Chapter 1

The Energy Crisis

1.1. Introduction

Our civilisation and our standard of living depend on an adequate supply of energy. We need energy to light and heat our homes, to cook our food, to drive our transport and power our communications and to provide the motive force that drives the factories. Without energy all this would be impossible on the scale needed, and our civilisation would soon collapse into barbarism. Our dependence on energy is strikingly illustrated by the connection between average life expectancy and energy consumption. People in the poorer countries, especially in Africa and Asia, have an average energy consumption between 0.01 and 0.1 tons of coal equivalent per person per year and have an average life expectancy of between 35 and 45 years. At the other end of the scale, people in the rich well-developed countries in Europe, North America and Japan use between five and ten tons of coal equivalent per person per year and have an average life expectancy between 70 and 75 years. This difference is a measure of the energy that is needed to bring the standard of living of all people to the level now enjoyed by the most favoured ones.

Over the centuries this energy has been obtained in many ways. In ancient times wood was the main fuel, and it provided heat for cooking and warmth. It was often used more rapidly than it was replaced by new growth, and the forests of countries surrounding the Mediterranean were gradually destroyed, followed by the forests of central Europe. In many countries even today wood is the main fuel, but housewives have to walk increasing distances to gather the wood they need. Other energy sources are crop residues and dried animal dung. Ideally these organic residues should be returned to the soil, so burning them gradually reduces its fertility. These are still the main sources of fuel for some two billion people in the developing countries. They provide the energy equivalent of about a billion tonnes of oil each year, about the same as the energy provided by coal in Europe and the USA combined.

The increasing scarcity of wood stimulated searches for alternative energy sources, and soon coal was found, first near the surface and later underground. It has a higher calorific value than wood and can be transported rather more easily. Soon it became the main energy source in many developed countries and provided the power for the industrial revolution, especially in places where iron ore was also available.

During the nineteenth century oil was found, first in the USA and then in many other countries. It has many advantages over coal: it can easily be transported over large distances by pipelines and tankers, and is the basis of the petrochemical industry. During the twentieth century it gradually displaced coal as the favoured energy source. Natural gas was often found in association with oil, and provided a convenient source of lighting and heating.

The nineteenth century also saw the rapid development of the electrical industry for communication, heating and power. Electricity has the advantage of being very easily transported from the generating station to where it is needed. It soon displaced gas as a source of light and became a convenient power source for factories. Electricity is practicable for suburban trains, but long distance trains and ships, which used to be driven by coal, are now mainly driven by oil.

Electricity is generated by turbines driven by steam produced by burning coal or oil. The turbine can also be driven by water, and indeed water wheels have been used since ancient times to rotate the millstones to grind corn. Hydroelectric power is thus another source of electricity.

During the twentieth century the world's economy and population increased more rapidly than ever before and the total energy consumption rose even more rapidly. World population is doubling on the average every 35 years; the rate of increase varies greatly from country to country, it is greatest in Africa and Latin America and almost stationary in more developed areas such as Europe and North America. Together with the increase in the standard of living, this results in the world energy consumption doubling every fourteen years. This is not a measure of the real energy needs, and many billions of people still lack the energy for even some of the basic necessities of life. At present people in the less developed countries are forced to try to survive on a small fraction of the energy used by people in the developed world. The amount of energy needed to raise the standard of living of the people in the poorer countries to that in the developed ones can be estimated from the United Nations Human Development Index. This shows that an acceptable standard of living requires about five thousand kWh per year, or 200,000 megajoules (MJ) per person. Assuming that the world population will rise to eight billion this gives an energy requirement of about 1.6×10 (15) MJ. The present population of six billion uses about 0.41×10 (15) MJ. Thus world energy production will have to be increased at least fourfold to bring the standard of living of people in the developing countries up to that in the developed ones (Fanchi 2006). This estimate does not take account of the likelihood that most of the increase in population will take place in the poorer countries. It has been estimated that world energy production will grow from 4.43×10 (14) MJ in 2003 to about 7.6×10 (14) MJ by 2030, which is completely inadequate. Another estimate is an increase from 9.3 billion toe (tonnes of oil equivalent) in 2003 to 15.4 in 2020, with 90% of the increase in the developing countries.

The world consumption of energy increased by 4.3% from 2003 to 2004, and this trend is likely to continue. At present the relative amounts due to the various sources are: oil 36.8%; gas 23.7%; coal 27.2%; nuclear 6.1% and hydro 6.2%. Of these coal is the fastest growing and also the most polluting. The main sources of energy at the present time, coal, oil and gas, are limited and indeed are fast being exhausted. Studies of the available resources indicate that in the foreseeable future they will become increasingly difficult to extract in the quantities needed. Furthermore, they are seriously polluting and are already causing great damage to the earth and its atmosphere. Eventually we shall have to learn how to do without them, and the sooner we do so the better.

The generation of electricity is expected to show a similar rise, increasing from 13,290 billion kWh in 2001 to 23,702 in 2025. In the developing countries the rate of increase is 3.5% per year, compared with 2.3% per year for all countries. The proportion of electricity generated by natural gas increased in the same period from 18% to 25%.

What can replace them? There are many possibilities, and they have to be assessed considering their capacity, cost, reliability, safety and effects on the environment. This is done in the following sections. Whenever possible, these assessments must be made numerically because this is the only way to make objective comparisons. As Lord Kelvin once remarked, "*unless you can measure what you are talking about, and express it in numbers, your knowledge is of a meagre and unsatisfactory kind*". When evaluating the characteristics of the production of energy by different sources these numbers are often subject to many uncertainties, so it is also important to estimate the range of these uncertainties. Approximate numbers are better than no numbers at all. The existence of numerical data is not however a guarantee of its correctness. Many numbers widely quoted are simply wrong, and sometimes numbers that are correct are extrapolated far beyond their range of validity and used as the basis of inaccurate generalised statements. It is thus not enough to collect a few isolated examples and assume that they are representative of global trends. There is no way of avoiding the laborious task of collecting fully representative statistics and recognising that they can only be used to reach valid conclusions for the time and area actually studied.

It is useful to collect and compare numerical estimates of the same quantity obtained by different investigators as, for example is done in Table 3.3 for the costs of electricity from various sources. Physicists know very well how difficult it is to obtain a reliable measurement of some physical quantity such as the charge on the electron, when no one has any motive for preferring one result rather than another. It is quite different when comparing energy sources, because there may be strong political pressure to reach a favoured result. Furthermore, there is an inherent difference between the degree of accuracy that can be reached when measuring physical quantities, and that attainable in a social context. Thus the accuracy of determination of the charge on the electron can presumably be increased without limit, whereas there is an inherent limit to the values of social parameters. Thus we can collect statistics relating to a specific stretch of time at a certain place. We cannot improve the statistics by extending the period of time because the method of energy production may itself have changed; we cannot be sure that the quantity we are measuring is independent of time and place and this inevitably affects the accuracy with which it can be determined. The figures given here are the best I could find, but certainly in many cases better figures will eventually become available.

Energy sources are often divided into renewable and non-renewable. A renewable source is one that is not used up, but what we really want is one that is always available. This is satisfied by a source such as water, the fuel for fusion reactors, that is so plentiful compared with our needs that it will never be exhausted, and also to a lesser extent uranium. Coal and oil are non-renewable because there are limited amounts present in the earth. However the reserves of oil and coal are not like the gold in the Bank of England, where the number of bars can be counted. The amount we can extract depends on the price we are prepared to pay for it. Oilfields, for example, have very different extraction costs. In the Middle East, oil gushes out freely and is cheap and readily available. It is much more expensive to extract it from the North Sea, as oil rigs have to be built in deep water. This consideration applies even more strongly to minerals such as those containing uranium. Rich ores are relatively rare, while poorer ones are very widespread. It is even possible to extract uranium from sea water.

It might be thought that the lifetimes of availability of an energy source can be obtained by dividing the estimated reserves by the yearly consumption. This gives about 42 years for oil, 65 for natural gas and 217 for coal. Another way of expressing this is to divide the total recoverable resource of 1260 TWy (terawatts per year) by the world consumption, which amounted to 14.1 TWy in 2003. This gives about 90 years. By 2030 the world consumption is expected to be about twice this, halving the expected lifetime (Avery 2007, pp. 107, 113). However the situation is not as bad as this because there are several competing effects that occur when any raw material becomes more difficult to obtain. Initially the price rises, providing an incentive to reduce consumption and to look for alternatives sources. Improved technology and the higher price make it economic to bring into operation sources previously considered to be exhausted. The Stone Age ended because bronze and iron were discovered, not because the supply of flints ran out. This process continues: steel and other metals are replaced by plastics and composites. In other cases the incentive for change comes from other motives, such as the replacement of domestic coal fires by electric heaters and much correspondence by e-mail. The net result of all this is that, contrary to what might have been expected, it is found for coal and oil that the ratio of reserves to annual consumption and the cost both remain remarkably steady as a function of time (Lomborg 2001/2004), as shown in Figures 1.1 and 1.2. Of course this cannot go on for ever, but it is difficult to estimate the lifetimes, although prices are certainly expected to rise.

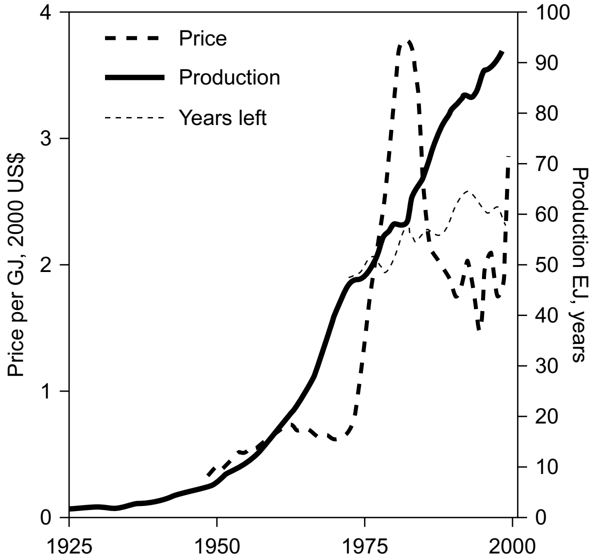

Figure 1.1. World gas production, price and years of consumption. Production in exajoule, 1925–1999, price in 2000 US$ per gigajoule, 1949–2000, and years of consumption, 1975–1999 (Lomborg 2004).

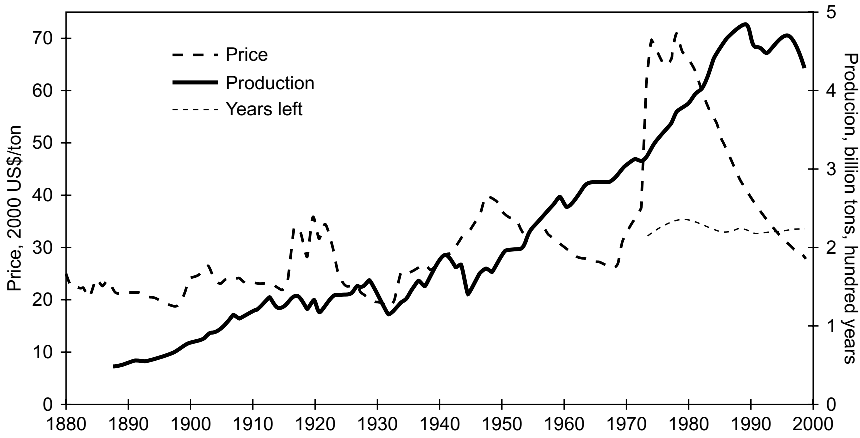

Figure 1.2. World coal production, price and years of consumption. Production in billion tons, 1888–1999, price in 2000 US$ per ton, 1880–1999, and years of consumption, 1975–1999 in hundreds of years (right axis) (Lomborg 2004).

It is also difficult to obtain accurate estimates of the cost of energy from various sources. It is relatively easy to determine the cost of construction of a power station, but not to foresee its working life. A power station may last fifty years or more, and it is not easy to determine the lifetime in advance. During that time the value of the currency is likely to change substantially which makes it difficult to calculate the true cost of the electricity generated.

For most industrial and domestic uses, particularly when electricity is being used, it is essential that the supply is reliable. The use of computers is spreading, and an interruption of electrical power immediately brings many vital activities to a standstill. Industrial processes controlled by computers come to a stop, electronic communications are cut, and supermarkets have to close. The cost of such interruptions, even if quite short, can be very high. If the breakdown is prolonged, households relying on electricity are in severe difficulties as heaters, lights and refrigerators fail. We are so used to relying on our power supplies that we are thrown into disarray when they cease. In New York a few years ago, a power station was overloaded and so automatically cut out, throwing more load on another power station, which also cut out and so on until the whole electrical grid was down. The system was so complicated that it took several days before power was restored. Such events are very rare, but power breakdowns are everyday occurrences in many countries, so that it is not possible to carry out lengthy computer calculations or delicate manufacturing processes.

It is neither possible nor necessary for every power station to be able to operate indefinitely, but they should at least normally operate for several months at a time, and this is the case for coal, gas, nuclear and hydroelectric power stations. Their electrical output is fed into a national grid, so if one power station breaks down the load can be carried by the others without interrupting the supply. From time to time power stations must be shut down for routine maintenance, and the grid allows this to be done without difficulty. The demand for electricity fluctuates, but usually in a predictable way. The greatest demand is in the winter, so most maintenance shutdowns are scheduled for the summer. The greatest demand comes during sharp cold spells, so the maximum number of power stations are made available at times when this may happen.

There are some applications where the reliability of the energy source is not important. For example, a farmer may need to have water available for irrigation, so he installs a storage tank and uses a windmill to pump water from below ground to fill it. Providing the tank is large enough, and the wind blows now and then, there is always enough water when needed, and it is topped up whenever the wind is blowing. In this way the unreliability of the energy source is converted to reliability of the system. This is only possible when the amount of energy to be stored is relatively small, as it is uneconomic and often impossible to store very large amounts of energy.

Another requirement is that the energy is available in concentrated form, that is at a higher temperature than the surroundings. Every room contains a large amount of energy, but it is useless for boiling water in a kettle since the availability of energy depends on the temperature difference between source and surroundings. Energy exists in many form, kinetic, potential, electrical and chemical, and since conversion from one form to another always takes energy it should be in the form needed whenever possible. As MacKay (2008) remarks, ‘you can’t power a TV with cat food, nor can you feed a cat with energy from wind turbines’.

Safety is an essential requirement for energy generation. Perfect safety is impossible, so it is necessary to ensure that any source is a safe as reasonably possible. Increasing safety is costly, so a balance has to be struck between conflicting demands. The same applies to the requirement that adverse environmental effects should be minimised.

Energy is very often wasted, and it is frequently urged that the energy crisis can be solved by increasing the efficiency of energy use and eliminating waste. This is discussed in the next section and in the following sections the possible alternative energy sources are assessed according to the five criteria proposed above.

1.2. Energy Conservation

It is frequently argued that we could solve the energy crisis simply by using energy more efficiently. At present we are very wasteful. We leave lights on in empty rooms, heat parts of our houses that are not in use, and allow the rooms in use to be too hot, so that most of the heat escapes through the windows and walls. In many warm countries air conditioners are over-used in summer so that the rooms become too cold. Much larger amounts of energy are wasted by inefficient processes in factories. Huge amounts of energy are spent on unnecessary journeys and leisure activities. Advertising and high-pressure salesmanship encourages people to buy things that they really do not need, and credit schemes make it easy to do so. Changes of fashion in clothing and house-styles mean that perfectly useable items are thrown away. Many machines are not designed to last as long as possible; on the contrary, manufacturers ensure by built-in obsolescence that they will have to be frequently replaced. The aim is to increase their production and maximise their profits at the expense of the consumer, and in the process much energy is wasted. It is very often easier and cheaper to throw away a defective machine and buy another rather than have it repaired. Indeed it is now almost impossible to find people willing to repair anything.

All this is happening at a time when billions of people lack the energy needed to provide the bare necessities of life. It is immoral to allow this to continue. In any case in the long run it cannot continue as the resources of the earth are limited and thus unable to sustain indefinite growth.

It is very easy, and indeed it is a moral duty, to save energy by quite simple measures. We can switch off lights not in use, and install thermostats to keep the temperatures of the rooms at a moderate level. Fitting double glazing, lagging pipes and insulating walls and roofs also cuts down the energy loss. We can avoid unnecessary journeys, use public transport whenever possible, walk instead of driving, and avoid leisure activities that waste energy. Houses can be built to save energy and Industrial processes can be designed in a more efficient way. It has been estimated that if such measures are introduced the energy use can be reduced by a very substantial factor (Von Weizacker *et al*. 1996).

Many of these energy-saving measures can be taken immediately, but others take time and may themselves be energy-consuming. Thermostats and lagging, for example, have to be manufactured, and this costs energy. There is a time-lag before there is a net saving of energy. It is much easier to design and build an energy-saving house than to convert an existing building.

It is easy to urge that energy be saved, but far more difficult to convince people to take the necessary action. If energy is cheap, people just cannot be bothered to take energy-saving measures. Furthermore, many of the energy-saving measures themselves cost money, and even if there is a long-term gain this is a strong disincentive. It is easy to reduce energy consumption by increasing the price but this can provoke a violent political reaction, as happened recently in the UK when the price of petrol was raised. Furthermore, a rise in energy price hits the poor harder than the rich, and can seriously affect their health. Many poor people suffer from malnutrition and even die from hypothermia in the winter because they cannot afford food and fuel. Care must be taken to avoid this by measures such as reducing the price of electricity for the first few units every month and then increasing the price for higher levels of consumption.

There are also larger changes concerning the management of the economy and changes in the structure of society that could effect large energy savings and save scarce resources. Transport is a large consumer of energy in the form of petroleum, which is polluting as well as running out. It is thus very desirable to switch to other means of propulsion such as electricity. Already there are battery-driven cars and improved designs are being developed. These are designed so that the batteries can be recharged when the car is not in use. At present they are more costly than petrol-driven cars, so perhaps government intervention in the form of subsidies could encourage the widespread use of such vehicles. To avoid pollution the electricity must be generated by a non-polluting source, of which nuclear is the only practical way at the present time. It is also possible that some time in the future transport could be driven by hydrogen, as discussed in Section 3.10

Further energy savings can be obtained by encouraging the use of more energy-efficient means of transport such as trains and buses instead of cars and lorries for passengers and for freight. To illustrate this, MacKay (2008) gives the following transport efficiencies in Japan (1999) in kWh per 100 passenger-km: car 68, bus 19, rail 6, air 51, and sea 57.

As the cost of travel increases, mainly due to the rise in oil prices, it will become more difficult for people to afford to travel long distances to work, or even to have a car for themselves. This in turn will make living outside the towns and cities less attractive. This may be partly offset by the use of modern technology to make it possible for many people to work at home, at least for some of the time. This implies large changes in the structure of society, and it would be wise to bear this in mind when planning new housing developments. Another consideration is that the predicted rise in sea level makes it undesirable to build houses on low-lying land liable to flooding.

It is also necessary to ensure that energy-saving measures are not counterproductive. A consideration that is often overlooked is that using more efficient manufacturing processes can reduce the cost of production and, to gain an advantage over their rivals, manufacturers can then reduce the price of their goods and hence increase the sales. The final result is that more energy is used than before. This was already recognised by the Victorian economist Stanley Jevons who wrote: 'It is wholly a confusion of ideas to suggest that the economical use of fuel is equivalent to a diminished consumption. The very contrary is the truth. It is the very economy of the use which leads to its extensive consumption. It has been so in the past and will be so in the future.'

Many of these energy-saving measures are being implemented but nevertheless the increasing world population and the average rise in living standards are causing the world consumption of energy to rise linearly with time at the rate in 2004 of about 4.3% per year. Thus while energy conservation is extremely important and should be encouraged by all practicable means it will not by itself solve the energy crisis. It is therefore still necessary to examine all possible energy sources to see which of them can best provide our energy needs.

Quite often there is more energy available than we need at the time, so many of our energy problems would be solved if energy could easily be stored on a large scale. It has already been mentioned in connection with storing water on a farm using a windmill that inevitably operates discontinuously. When the reservoir is full and the wind still blows that energy is wasted. This does not matter because relatively small amount of energy are involved. The situation is quite different for large amounts of energy. It is then necessary to have enough power stations to meet periods of peak demand, with extra allowance for unexpected failures. At other times there is a large excess capacity, and if the extra energy generated in these periods could be stored then fewer power stations would be required. Unfortunately this is not possible because electrical energy must be used as soon as it is generated and it cannot be stored economically. Batteries are unsuitable and far too expensive for this purpose. A practicable possibility is to use excess energy generation to pump water from a lower to a higher level and then to let it flow down through turbines when demand requires. This can be done in places where there are two large lakes not far apart at very different altitudes, but there are very few such places and in addition the process itself wastes about 30% of the energy. Another possibility is to use the excess electricity to decompose water into hydrogen and oxygen and store the liquefied gases. These can be allowed to recombine when the stored energy is needed. This process is expensive and at present more so than the cost of building extra power stations.

Other possible energy storage methods are flywheels, supercapacitors and superconducting coils (Swamp 2007). One of the problems in supplying power for spacecraft is that batteries last only a few years, so it is proposed to replace them by flywheels. It is also planned to develop a 20 MW power plant to be connected to the national electricity grid. This could store energy and release it very rapidly, in about 4 seconds, when there is a surge in demand. Another application is to store the energy of heavy vehicles such as buses and lorries when they brake, and then release it when they start to move again. This could halve the fuel used by vehicles that frequently stop and start. However the cost of this device is about $50,000, three times that of a fuel cell. Supercapacitors are already used in laptops and other electronic devices. For most applications, however, supercapacitors and superconducting coils are far too expensive.

1.3. World Energy Consumption

Before considering each energy source in detail it is useful to compare their contributions to world energy consumption. This serves to keep their relative importance in perspective. Figures 1.3 and 1.4 and Table 1.1 provide some figures for past consumption and estimates for the future. The four main producers are coal, oil, natural gas and nuclear, with smaller contributions from other sources. Hydro is the next in importance but as it is limited by the number of suitable rivers its contribution remains almost constant and its relative contribution decreases. The contribution of the remaining sources is rather small. The 'traditional' renewable energy sources such as wood, straw and dung (biomass) amounted to 0.9 GTOE in 1990. Modern biomass is growing special crops such as willow for subsequent burning.

World energy consumption increased by 4.3% in 2004, with some countries increasing faster than others. Thus Chinese consumption increased by 15% in one year (Nuclear Issues, June 2005). Consumption is expected to double by 2050. China imported about 40% of its oil consumption of 250M tonnes and this is expected to increase to 60%

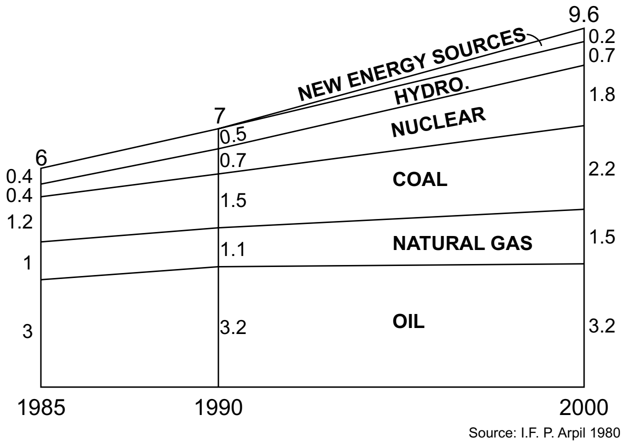

Figure 1.3. Energy Consumption Outlook in the Western World (GtOE) (World Energy Needs and Resources).

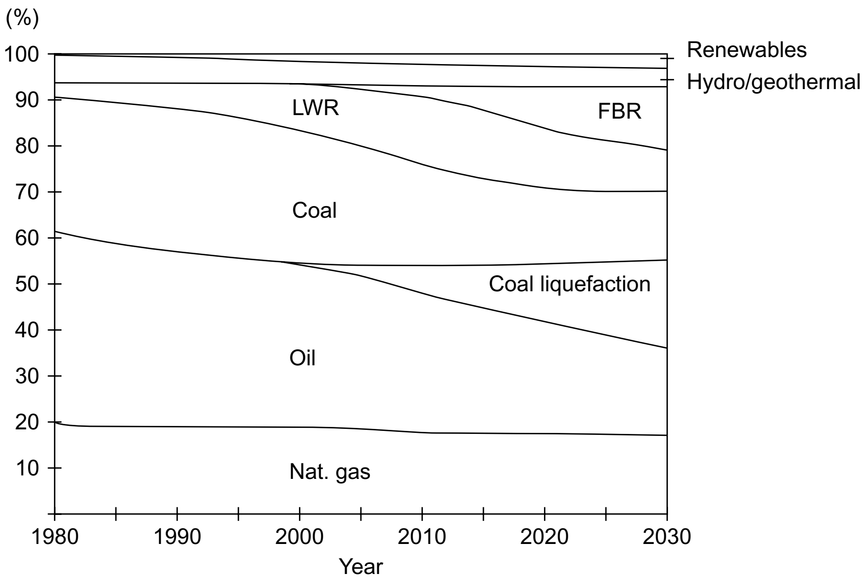

Figure 1.4. Shares of primary energy sources in the global energy balance (World Energy Needs Resources).

Table 1.1. Global Primary Energy Consumption (in million tons of oil equivalent)

Energy Source	1860	1900	1950	2000
Wood etc	270	330	470	~1000
Coal	100	470	1300	2220
Oil		20	470	3400
Natural gas			170	2020
Hydro-electric		10	120	230
Nuclear				630
Other renewables				~200
Total	370	830	2530	~9700

Sources: For 1860, 1900 and 1950: Nuclear Energy in Industry (Crowther 1957); figures converted from coal equivalent to oil-equivalent energy by dividing by 1.5. For 2000: Statistical Review of World Energy (1999 BP Amoco), trended up to 2000; except wood etc., from Rural Energy and Development (1996 World Bank). For primary energy, BP assumes that one tonne of oil produces 4000 kWh in a modern power station.

by 2020 (Nuclear Issues, June 2005). An additional 2 million cars were sold in 2003, an increase of 80% over 2002.

Comparison of Figures 1.3 and 1.4 with Table 1.1 show general agreement for past consumption, but substantial differences for the future. Thus for example, in Figure 1.3 nuclear in 2000 is estimated in 1980 to be 1.8, while the estimate in Table 1.1 from data obtained in 1999 is only 0.63. This sharp reduction in the nuclear estimate is due to the reaction against nuclear power that is discussed in Section 8.5. The projections in Figure 1.2 for the years up to 2030 are even less reliable. For example, the fast breeder reactors (FBR) are projected to rise quite sharply after 2000 and the produce more than the light water reactors (LBR) by 2030. In fact, fast breeder reactors have not been deployed at all, for the reasons discussed in Section 4.7

These uncertainties are characteristic of all estimates of future energy production and demand. Some variability is to be expected due to different availabilities and costs of raw materials, different legal requirements concerning the siting, building and running of power stations and in addition large variations may occur due to political pressures and unexpected events. It is also not unknown for figures to be carefully selected according to different criteria in order to produce a result that is already desired on political grounds. It is therefore important to collect statistics from various sources whenever possible and analyse them in detail before reaching a final estimate.

The rates of energy consumption vary from one country to another, depending on the wealth of the country, its Government and its natural resources. The energy use in Britain, Switzerland, India and the USA is given by Ramage (1997).

It is instructive to compare these figures with those for the sources of electricity in France, one of the countries with the highest nuclear component. In 2006 the production was 549 TWh, consisting of 429 (78%) nuclear; 61 (11%) hydro; 57 thermal (10%) and 2.2 Wind (0.4%) (Nuclear Issues 30, March 2008).

1.4. Wood

As already mentioned, wood is still extensively used as a major source of fuel in poorer countries. If more is used than is replaced by additional growth this can lead to desertification. It is therefore desirable to replace wood by more efficient and less damaging fuels, and certainly the use of wood cannot hope to solve the energy crisis.

References

Avery, John Scales (2007) *Energy, Resources and the Long-Term Future* (London: World Scientific).

Barnham, K.W., Mazzer, M., and Clive, B. (2006) Resolving the energy crisis — nuclear or photovoltaics, *Nature (Materials)* **5**, 161.

Hafele, Wolf Ed (1981) *Energy in a Finite World: A Global Systems Analysis* (Ballinger Publishing Company).

Hodgson, Peter Edward (1999) *Nuclear Power, Energy and the Environment* (London: Imperial College Press).

Lomborg, Bjorn (2004) *The Skeptical Environmentalist* (Cambridge: Cambridge University Press).

MacKay, David J.C. (2008) *Sustainable Energy: Without the Hot Air*.

Ramage, Janet (1997) *Energy: A Guidebook* (Oxford: Oxford University Press).

Swamp, Bob (2007) Energy storage takes off. *Physics Word*, July, p. 42.

Von Weizacker, E., Lovins, A.B., and Lovins, L.H. (1996) *Factor of Four: Doubling Wealth-Halving Resources: The New Report to the Club of Rome* (Earthscan Pulications Ltd.).