From "The Future of Energy Use", by Robert Hill, Phil O'Keefe and Colin Snape, St. Martin's Press, NY, 1995.

The Future of Energy Use

INTRODUCTION

Evidence for our use of energy in the course of development may be seen almost everywhere. In the UK, tracks, scored by bulldozers across remote Scottish mountains, lead to new forests of conifers; six-lane motorways carry traffic across the country; derelict, or newly gentrified, windmills abound and on Orkney, among other places, a new generation of wind machines is being built. Spoil heaps from mines of all kinds, coal, shale oil, lead and tin among them, are witness to the consumption of raw materials. Scrap yards and rubbish tips mark the final destination of much that was produced from them. Crofts and mining villages lie deserted and ruinous, while new designer apartments in Thames warehouses in London illustrate changes in living arrangements.

All this activity depends on energy. In the home energy is needed for warmth and cooking. Outside it, activities from housebuilding to farming, from industrial production to hobbies and sport all call for energy. Each of us can see this simply by looking at our way of life and by trying to imagine it without gas, coal, oil or electricity. We may also see this obvious phenomenon all over the world and in all other cultures, for example, those first Australians still following their ancient ways cook over open fires; Thais powering their gondola-like taxis with V-8 engines; the Inuit now using ski-doos, rifles and outboard motors.

These examples are not of energy use for its own sake, but of its use as a means to many ends. We all want goods and services, the most basic of which are appropriate and adequate food and shelter. For this, sources of heat for cooking, for making utensils and construction materials, and, frequently, for warmth and light, are required. After food and shelter the list of desired goods and services extends almost indefinitely; for example, clothing, health care, education, transport, entertainment, sport and so on. All of these need energy both for the creation of their materials and for their continued employment.

The purpose of this book is to show that energy is vital to the provision of goods and services. It will consider where the sources of energy (fuels) are to be found, the history of their use and the future of their supply. It will look also at the ways in which less fuel can be used in the production of the same level of services and at the consequences, commonly undesirable, of consuming large quantities of various fuels.

ENERGY DEPENDENCY

The way in which we live our lives is largely determined by the energy resources at our personal disposal. Every household in the developed world contains a number of appliances which consume fuels of various sorts. They help to free their owners from time-consuming and routine domestic chores, and allow more time for work, hobbies or other pursuits. We have only to consider the appliances found in our own homes, the uses to which they are put, the fuels that they consume, their power rating and the time that they save compared with carrying out their functions by hand to see the point.

Table 1.1 is an inventory of energy-using appliances which might be found in a typical house with a large garden. Four items in it are probably crucial to living comfortably in such a house.

1. An automatically controlled central heating boiler means that the heating looks after itself and the house is warmed when its inhabitants need it to be. Timing controls and thermostats ensure that this end is achieved as economically as possible.
2. An automatic washing machine will do the washing while the inhabitants get on with the tasks that need supervision (for example, cooking) or relaxing.
3. A power driven lawnmower will be used to keep the garden tidy with a minimum of effort, and a substantial saving of time which can then be used for more pleasurable tasks like growing vegetables and tending flower borders.
4. A car, preferably small and economical, makes it possible to get to work, to visit family and friends, to get to social events at any time of the day or of the year. Public transport may, of course, be available for work but is often limited in the evenings and at weekends.

In addition to these four there are many other items in the table, but they all have one thing in common – they are used either, as in the case of the automatic systems, to replace human supervision and decision, or, as in the case of the powered lawnmower, to increase the speed at which the operator can perform the task at issue. The price to be paid for these conveniences includes not only capital and running costs, but also the depletion of natural resources. Users may also become locked into a lifestyle in which the gadgets play an essential part and from which it would be painful to withdraw.

THE POWER OF MACHINES

A person working steadily can sustain an output of power of about 100 watts, while a horse might manage about 750 watts. Table 1.1 also gives the amount of power supplied to the machines it lists. In all but one or two instances this is greater than that which a person can produce and, in the case of the more powerful appliances, greater than that which a horse can produce. In many cases the fuel costs are quite small, particularly as many of the machines are used only for short periods. Detailed consideration of these values reveals just how much power there is at the command of a modern householder or gardener. For instance, a lawnmower with a small petrol engine has power approximately equivalent to that of a team of four horses. It can mow half an acre of lawn in about three hours at a fuel cost of about 50 pence and its maintenance costs are very low. Similarly the motor which drives the automatic washer exerts more power than is possible by hand, and this allows the wash to be done more quickly. The fuel cost for a typical load of washing is about 5 pence and the maintenance costs for the machine are well below £1 a week.

In both these examples the cost of using machinery is very low, compared with the cost of using human or animal labour, and in the domestic and other environments of the developed world, this is invariably the case. So it is that the trend towards machinery and away from human or animal labour in order to save costs continues. This is as true in industry, agriculture and transport as it is in the home. So far the service sectors of the economy have not been affected to the same extent, but it is not difficult to imagine that much of the routine work in such professions as medicine and the law will, in the near future, be undertaken by computer-based systems. The 'brains' of these machines will need much less power than, say, a lawnmower, but the overall effect of replacing human labour with power derived from fuels will be the same.

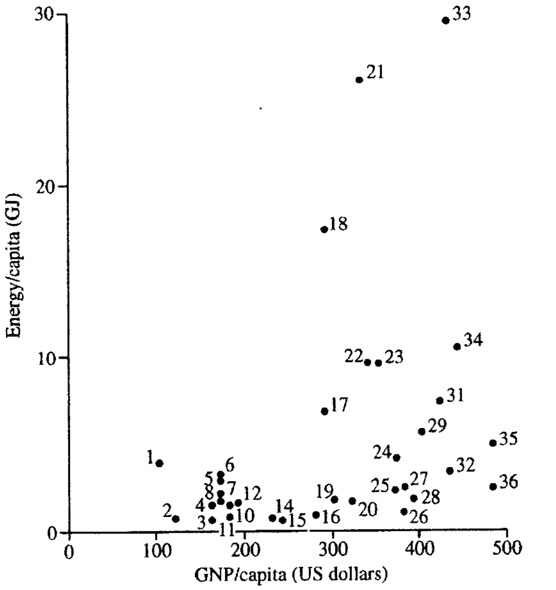
Item	*Power rating (Watts)*	*Running costs/hour at 5.5p/kwh*
Electric drill	400	2.2
Electric saw	1250	6.9
Paint stripper	1600	8.8
Lawn mower (150 cc)	3000	16.5
Strimmer (20 cc)	500	2.3
Hedge trimmer	250	1.4
Washing machine		
motor at 700 w		
water heater at 2.5 kw	total 3200	Depends on programme
Drier	2000	11.0
Car (1000 cc)	37000	204.0
Cooker		
rings at 2 kw		
grill at 2 kw		
oven at 2.9 kw	total 12900	Depends on use
Fridge-freezer	195	1.1
Mixer	110	0.6
Blender-grinder	330	1.8
Kettle	2500	13.8
Electric frying pan	750	4.1
Radio	25	0.1
Yoghurt maker	15	0.1
Iron	1000	5.5
Vacuum cleaner	225	1.2
Sewing machine	75	0.4
Hi-fi	160	0.9
Television	50	0.3
Slide projector	50	0.3
Fan heater	2000	11.0
Radiant electric fire	1000	5.5
Electric blanket	75	0.4
Table lamp	60	0.3
Hair drier	300	1.7
Immersion heater	3000	16.5
Central heating boiler	18000	99.0
For comparison:		
Person working hard	100	
Horse working steadily	750	

Table 1.1 *Some domestic appliances and their power consumption*

ENERGY USE AT DIFFERENT STAGES OF DEVELOPMENT

A brief historical consideration of development shows that as civilizations take on more complex physical forms, their consumption of fuels of various sorts increases. A line of development from the harnessing of fire, through settled agricultural practices, to increasing levels of industrialization involves greater and greater per capita use of fuels. This development also increases the number of people that a particular area of land will support.

Early humans lived in warm climates, and where wild fruits and vegetables would provide sustenance for the year round. It was the least energy intensive of societies in which the minimum daily intake of metabolic energy, about 2000 kilocalories (8.2 MJ), was provided by the food which they gathered.



Note: Numbers identify countries (see Appendix I, Table I.1
Source: World Bank, 1990

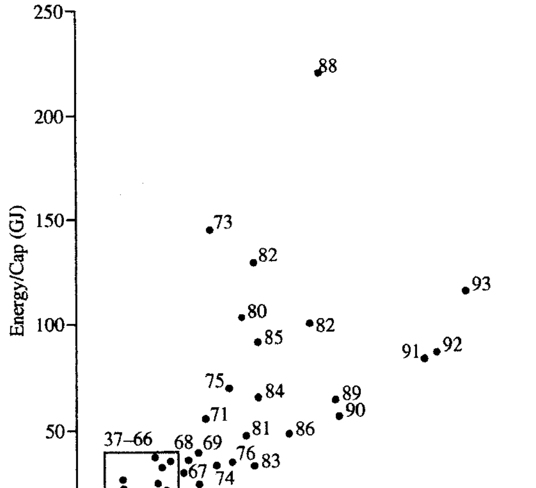
Figure 1.1 *Energy/capita* v *GNP/capita for low income economies in 1988*

A million or so years ago the controlled use of fire, and the development of hunting methods allowed a more varied diet and made possible the colonization of less hospitable regions. People still lived off the land, but could now make use of animal products. The use of fire for cooking, heating, lighting and as a focus for social activity, probably entailed a doubling of individual energy use to a daily average of 4000 kilocalories (16.4 MJ).

When semi-settled (slash and burn) and settled agricultural practices were adopted, a greater investment in materials was required in the home and on the farm. By then, as much as three times the daily energy use of the hunter-gatherers was probably entailed, ie 12,000 kilocalories (49.2 MJ). These practices were used in the Middle East around 4000BC, but, in many parts of the world communities are still to be found living in this fashion. But most of the world's peoples developed more advanced agricultural societies where settlement was permanent, where there was a sizeable investment in premises, animals and machinery, and goods were widely traded and transported. Occupations became more specialized, a significant service sector emerged and the use of materials such as metals, glass, spices etc became widespread. The daily per capita energy use in this way of life, familiar to the Romans and, by AD1500, common throughout Europe and, indeed, still continuing in many countries, was very much higher than that of previous civilizations, reaching about 21,000 kilocalories (88.2 MJ).

In Europe, after many centuries of this development, a rapid transition, largely beginning in the eighteenth century, to an urban, industrial existence took place. Many parts of the world are now experiencing a similar change. This new society is much more energy dependent than its predecessors. Its particular characteristics include city living, better housing, a wider variety of food, and much more transportation of people and goods. In it, daily per capita energy consumption is estimated to be 90,000 kilocalories (378 MJ).

Some parts of the world, for example Europe, USA, Canada, Australia, have now entered a stage of development which differs yet again from early industrial civilizations. Its characteristics include very comfortable housing, personal transport, international air travel, access to a wide variety of goods and services, a high standard of education and health care, a concern for pollution control and a population chiefly working in the service industries. To

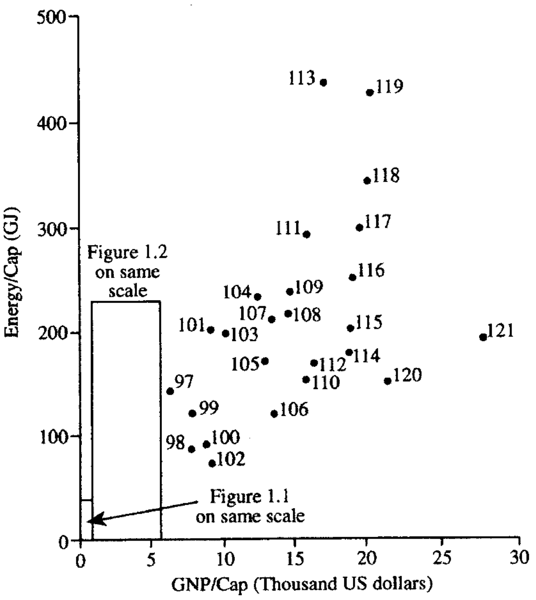


Note: Numbers identify countries (see Appendix I, Table I.1)
Source: World Bank, 1990

Figure 1.2 *Energy/capita* v *GNP/capita for middle income economies in 1988* maintain this lifestyle a daily per capita energy consumption of 250,000 kilocalories (1 GJ) is needed.

The estimates of early populations and their consumption of energy on which these comments are based are subject to wide error, and, to some extent, are derived from studies of similar societies which exist today. For the more settled farming communities, industrial and post-industrial societies, there are numerous examples available, and, often, fairly reliable historical records.

The next section investigates some of the sources available and discusses some of the information that they give us.



Note: Numbers identify countries (see Appendix I, Table

Source: World Bank, 1990

Figure 1.3 *Energy/capita* v *GNP/capita for high income economies in 1988*

ENERGY'S ROLE IN THE ECONOMY

So far the discussion has been about the progression of societies towards more 'advanced' technological development. Along with this development has been a growth in the population of these societies and, by and large, services have kept pace with population. We know that energy is used in transport, blast furnaces, home heating, tractor fuel and a thousand other individual ways. Is it possible to discern any fundamental reason why energy use is so essential to the economy?

Energy is not used for its own sake. Mention has been made earlier that consumers require goods and services, not energy supplies, and that the use of energy allows the provision of these goods and services. Malcolm Slesser has pointed out that the key to understanding the

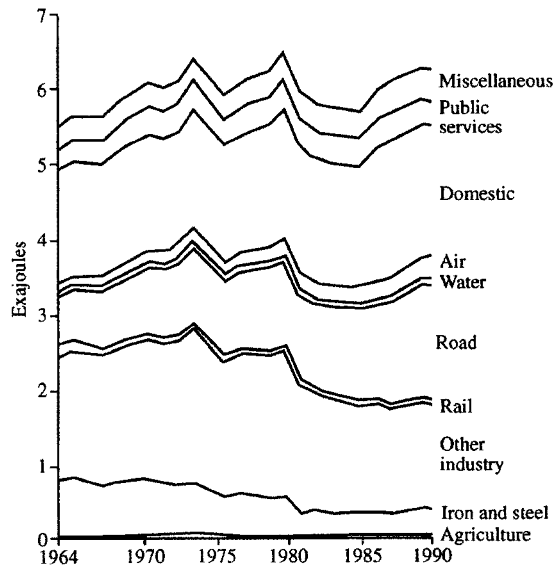


Figure 1.9 *UK energy consumption by final users*

dominant role of energy in the economy is that its use allows various substitutions or trade-offs to take place.

Capital–energy substitutions

As larger populations are catered for and as standards of living increase there is an accumulation of capital assets, with more houses, more schools, more hospitals, more cars, more roads, more garden gnomes and so on. These have been provided by the prevailing economic and production system, and have resulted from the conversion of raw materials into the final goods. This procedure is made possible by using fuels to power the processes of conversion of raw materials to useful materials and to power the machinery used to fashion the final objects from the processed materials. Some of these goods could be provided for a small population using manual methods, but their mass production requires large amounts of energy. We have utilized energy from fossil fuels to increase our capital stock.

Conversely we can also use capital goods to reduce energy use. For example, the one-off investment of energy in the production of insulating materials for buildings can reduce the fuel required to maintain their internal temperatures at satisfactory levels and thus over the lifetime of the insulated building less energy is consumed. Poor insulation is cheaper to provide initially and requires less energy to produce, but in the longer term involves greater expense and higher energy use.

Time–energy substitutions

One of the major uses of energy is to ensure that tasks are carried out quickly. This is easily seen in the case of transport. For example, we may compare the time taken to travel 1000 miles by bicycle (perhaps 10 days) with the time taken by a car or train (say 1 day), or with that taken by a fighter plane (1 hour). The quicker the journey, the greater is the expenditure of energy.

However, it is not so obvious that chemical and mechanical manufacturing processes follow the same rule. Chemical reactions proceed most efficiently towards a maximum yield of their products at a very slow pace. If they are to produce a useful yield in a reasonable time they need greater temperatures or pressures, or other special conditions, and the yield is always less than the maximum possible. Energy is used to provide these special requirements and to separate the product from the so far non-reacting constituents. In manufacturing processes increased speed of machining or assembly involves a larger investment in plant and, frequently, in more powerful plant to produce the increased output.

Space–energy substitutions

There are various ways in which space, or land area, and energy are substituted. In agriculture more food may be grown on the same area by increasing inputs of fertilizer and by giving greater attention to the crop (for example, irrigation, pesticides and chemical weed control). All these things use energy.

Large amounts of land can also be taken up in the provision of power supplies. However, a change from the large, fossil fuelled power stations of today to power stations based on sources of renewable energy will call for changes in land use, but not necessarily for more land.

Compared with their more compact counterparts, life in sprawling cities like Los Angeles entails more travel over more roads and more widely distributed services. As populations grow so the amounts of land needed for housing and other services grow too. Agricultural land decreases simply because the same sort of land is preferred for both purposes. All this means that, again, energy use increases.

Labour–energy substitutions

One of the most obvious substitutions of energy is of machine work for that of humans and animals. We have discussed this earlier and have seen that machine power is so far in excess of the power of either people or animals that it is now used almost exclusively for tasks once the province of physical labour. Human operators largely act as directors of this power in the form of digger drivers, crane operators, machinists, computer programmers and so on.

WHAT IS ENERGY?

In the preceding sections the word 'energy' has been used many times, occasionally with slightly different meanings. In particular, 'energy' and 'fuel' have been used almost synonymously. But what, exactly, is 'energy'?

The concept arose in the nineteenth century from experiments which established that mechanical work and heat are equivalent. It was found that a given amount of work will produce a fixed amount of heat. Reversing this process, to convert heat into mechanical work, is, however, a bit more complicated. One of the most familiar examples of work converted into heat may be seen when two rough surfaces are rubbed together. The work in overcoming the friction between them is manifested as heat.

It was later found possible to incorporate heat generation by electric current and heating by the absorption of the radiation emitted by hot objects into the general scheme of things by proposing that all these processes were examples of changes in a property called energy. This followed from the realization that a closed system has something that remains fixed in quantity when the conditions of the system do not change. If heat or work are put into or removed from a system, it will be left in a different set of conditions. The difference between its initial and final state is said to be a change in its energy. By 'system' is meant a device or process which has well-defined boundaries, for example, an internal combustion engine, an elastic band, a saucepan of food or a planet.

This concept is embodied in the law of conservation of energy, which states that energy may be converted from one form to another (eg from work done against friction to heat or from mechanical energy to electrical energy), but it can neither be created nor destroyed. The possibility of energy changing to a form where it is no longer available for use in performing work is not ruled out, but the energy has not 'disappeared' from the world.

Energy, then, is an abstract idea or concept, not an object, or a fluid, nor anything else which can be isolated and separately identified. The concept was invented to provide a means of unifying the scientific approach to various related phenomena involving work, heat and temperature.

To visualize this concept in a more concrete way it is probably easiest to think of energy as the potential a system has for doing mechanical work. Of course this means that we now have to say what we mean by work and a precise scientific definition is given in Appendix I. To perform useful work it is necessary to take a process which effects the conversion of energy from one form to another. The process may convert all or some of the initial energy to work.

For example, the potential energy of a large mass of water in an elevated dam can be converted by leading the water to a lower level via a turbine. The kinetic energy of the moving stream turns the turbine and this mechanical energy (of rotation) can be used to perform work. Or again, the aerobic conversion of foodstuffs in metabolic processes allows muscles to contract or relax, so allowing a person to run for long periods at a steady rate. At the end of each of these processes, and all others, when the work has been done the eventual outcome is that heat has been dissipated into the atmosphere. That is to say that real processes are not completely reversible.

All the substitutions above involve the performance of work, indeed the whole relevance of the use of fossil, and other fuels and machinery such as wind and water mills, is that they allow the performance of work to counteract other shortages of one sort or another.

There is one further point to consider, which is that not all sources that can deliver work are of equal usefulness. Some, perhaps most, of our requirements involve only very small departures from normal conditions, eg to keep warm we need only to raise the temperature of our homes by a few °C. Others, for example, motor car engines or steel production, call for high temperatures at some point to achieve the desired result. There are many ways of providing small temperature increases, but comparatively few sources for high temperature heat. The latter are known as sources of energy of high quality and include the fossil fuels.

THE LAWS OF THERMODYNAMICS

There are two scientific laws which are fundamental to the consideration of any processes involving energy. These are the first and second laws of thermodynamics. Both are empirical, and are based on experiments which measure common variables such as pressure, temperature, length and voltage; they do not rely on making any assumptions about the way in which the world works and this is their strength. It is also the reason why scientists are confident that the laws will not be jettisoned in the future in favour of some newer ideas.

The first law of thermodynamics

The first law of thermodynamics is also known as the law of conservation of energy. When it is stated in terms of the conservation of energy some deductions can be made from it, but very few.

For example, it follows straightforwardly that it is impossible to devise perpetual motion machines, because if the machine's motion is to go on for ever none of its original kinetic energy must be dissipated. However, some heat will always be produced by friction between the components of the machine and lost from it. This will reduce its energy of motion, which, in turn, will cause it to slow down and eventually to stop.

Stating the first law in this broad way is not very helpful when a wider range of applications is being considered. Restricted formulations are often more useful and are frequently called 'operational' definitions, because they are stated in such a way as to allow experiments to be constructed and deductions to be drawn. Comparison of the results of the experiments with those deduced from the law allows the law to be tested. If the results from a variety of experiments and applications agree with the inferences made using the law, confidence is increased in the law's relevance and universal applicability.

The most common operational definition of the first law may be expressed in words as 'When heat energy is added to a system, the energy appears either as increased internal energy or as external work done by the system' or in mathematical symbols as:

$$dQ = dU + dW,$$

where dU is the change in internal energy of the system when an amount of heat, dQ, is added to it and an amount of work, dW, is done by the system.

The second of these two statements is just a mathematical formulation of the first. A system's internal energy resides in the potential and kinetic energy of its atoms, and the system's temperature provides a measure of it.

(NB If the system under consideration is very large, the whole earth for example, the quantity dW is usually very small compared with dQ and dU. In this case, changes in the heat content are the same as changes in the internal energy, and if we imagine that under some particular conditions the heat content of the system (technically known as its enthalpy) has a reference value, we can talk either of changes in heat content, or of changes in energy, from this reference state, the quantities involved being equivalent. In general conversation, the tendency is to refer to the energy of a system, when, more correctly, its heat content or internal energy is meant. We shall do the same, bearing in mind the above qualification.)

Using the first law the efficiency of an energy transformation or conversion system can be defined as

$$\text{Efficiency} = (W/Q) \times 100 \text{ per cent}$$

where W is the work (or energy) provided by the system and Q is the energy supplied to the system.

For example, if, of the 90 therms of energy supplied to a gas boiler, only 70 therms eventually appears as heat in the water to be circulated to the radiators the boiler is $(70/90) \times 100 = 78$ per cent efficient.

The second law of thermodynamics

The first law does not specify a direction in which energy changes happen, but it is the common observation that some processes have a directional property, for example that heat flows from hot objects to cold ones and not vice versa. The second law of thermodynamics addresses these processes.

It is also a matter of our experience that some material changes have a natural direction, eg the sugar in our tea dissolves and spreads throughout the liquid rather than the sugar in sweet tea spontaneously crystallizing in the bottom of the cup; and iron rusts, rather than rust becoming pure iron. Neither of the 'unnatural' effects necessarily offends against the first law and a realization that it did not tell the complete story led to the introduction of the second law. The second law of thermodynamics qualifies the first law to restrict its application to the sort of changes which do occur in nature.

There are various statements of this law which refer to specific applications. The following two are probably the most useful.

1 'It is not possible to produce a machine which can convert all of a given amount of heat into useful work'. One important consequence of this is that heat engines, eg internal combustion engines or turbines, must produce waste heat, which means that they have a limiting efficiency which is less than 100 per cent.
2 'All processes go in the direction which increases the amount of disorder, or chaos, in the universe'. For instance, iron rusts, rock becomes sand and so on. It is possible to produce iron from widely dispersed iron ore, but this involves large amounts of energy and if the whole process of mining of ore, extraction, refining and of fuel production is taken into account the overall result is an increase in disorder. Disorder may be quantified and entropy gives a measure of it.

Engines and refrigerators

To see what effects the second law might have, we can consider the efficiencies of two ideal machines, a heat engine and a heat pump (or refrigerator). Idealized, simplified versions of these machines are set out in Figure 1.12.

Engines

For the heat engine, which in practice might be an internal combustion engine, or a gas or steam

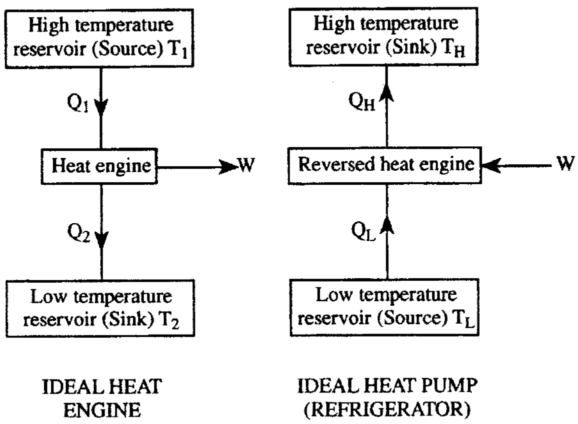


Figure 1.12 *Idealized heat engines*

turbine, we are interested in how much of the heat energy that it absorbs from the high temperature reservoir can be delivered as external work. In a power station this would involve considering how much of the energy released when the coal is burned is eventually available as electrical energy. If the work delivered is W and the heat absorbed from its high temperature source is Q_1 then the efficiency is W/Q_1. In one cycle of operation of the engine Q_1 units of heat are absorbed from the high temperature reservoir, Q_2 units rejected to the low temperature reservoir and W units of work are carried out.

The second law tells us that it is inevitable that some heat is rejected in this way, but the first law allows us to write down the energy balance for the process which is:

$$W = Q_1 - Q_2$$

Therefore,

$$\text{Efficiency} = W/Q_1 = (Q_1 - Q_2)/Q_1 = 1 - Q_2/Q_1$$

and if the absolute temperatures of the high and low temperature reservoirs are T_1 and T_2 respectively this becomes:

$$\text{Efficiency} = 1 - T_2/T_1,$$

because the heat flows are proportional to the absolute temperatures. Expressed as a percentage:

$$\text{Efficiency} = (1 - T_2/T_1) \times 100 \text{ per cent.}$$

A more extensive theoretical investigation would demonstrate that Q and T are related as stated, and that the expression obtained for efficiency is the maximum theoretical efficiency that such an engine can attain. It is usually referred to as the efficiency of a Carnot engine (the name given to this idealized perfect engine) or the Carnot efficiency. A real engine working between the same temperatures would not be able to achieve this level of efficiency because of practical constraints, for example, energy losses due to friction between moving parts, temperature differences within the engine, imperfect heat transfer and so on.

As an example of the implication of this limiting efficiency on the output of electrical power stations, we can apply it to an advanced gas-cooled reactor (AGR). The temperature of the carbon dioxide cooling gas leaving the core of an AGR nuclear reactor is 634°C. This is used to produce high temperature steam for the turbine of the generator. The temperature of the steam leaving the turbines is cooled to 100°C by water circulated through the cooling towers. Its maximum possible efficiency is the Carnot efficiency, ie:

$(1 - 273 + 100/273 + 634) \times 100$ per cent

$= (1 - 373/907) \times 100$ per cent

$= (1 - 0.41) \times 100$ per cent

$= 59$ per cent

If the station can achieve 60 per cent of the Carnot efficiency, its actual efficiency is 60 per cent of 59 per cent which is 35 per cent.

Refrigerators

The action of a refrigerator is the reverse of that of an engine. Its purpose is to use external work to extract heat from a low temperature reservoir and reject it to a high temperature sink, it is therefore moving heat up from a lower to a higher temperature and for this reason is often known as a heat pump. The first law again allows us to write down the energy balance for this process, which is:

$$Q_H = W + Q_L$$

(see Figure 1.12).

The amount of heat delivered at the higher temperature is obviously greater than the work supplied and the ratio (Q_H/W) is known as the coefficient of performance of the system when it acts as a heat pump, ie when we are interested in using it to provide heat. However, if we are interested in the way the system performs in cooling a low temperature source the coefficient of performance will be (Q_L/W), because the amount of heat extracted for a given amount of work done by the engine is what will determine running costs. These two coefficients may be written as follows.

Coefficient of performance of the heat pump

$$(\mathrm{COP}) = Q_H/W = Q_H/(Q_H - Q_L) = T_H/(T_H - T_L)$$

Heat pumps have considerable potential for providing heating. They offer the possibility of removing heat from the outdoors and using the heat extracted to warm the indoors. The amount of heat deposited indoors will be larger by three or four times (for a COP of three or four) than the amount of gas or electricity bought from the supply company. At present heat pumps are more expensive than conventional heating appliances.

Coefficient of performance of the refrigerator

$$(\mathrm{COP}) = Q_L/W = Q_L/(Q_H - Q_L) = T_L/(T_H - T_L)$$

If the temperature inside a refrigerator is 2°C when the room temperature is 20°C, its Carnot COP is:

$= T_L/(T_H - T_L) = 275/(295 - 275)$

$= 275/20 = 13.8.$

And if the refrigerator can achieve can efficiency of 50 per cent of this, its actual COP is $0.5 \times 13.8 = 6.9$. This means that 6.9 joules can be transferred from the refrigerator cabinet to the room for every joule of electrical energy supplied to the refrigerator from the mains.

SUPPLY, DEMAND AND END-USE: TRENDS AND DEVELOPMENTS

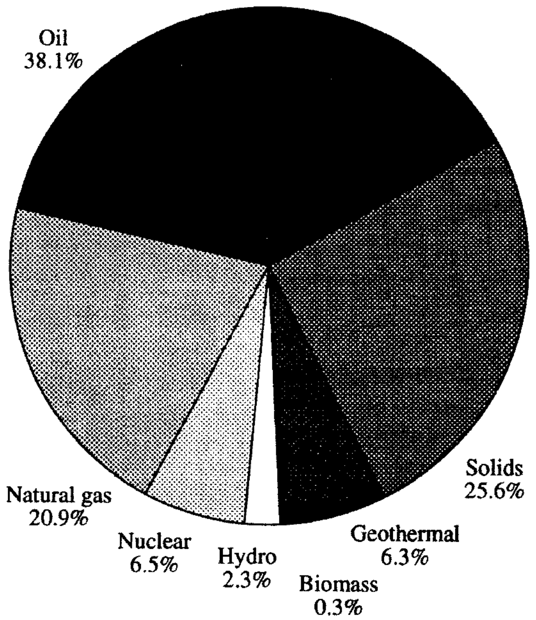
In addition to the technical assessment of energy resources no introduction would be complete without an overview of the changing make-up of energy supply, demand and end-use for the UK, Europe and the world. This section will highlight the major variations over the last 20 years, as well as providing one possible short term energy outlook.

The debate over energy futures has become a central theme in resource management, embracing socio-economic, political and environmental concerns. Energy is a foundation stone of the modern industrial economy, as well as a 'basic need' in subsistence economies. For this reason, an understanding of its supply, demand and end-use is important for energy planning. The patterns of energy flow in any economy broadly reflect the flow of energy from production to consumption, from primary productivity and imports through to end-use. Tracing these energy flows allows the calculation of energy need for everything from individual households up to the whole world. Present debates concerned with energy futures reflect a change in analysis from supply to demand side with an emphasis on end-use.

The debate over energy futures has recently been widened to include, of course, environmental futures, particularly the impact of global warming.

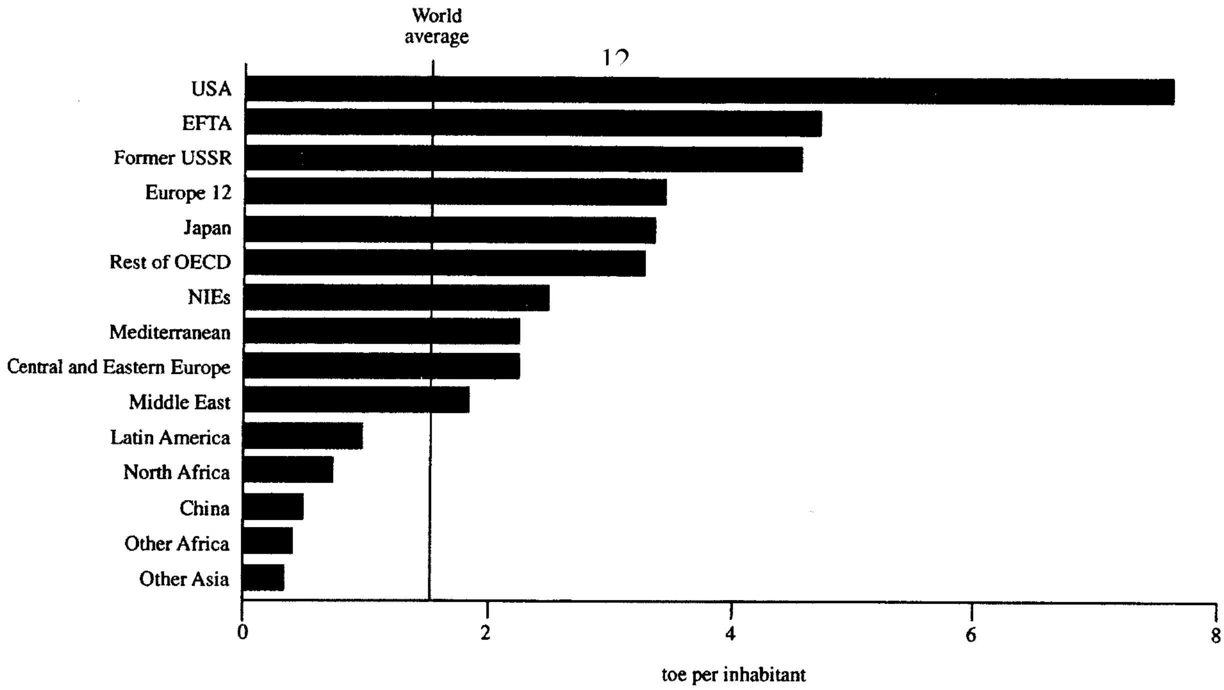
The world

The fuel mix associated with the developing world provides a view of the diverse nature of energy resources. In Africa, for example, annual biomass dependency is put at about 35 per cent of total energy needs. This, of course, hides figures like the 98 per cent dependence in Ethiopia. Although woodfuel and its charcoal derivative is the predominant energy source in many of the



Source: *Annual Energy Review*, 1993

Figure 1.14 *World share of primary fuels, 1991*



Source: *Annual Energy Review*, DGXVIII, 1993

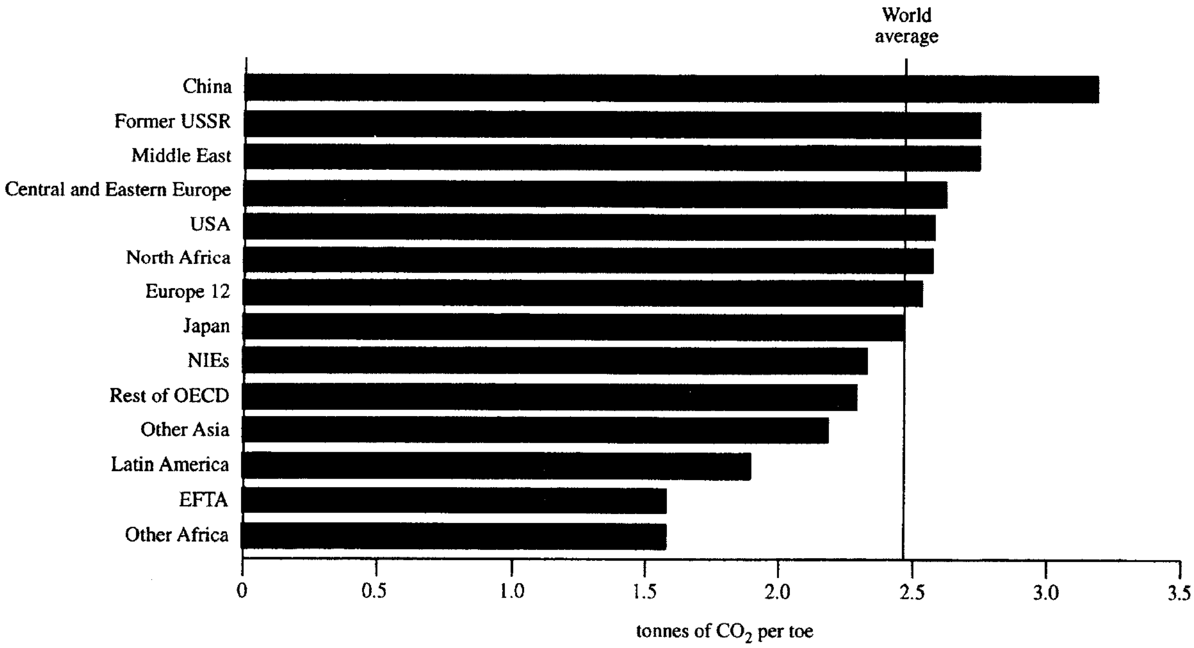
Figure 1.15 *Energy consumption per capita in 1991*

poorest nations, it is by no means always the case. In India, energy from burning dung and agricultural residues totalled over 110 million tonnes against '133 million tonnes of fuel wood' (K Smith, 1992). In Bangladesh, fuelwood is even less important, representing only 17 per cent of the total energy consumption against '66 per cent of crop residues' (FAO, 1986).

Between 1985 and 1990 total gross energy consumption increased annually by 2.2 per cent, however, in 1991, this was reduced to 0.9 per cent. These composite figures hide regional variations such as a fall of 9.5 per cent in 1991 for Central and Eastern Europe, as well as an increase of 10.2 per cent in the newly industrialized countries (NICs). This wide variation in energy consumption makes an analysis of global trends difficult. During the 1990s, oil demand showed little increase, dropping 0.2 per cent per annum, natural gas, on the other hand, continued to grow by 3.7 per cent. Figure 1.14 shows world shares of primary fuels in 1991. World energy consumption was dominated by oil with 38.1 per cent of the total. Solids make up 25.6 per cent and natural gas 20.9 per cent. The total renewable gross consumption makes up 8.9 per cent of the total. Once again these composite indicators hide wide variations in fuel mix. In 1991, the dominant primary fuel in China was solid fuel at 73.2 per cent. This dependence on solid fuel is reflected in CO_2 emissions where China is ranked as having the highest CO_2 to energy ratio. The primary fuel consumption in the Mediterranean reflects a 90.6 per cent oil dependence and 9.1 per cent solid consumption.

Figure 1.15 represents energy consumption per capita for 1991. According to these figures the average American used 7.5 toe/inhabitant compared to 3.3 toe/inhabitant in Europe and 0.5 toe/inhabitant in China. The average USA inhabitant consumes 14.5 times more energy in one year than a Chinese inhabitant. Figure 1.16 presents CO_2/energy ratio by region for 1991. While the highest CO_2 to energy ratio is exhibited in China, its share of total emissions is small because of a low per capita energy consumption. The CO_2 to energy ratio for USA equals the world average, but the USA was responsible for 20 per cent of annual CO_2 emissions.

Total final energy demand showed an increase from 4824.8 Mtoe in 1985 to 5326.8 Mtoe in 1990, an increase of some 2.0 per cent per annum over the period. Major fuel changes in this period include an increase in electricity demand by 3.6 per cent and a drop in biomass demand of 0.9 per cent. This is due in part to



Source: *Annual Energy Review*, DGXVIII, 1993

Figure 1.16 *CO_2 to energy ratio by region in 1991*

rural electrification schemes, improved combustion efficiencies and decreased biomass availability.

It is anticipated that biomass and solid fuel energy will continue to decline as oil, gas, nuclear and renewable energy penetrate the economies of NICs and developing countries. World energy production will expand most rapidly in non Organization for Economic Co-operation and Development (OECD) areas, such as NICs, which provide new markets for oil and gas. The Middle East is expected to hold its share of exports at about 58 per cent of world export markets.

ENERGY AND ECONOMIC DEVELOPMENT

Increased energy consumption has often been used as an indicator for economic growth. However, a fundamental problem exists with this general correlation. Two different economies, one supplying large quantities of energy very inefficiently and the other supplying smaller quantities of energy with greater efficiency, may deliver the same volume of energy services but the amount of energy consumed varies enormously. The ideal society is one that achieves high efficiency, through renewable technology, and thus has a low relative energy demand.

Improving the quality of life, and enabling economic and industrial growth, calls for increased amounts of usable energy; but what is also required is an increase in end-use efficiency. An understanding of the difference is fundamental to understanding the relationship between energy and economic development.

Imagine two households, one using incandescent light bulbs drawing 100 watts of electricity, the other using a 20 watt compact fluorescent bulb. The incandescent bulb uses energy very inefficiently, while the compact fluorescent bulb requires a much smaller amount of energy. However, the energy services provided by both bulbs are identical. This is important because this investment in end-use efficiency, if taken up nationally, substantially reduces the requirement for energy provision. The economic benefit of investing in energy efficiency can outweigh the economic costs of building additional electricity generating stations. In turn, this means large savings to the utility, increased services to the customer and fewer emissions of greenhouse gases.

Energy opportunities and constraints

The steady take-up of renewable energy technologies provides perhaps the greatest opportunity for change in energy supply. The opportunity to supply present and future global energy requirements while conserving resources and promoting environmental sustainability is very great. Seizing the opportunity is particularly vital at a time when excessive CO_2 production, largely the result of fossil fuel use, threatens the stability of the global climatic system. Given the seriousness of the present energy/environment relationship, a number of opportunities can be highlighted as essential to long term sustainability. These are:

- an investment in renewable energy (wind, solar, biomass etc);
- nuclear generation (providing suitable disposal arrangements are delivered);
- savings on energy conversion (eg combined heat and power);
- savings on end use (eg building insulation);
- intra fossil switch (eg from coal to gas);
- recycling (eg waste plastics);
- CO_2 removal (eg at coal power stations).

(Okken et al, 1991)

Fifteen years ago, such an energy strategy would have seemed unsuitable for the provision of future energy requirements. However, changes in the efficiency and cost of renewable technologies, along with present environmental deterioration, mean that this strategy is quickly becoming the blueprint for a sustainable energy future. These changes will radically alter the conventional patterns of energy supply.

In the UK, the energy demand has largely stabilized, although slight increases in consumption will continue. During the 1970s, threats to the stability of the UK's energy supply came from the Middle East. However, the discovery of and investment in indigenous oil means that the UK has suitable oil reserves to fulfil the medium term UK requirement. One direct constraint, a product of the Earth Summit, on all fossil fuel generation will be the requirement to reduce CO_2 emissions to 1990 levels by the year 2000. This alone will provide an institutional incentive to change from conventional to non-conventional generation.

Constraints on nuclear energy supply will largely depend on the success of efforts to store low, medium and high level nuclear waste safely. This has always been a problem for the nuclear industry and seems likely to remain so largely because of public opposition to such measures.

There are a number of restraints on the development of renewables in the UK. Enormous sums were spent on the nuclear industry which was developed for military purposes before being transferred to the public sector. Renewables, on the other hand, enjoy only limited funds for research and development. But even if that funding were to improve, there are several additional constraints. The main one has to do with pricing policy. At present the cost of cleaning up the environmental damage caused by conventional electricity production is not included in the end price. If these costs, externalities, were included the price to the consumer would double. Such a move would tip the balance in favour of environmentally benign renewables and would actually help in the abatement of global warming. There are a number of other benefits to be derived from the use of renewable energy resources which are not at present included in standard economic accounts.

The development of renewables would provide new opportunities both for employment and for economic development. This would particularly be so in rural areas where their generation sites are likely to be built. Rural poverty and rates of urbanization would thus decline and, as one consequence of the use, for example, of methanol or hydrogen technologies, air pollution would be reduced. Biomass production would mean increased land restoration and so would also increase the productivity of denuded land. The creation of large areas of multi-purpose biofuels would also provide wildlife habitats.