions are often included in commercially available packages.

Cambridge University Press
978-1-107-02848-7 — Renewable Energy Engineering
Nicholas Jenkins , Janaka Ekanayake
Excerpt
More Information

Given a discount rate of r_d,
the present value of a sum received or paid n years in the future is:

$$V_p = \frac{V_n}{(1 + r_d)^n}$$

where

V_n is the value of a sum in year n
V_p is the present value of the sum.

The discount rate chosen reflects the value that the decision maker places on money and the risks that are anticipated in the project. The effect of a high discount rate is to make any sums in the future appear less significant. A discount rate of 10%–15% would not be unusual for industrial energy efficiency projects.

Example 1.3 – Economic Appraisal of an Energy Efficiency Measure

Consider the installation of a building management system that controls the heating and cooling systems of a large building. The cost of installing the management system is £30 000 and it will result in savings of £10 000/year. Evaluate the project by calculating Payback Period and Net Present Value (NPV) at a discount rate of 15%.

The simple (non-discounted) appraisal is

$$\text{Payback Period} = \frac{\text{Capital cost}}{\text{Annual cost saving}} = \frac{30\ 000}{10\ 000} = 3 \text{ years}$$

However, the simple Payback Period does not reflect the time value of money.
Assume that a discount rate of 15% is chosen.

Year n	Expenditure £	Saving £	Discount Factor $\frac{1}{(1+r_d)^n}$	Net Present Value at year n.
0	−30 000		1	−30 000
1		10 000	0.869	−21 304
2		10 000	0.756	−13 743
3		10 000	0.657	−7168
4		10 000	0.571	−1450
5		10 000	0.497	3522

