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Energy

Management, Supply and Conservation

CHAPTER 1

Energy and the Environment

Society in the developed world is built on the assumption that energy is both freely available and relatively cheap. However, there are environmental costs associated with the continued use of fossil fuels and these are causing a reappraisal of the way in which energy is used. This chapter investigates the global use of energy and its impact on economies and the environment.

1.1 Two Worlds

Those of us who live in developed countries take energy very much for granted. Although we may not understand exactly what it is, we certainly know how to use it. Indeed, never before has there been a society, which is as reliant on energy as our own. Consider for a moment the number of everyday items of equipment, tools and appliances that run on electricity – lamps, washing machines, televisions, radios, computers and many other 'essential' items of equipment – which all need a ready supply of electricity in order to function. Imagine what life would be like without electricity. Both our home and our working lives would be very different. Indeed, our high-tech, computer-reliant society would cease to function; productivity would fall drastically and gross domestic product (GDP) would also be greatly reduced, a fact highlighted by the power cuts that brought California to its knees in 2001 [1]. Similarly, if oil supplies ceased, then the fabric of our society would very quickly fall apart. Those living in the UK may remember the events of September 2000, when a relatively small number of 'fuel protesters' managed to almost stop petroleum supplies to the UK's petrol stations, resulting in the economy grinding to a halt within days; people could not get to work and the supermarkets ran out of food. Those in the UK with longer memories might also recall how a combination of striking coal miners, power workers and crude oil price rises in the 1970s brought the UK to a standstill; electricity power cuts were commonplace, vehicle speed restrictions were introduced, and ultimately the government was forced to introduce a three-day working week in order to save energy. Clearly, although all too often taken for granted, cheap and available energy is essential to the running of any advanced industrialized society. Understanding the nature of energy, its supply and its utilization is therefore a subject of great importance. For without energy we in the developed world face an uncertain future.

To some reading this book, the society that has just been described may seem alien. Those living in developing countries will be all too aware that energy is a very finite resource. In many poorer countries, electricity is supplied only to major towns, and even then, power cuts are commonplace. This not only reduces the quality of life of those living in such countries, but also hampers productivity and ultimately ensures that those countries have a low GDP. If you live in one of these poorer nations, then you are in the majority – a majority of the world's population that consumes the minority of its energy. This is indeed a great paradox. One-third of the world's population lives in a consumer society which squanders energy all too easily, while the other two-thirds live in countries which are often unable to secure enough energy to grow economically – a fact highlighted by the USA which consumes approximately 21% of the all world's primary energy [2], while having only about 4% of the world's population.

The inequalities between developed and developing countries are real and should be cause for great concern to the whole world. Unfortunately, political self-interest is often much stronger than altruism, and the gap between the rich and the poor nations has widened in recent years. However, when confronted with unpalatable facts about gross inequalities between rich and poor nations, our usual response is to assume that the problem is altogether too large to solve and to forget about it. After all, most of us have many other pressing needs and problems to worry about. This, of course, is a very understandable response. However, forgetting about the problem does not mean that it will go away. In fact, the reality is that as the economies of the developing world grow, so their demand for energy will also grow. This will increase pressure on the Earth's dwindling supply of fossil fuel and will also increase greenhouse gas emissions and atmospheric pollution in general. It is worth remembering that the Earth is a relatively small place and that atmospheric pollution is no respecter of national boundaries. Indeed, issues such as climate change and third-world debt are now impinging on the comfort and security of the developed world. Indeed, it is the perceived threat of global climate change that has been the driving force behind all the intergovernmental environmental summits of the late twentieth century. In historical terms, the summits at Montreal, Rio and Kyoto were unique – never before had so many nations sat down together to discuss the impact of humans on the environment. In fact, it could truthfully be said that never before in the history of the world have so many sat down together to discuss the weather! Collectively these summits produced protocols which set targets for reducing ozone depletion and greenhouse gas emissions, and have forced governments around the world to reappraise policies on energy supply and consumption. The collective agreements signed at these summits have impacted, to varying degrees, on the signatory nations and manifest themselves in a variety of ways. For example, in the UK, a large proportion of the electricity supply sector has switched from coal, a high carbon intensity fuel, to natural gas, which has a much lower carbon content. In the construction industry, so-called 'green buildings' are being erected which are passively ventilated and cooled with the express intention of minimizing energy consumption and eliminating the use of harmful refrigerants. In addition, the high-profile nature of the various intergovernmental summits has meant that concern about energy and its utilization is now at the forefront of public consciousness.

Because most lay people focus on the consumption of energy it is often forgotten that the supply of energy is itself a large and important sector of the world's economy. For example, the energy industry in the UK is worth 5% of GDP and employs 4% of the industrial workforce (1999 data) [3], making it one of the largest industries in the UK. The energy supply sector is also very multinational in nature. For example, crude oil is transported all around the globe, with a total of 52,561 barrels being transported daily in 2006 alone [2]. Similarly, large quantities of natural gas are piped daily over long distances and across many international borders, and electricity is traded between nations on a daily basis. Given the size of the energy supply industry, its multinational nature and its importance to the world economy, it should come as no surprise that many parties have a vested interest in promoting energy consumption and that this often leads to conflict with those driven by environmental considerations.

1.2 Politics and Self-Interest

Any serious investigation of the subject of energy supply and conservation soon reveals that it is impossible to separate the 'technical' aspects of the subject from the 'politics' that surround it. This is because the two are intertwined; an available energy supply is the cornerstone of any economy and politicians are extremely interested in how economies perform. Politicians like short-term solutions and are reluctant to introduce measures that will make them unpopular. Also, many political parties rely on funding from commercial organizations. Consequently, political self-interest often runs counter to collective reason. For example, in many countries (although not all), politicians who put forward policies which promote congestion charging, or petrol price increases, become unpopular, and are soon voted out of office. As a result, measures which might at first sight appear to be extremely sensible are discarded or watered down due to political self-interest. It is of course far too easy to blame politicians for hypocrisy, while ignoring the fact that we as individuals are also often culpable. Consider the case of a rapidly growing large city which has traffic congestion problems; journey times are long and air quality is poor. Clearly the quality of life of all those in the city is suffering due to the road congestion. The solution is obvious. People need to stop using their cars and switch to public transport. If questioned on the subject, car drivers will probably agree that the city is too congested and that something should be done to reduce the number of cars on the roads. However, when it is suggested that they, as individuals, should stop using their own cars, then self-interest tends to win over reason; objections are raised, sometimes violently, that such a measure is too extreme and that the freedom of the individual is being compromised. From this we can only conclude that it is impossible for politicians alone to bring about changes in 'energy politics' without changes in public opinion. In many ways it is true to say that we all get the leaders we deserve!

The road congestion example discussed above is a good illustration of the contradiction between reason and self-interest, which is often manifest within individuals. However, exactly the same contradiction is often all too evident at a governmental and international level. When it comes to environmental issues, governments often refuse to implement sound policies because in so doing they might inhibit economic growth. To those concerned with environmental issues, the idea of putting national 'self-interest' before the environmental health of the planet might seem absurd. However, the issue is not as clear-cut as it would appear at first sight. There is a strong link between energy consumption and GDP. Without a cheap and available energy supply, the economic growth of many nations will be restricted. Consequently, any enforced reduction in GDP due to environmental control measures is going to be much more painful to the inhabitants of poorer countries than an equivalent cut in a developed country. Indeed, to many poorer nations, the notion of rich, developed countries telling them to reduce greenhouse gas emissions is hypocritical; after all, the advanced nations of North America and Europe only became rich through intensive manufacturing. Since the eighteenth century, the developed countries have consumed large amounts of primary energy and produced high levels of pollution. So in the twenty-first century when – having created many environmental problems – these same nations turn to their poorer neighbours and expect them to restrict economic growth in the name of environmentalism, it is not surprising that to many in the developing world this approach appears high-handed. Therefore, perhaps it is up to those of us in the developed world to lead by example and alter our approach towards energy consumption.

1.2.1 Human Nature

From the discussion above it is clear that the management and conservation of energy is strongly influenced by the collective mindset of society. With respect to this, we cannot ignore the role played by human nature, as it influences both politicians and consumers alike, and does not necessarily lead to outcomes that benefit either society or the environment. Consider, for example, the case of Easter Island, a small and remote rocky outcrop in the Pacific Ocean. As one commentator has aptly pointed out:

> The Easter Islanders, aware that they were almost completely isolated from the rest of the world, must surely have realized that their very existence depended on the limited resources of a small island. After all, it was small enough for them to walk round the entire island in a day or so and see for themselves what was happening to the forests. Yet they were unable to devise a system that allowed them to find the right balance with their environment. [4]

Faced with dwindling timber resources, the ancient tribal groups on Easter Island fought each other for control of supply and ultimately consumed all the timber on the island, with disastrous consequences for their society. Unfortunately, rather than acting cooperatively, societies, groups and individuals tend to act out of self-interest and consume as much as they can. This has led some to postulate that all societies evolve to degrade as much energy as possible. Consequently, governments, societies and individuals tend to use their power (be it political, military or financial) to maximize their consumption of energy and other finite resources. One only has to look at the global conflicts of the twentieth and early twenty-first centuries to see that many have considered scarce commodities well worth fighting over. Indeed, in 1999 US Secretary of Energy, Bill Richardson, stated:

> Oil has literally made foreign and security policy for decades. Just since the turn of this century, it has provoked the division of the Middle East after World War I; aroused Germany and Japan to extend their tentacles beyond their borders; the Arab Oil Embargo; Iran versus Iraq; the Gulf War. This is all clear. [5]

Oil is an extremely high-quality fuel, which has a higher energy content per unit weight than coal and which can be burnt at a higher temperature. It is easier to transport than coal and can be used to power internal combustion engines. No other primary energy source has oil's intrinsic qualities of extractability, transportability and versatility, at relatively low cost. Given this, and the fact that people and commodities throughout the world are transported by oil-powered vehicles, it is not surprising that individuals and governments will go to extreme lengths to secure its supply. In short, the unhappy truth appears to be that human nature will seek to maximize consumption while stocks last – only when oil runs out will things change! Perhaps we are not too different from the Easter Islanders after all?

1.3 What is Energy?

Before discussing global energy production and consumption, it is perhaps wise to first look at the physics associated with energy. Although most are familiar with the term *energy*, surprisingly few people fully appreciate its true nature. In everyday language, the word *energy* is used very loosely; words like *work*, *power*, *fuel* and *energy* are often used interchangeably and, frequently, incorrectly. To the physicist or an engineer, energy is a very specific term which is perhaps best explained by means of an illustration.

Consider a mass of 1 kg which is raised 1 m above a surface on which it was originally resting. It is easy to appreciate that in order to raise the weight through the distance of 1 m, someone, or some machine, must have performed work. In other words, work has been put into the system to raise the mass from a low level to a higher level. This work is the amount of energy that has been put into the system. So, when the weight is in the raised position, it is at a higher energy level than when on the surface. Indeed, this illustration forms the basis for the International System (SI) unit of energy, the 'joule', which can be defined as follows:

> One joule (J) is the work done when a force of 1 newton (N) acts on an object so that it moves 1 metre (m) in the direction of the force.

and

> One newton (N) is the force required to increase or decrease the velocity of a 1 kg object by 1 m per second every second.

The number of newtons needed to accelerate an object can be calculated by:

$$F = m \times a \tag{1.1}$$

where m is the mass of the object (kg) and a is the acceleration (m/s^2). Given that the acceleration due to gravity is 9.81 m/s^2, a mass of 1 kg will exert a force of 9.81 N (i.e. 1 kg $\times$ 9.81 m/s^2). Therefore the energy required to raise it through 1 m will be 9.81 J.

If the 1 kg mass is released it will fall through a distance of 1 m back to its original position. In doing so the *potential energy* stored in the 1 kg mass when it is at the higher level will be released. Notice that the energy released is equal to the work put into raising the weight. For this reason the term *work* is sometimes used instead of *energy*. Perhaps a good way of viewing energy is to consider it as stored work. Therefore, *potential energy* represents work that has already been done and stored for future use.

Potential energy can be calculated by:

$$\text{Potential energy} = m \times g \times h \tag{1.2}$$

where m is the mass of the object (kg), g is the acceleration due to gravity (i.e. 9.81 m/s^2) and h is the height through which the object has been raised (m).

As the weight falls it will possess energy because of its motion and this is termed *kinetic energy*. The kinetic energy of a body is proportional to its mass and to the square of its speed. Kinetic energy can be calculated by:

$$\text{Kinetic energy} = 0.5 \times m \times v^2 \tag{1.3}$$

where v is the velocity of the object (m/s).

We can see that during the time the mass takes to fall, its potential energy decreases whilst its kinetic energy increases. However, the sum of both forms of energy must remain constant during the fall. Physicists and engineers express this constancy in the 'law of conservation of energy', which states that the total amount of energy in the system must always be the same.

It should be noted that the amount of energy expended in raising the weight is completely independent of the time taken to raise the weight. Whether the weight is raised in 1 second or 1 day makes no difference to the energy put into the system. It does, however, have an effect on the 'power' of the person or machine performing the work. Clearly, the shorter the duration of the lift, the more powerful the lifter has to be. Consequently, power is defined as the rate at which work is done, or alternatively, the rate of producing or using energy. The SI unit of power is the watt (W). Therefore, a machine requires a power of 1 W if it uses 1 J of energy in 1 second (i.e. 1 W is 1 J per second). In electrical terms, 1 W is the energy released in 1 second by a current of 1 ampere passing through a resistance of 1 ohm.

It is well known that if two rough surfaces are rubbed together, the work required in overcoming the friction produces heat. Also, it is known that electricity can be used to perform mechanical work by utilizing an electric motor. Therefore, it is clear that energy can take a number of forms (e.g. electrical energy, mechanical work and heat) and that it can be easily converted between these various forms. For example, fossil fuel can be burnt to produce heat energy in a power station. The heat energy produced is then converted to mechanical energy by a turbine, which in turn produces electrical energy through a generator. Finally, the electricity is distributed to homes and factories where it can be converted to mechanical work using electric motors, heat using resistance elements and light using electric lamps.

1.3.1 Units of Energy

For myriad reasons (too numerous to mention here), a bizarre array of units for energy has evolved. Books, articles and papers on energy quote terms such as 'kWh', 'therms', 'joules', 'calories', 'toe' and many more. This makes things very complicated and confusing for the reader. This section is, therefore, included to introduce some of the units more commonly in use.

Kilowatt-hour (kWh)

The kilowatt-hour (kWh) is a particularly useful unit of energy which is commonly used in the electricity supply industry and, to a lesser extent, in the gas supply industry. It refers to the amount of energy consumed in 1 hour by the operation of an appliance having a power rating of 1 kW. Therefore:

$$1\ \text{kWh} = 3.6 \times 10^6\ \text{J}$$

British thermal unit (Btu)

The British thermal unit (Btu) is the old imperial unit of energy. It is still very much in use and is particularly popular in the USA:

$$1\ \text{Btu} = 1.055 \times 10^3\ \text{J}$$

Therm

The therm is a unit that originated in the gas supply industry. It is equivalent to 100,000 Btu:

$$1\ \text{therm} = 1.055 \times 10^8\ \text{J}$$

Tonne of oil equivalent (toe)

The 'tonne of oil equivalent' (toe) is a unit of energy used in the oil industry:

$$1\ \text{toe} = 4.5 \times 10^{10}\ \text{J}$$

Barrel

The barrel is another unit of energy used in the oil industry. There are 7.5 barrels in 1 toe:

$$1\ \text{barrel} = 6 \times 10^9\ \text{J}$$

Calorie

In the food industry the calorie is the most commonly used unit of energy. It is in fact the amount of heat energy required to raise 1 g of water through 1°C:

$$1 \text{ calorie} = 4.2 \times 10^3 \text{ J}$$

1.3.2 The Laws of Thermodynamics

Thermodynamics is the study of heat and work, and the conversion of energy from one form into another. There are actually three laws of thermodynamics, although the majority of thermodynamics is based on the first two laws.

The first law of thermodynamics

The first law of thermodynamics is also known as the law of conservation of energy. It states that the energy in a system can neither be created nor destroyed. Instead, energy is either converted from one form to another, or transferred from one system to another. The term 'system' can refer to anything from a simple object to a complex machine. If the first law is applied to a heat engine, such as a gas turbine, where heat energy is converted into mechanical energy, then it tells us that no matter what the various stages in the process are, the total amount of energy in the system must always remain constant.

The second law of thermodynamics

While the first law of thermodynamics refers to the quantity of energy that is in a system, it says nothing about the direction in which it flows. It is the second law that deals with the natural direction of energy processes. For example, according to the second law of thermodynamics, heat will always flow only from a hot object to a colder object. In another context, it explains why many natural processes occur in the way they do. For example, iron always turns to rust; rust never becomes pure iron. This is because all processes proceed in a direction which increases the amount of disorder, or chaos, in the universe. Iron is produced by smelting ore in a foundry, a process which involves the input of a large amount of heat energy. So, when iron rusts it is reverting back to a 'low-energy' state. Although it is a difficult concept to grasp, disorder has been quantified and given the name 'entropy'. Entropy can be used to quantify the amount of useful work that can be performed in a system. In simple terms, the more chaotic a system, the more difficult it is to perform useful work.

In an engineering context it is the second law of thermodynamics that accounts for the fact that a heat engine can never be 100% efficient. Some of the heat energy from its fuel will be transferred to colder objects in the surroundings, with the result that it will not be converted into mechanical energy.

The third law of thermodynamics

The third law of thermodynamics is concerned with absolute zero (i.e. -273°C). It simply states that it is impossible to reduce the temperature of any system to absolute zero.

The first and second laws of thermodynamics are well illustrated by the ideal heat engine shown in Figure 1.1. Heat engines are devices, such as internal combustion

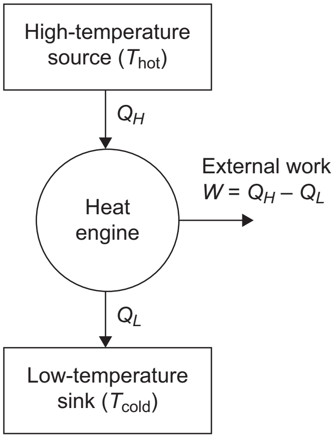

FIG 1.1 Schematic diagram of an ideal heat engine.

engines and gas turbines, which convert thermal energy into mechanical work. They do this by exploiting the temperature gradient between a hot 'source' and a cold 'sink'. As heat flows from the hot 'source' to the cold 'sink' it passes through the 'working' part of the engine where it is converted into mechanical energy.

If it is assumed that no energy is stored, then by applying the first law of thermodynamics it is possible to write down an energy balance for the system:

$$W = Q_H - Q_L \tag{1.4}$$

where W is the mechanical work produced by the engine (J), Q_H is the heat absorbed from the high-temperature 'source' (J), and Q_L is the heat rejected to the low-temperature 'sink' (J).

Similarly, the efficiency, η, of the heat engine can be expressed thus:

$$\eta = \frac{\text{work output}}{\text{work input}} = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H} \tag{1.5}$$

Because the respective heat flows are proportional to the absolute temperature of the hot 'source' and the cold 'sink', it is possible to express the efficiency of an ideal heat engine as:

$$\eta = 1 - \frac{T_L}{T_H} \tag{1.6}$$

where T_H is the absolute temperature of the hot 'source' (K), and T_L is the absolute temperature of the cold 'sink' (K).

Given that the second law of thermodynamics dictates that heat must flow from hot to cold, it can be seen from Eqn 1.6 that if no temperature difference exists between the hot 'source' and the cold 'sink', then heat cannot flow and the efficiency of the engine must therefore be zero. Conversely, if a large temperature difference exists between the hot 'source' and the cold 'sink', then the heat flow will be much greater, with the result that the efficiency of the cycle will be high.

1.3.3 Ecology, Society and the Second Law of Thermodynamics

Although often forgotten by policy makers and those involved in the management and conservation of energy, the second law of thermodynamics is of profound importance. Indeed, Albert Einstein stated:

> A theory is the more impressive the greater the simplicity of its premises, the more varied the kinds of things that it relates and the more extended the area of its applicability. Therefore classical thermodynamics has made a deep impression on me. It is the only physical theory of universal content which I am convinced, within the areas of the applicability of its basic concepts, will never be overthrown. [6]

So all-embracing is the second law of thermodynamics that it can be used to explain how the communities and ecosystems on Earth behave when they consume energy [7]. Consider for example, a large, sealed, clear container placed in sunlight, which contains air, water, soil, plants, microorganisms and animals all in carefully controlled proportions. As long as the sun shines, the ecosystem in the vessel will survive with no external maintenance. The biomass inside the container will increase until a steady state is reached in which the ecosystem is stable. If, however, the vessel is removed from the sunlight then the second law of thermodynamics will take over and the biomass will very quickly decompose into a foul-smelling high-entropy mess. Similarly, if pollution and toxins are allowed to build up in the vessel when it is placed in sunlight, the second law of thermodynamics tells us that the entropy (i.e. chaos) in the ecosystem will also increase.

The Earth behaves in much the same way as the sealed vessel described above. It is a sealed ecosystem, with negligible exchange of matter between its surface and space. It is also a balanced system, receiving all its energy from the sun in the form of short-wavelength radiation, which it then re-radiates to space as long-wavelength heat. Over millions of years the Earth has developed a stable ecosystem with a highly ordered low-entropy biomass, sustained wholly by the sun's energy. Solar energy not only heats the Earth, but also drives its atmosphere. Wind, rain, ocean currents and Earth's biomass all arise directly from the action of solar energy striking the Earth's surface.

If environmental pollution is low and only renewable energy sources are used, then the Earth should remain relatively stable, allowing a low-entropy ecosystem to survive and prosper. If, however, fossil fuels, such as petroleum, coal and natural gas, are consumed, then 'concentrated energy' from the sun, laid down in biomass hundreds of thousands of years ago, is suddenly released into the atmosphere. In thermodynamic terms, the energy trapped in fossil fuels is in a highly ordered low-entropy form. When burnt, this highly ordered energy is dispersed into the environment raising its entropy, which is exactly what the second law of thermodynamics predicts. So as more and more non-renewable fossil fuels are consumed the *Second Law* tells us that entropy-related problems, such as pollution and global warming, will inevitably increase.

It is impossible to 'buck' the second law of thermodynamics – entropy will always increase in the end! Even nuclear power, which some think might solve the Earth's energy crisis, conforms to the second law of thermodynamics. While nuclear power offers almost unimaginable amounts of energy from very small masses of uranium, the *Second Law* tells us that once this highly ordered energy is consumed it will inevitably be dispersed into the environment raising its overall entropy. This increase in entropy may, in part, explain why the safe disposal of nuclear waste has proven to be a considerable problem. Perhaps after all there is no such thing as a free lunch!

As well as explaining global behaviour, the second law of thermodynamics can be used to explain the behaviour of the various societies found on Earth. Those of us who live in the developed countries of Europe and North America are used to institutions, utilities and infrastructures that are reliable and function efficiently. By comparison, those in the developing world may be used to infrastructures and institutions that are less robust and more chaotic. In such countries, the infrastructure may be at best patchy and in many places non-existent. This suggests that these countries have higher-entropy societies compared to their more ordered low-entropy counterparts in the developed world. This is self-evident when one considers that the developed economies are amongst the highest consumers of energy on the planet. However, what is perhaps not so clear is the huge amount of energy consumed by these nations in maintaining robust institutions and infrastructures. One only has to observe the level of street lighting in Western Europe to realize that the governments of these countries consider an efficient infrastructure to be something of importance. What is less obvious, but nonetheless true, is the vast amount of energy consumed in schools, hospitals, universities and government organizations, ensuring that the institutions in these countries are run and maintained by healthy, highly educated individuals who are equipped to function in an efficient manner. By comparison, in the developing world much less energy is focused on health, education and the infrastructure, with the result that the economies of these countries are less efficient. In short, it takes huge amounts of focused energy to create a 'low-entropy' first-world society. The implications of this are far reaching. According to the second law of thermodynamics, while it is possible to have 'regions' of low entropy within a system, order can only increase in these zones if it decreases elsewhere within the system. When this is applied to the Earth as a whole, it implies that the low-entropy societies of Europe and North America have become so at the expense of less-developed societies in Africa and Asia – as the developed countries have become more ordered, so the developing nations have become more chaotic! It also implies that it is impossible for all the societies on Earth to acquire very low-entropy characteristics. Indeed, common sense tells us that this is true – as oil reserves dwindle, it will not be possible for every family in Africa and Asia to have two cars, like many in Europe and North America. The uncomfortable truth, according to the *Second Law*, is that entropy in the developing world can only be reduced if it increases in the developed world.

1.4 Energy Consumption and GDP

In the introduction to this chapter it was stated that it is almost impossible to remove politics from any discussion or study of energy. This is because the GDP of any nation is

TABLE 1.1 Historical overview of per capita energy consumption [8]

Period and location	Type of society	Characteristics	Daily per capita energy consumption, kCal (MJ)
Very early	Gatherers	Gathered wild fruit, nuts and vegetables	2000 (8.2)
1,000,000 BC	Hunter-gatherers	Gathered wild fruit, etc., hunted and cooked food	4000 (16.4)
4000 BC (Middle East)	Settled farmers	Sowed crops and kept animals	12,000 (49.2)
1500 AD (Europe)	Agricultural with small-scale industry	Agricultural society with specialized industries producing metal, glass, etc.	21,000 (88.2)
1900 AD (Europe)	Industrialized society	Large-scale industry, mass production and large cities	90,000 (378)
1990 AD (USA, Western Europe)	Advanced industrialized society	Consumer society, mass transport, many labour-saving devices	250,000 (1000)

related to its energy consumption. Perhaps the best way to illustrate this link is to look at energy consumption from a historical viewpoint. Table 1.1 shows the estimated average daily consumption of people in various historical societies.

From Table 1.1 it can be seen that per capita energy consumption has increased (almost exponentially) as societies have become more advanced and industrialized. The first humans were simple gatherers who lived off wild fruit, nuts and vegetables. However, as people began to hunt and live in less-hospitable regions, they learnt to use fire for cooking and heating. As time progressed, societies developed – first came agriculture and then industrial practices, such as the smelting and working of metals and increased trading of goods and materials. With these technological and social advances came increased energy consumption; buildings needed heating, food needed cooking and manufacturing processes required fuel. It is estimated that per capita energy consumption rose from approximately 4000 kilocalories per day, in the age of the hunter-gatherer, to approximately 21,000 kilocalories per day, in Europe prior to the Industrial Revolution [8]. The Industrial Revolution, first in Europe and later in North America, resulted in a rapid increase in per capita energy consumption during the nineteenth century. Populations grew rapidly and became concentrated in large towns and cities. Mass production became commonplace and with it more transportation of goods, raw materials and people. This dramatic increase in energy consumption continued throughout the twentieth century as more and more societies became industrialized, to such an extent that in technologically advanced countries such as the USA, per capita energy consumption has reached approximately 250,000 kilocalories per day [8].

From the above historical review, it is clear that there is a strong link between per capita energy consumption and economic growth. In simple terms, less-developed agrarian societies consume much less energy than their advanced industrial counterparts. Figure 1.2 shows data derived from the IEA Key World Energy Statistics 2006 [9]. These data

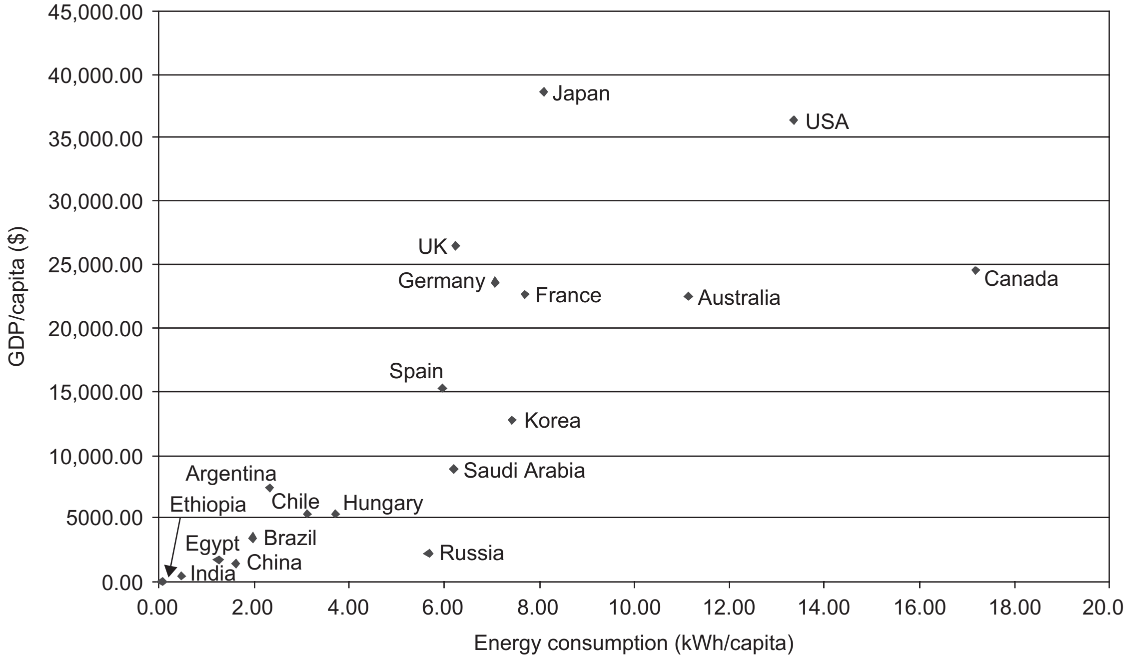

FIG 1.2 Per capita GDP versus energy consumption of various sample nations [9].

illustrate the relationship between per capita GDP and energy consumption for some of the world's nations. Although energy consumption is influenced by factors such as population density, weather and location, it can be seen from Figure 1.2 that for most nations, particularly developing countries, there is still a strong correlation between GDP and energy consumption. Broadly speaking in most societies, energy consumption and economic growth tend to move in parallel. However, comparison between countries can be complicated by geographical factors. For example, larger countries tend to expend higher levels of energy on freight transportation in order to ensure nationwide distribution of goods. Countries with cold climates may consume as much as 20% more energy per capita compared with countries which have moderate climates. Likewise, hot countries may expend 5% more energy per capita due to demand for air conditioning. In addition, due to the high energy intensity associated with processing raw materials, countries which produce large amounts of raw material expend considerably more energy per unit of manufacturing output than those which mainly import processed materials. For example, Canada has a high ratio of energy consumption to GDP, due to the fact that it is a large, cold country with a substantial raw materials processing sector. By comparison, Japan, which has a milder climate, a small land mass, and processes much fewer raw materials, has a lower ratio of energy use to GDP.

Although there has been a strong historical link between GDP and energy consumption, in recent years there has been a decoupling of this relationship in many of the more advanced countries. It has been observed that since the 1970s in these countries, increased GDP has not been accompanied by a pro-rata increase in energy consumption.

Indeed, in the UK and a number of other European countries, energy consumption has plateaued and remained relatively constant in recent years [8]. The reasons for the plateau effect are, in part, due to the adoption of energy-efficient technologies and partly because many older energy-intensive manufacturing industries have been replaced by high-tech and service sector industries, which consume much less energy. However, from a global perspective, it is simplistic to argue that this move towards the service sector is conserving energy, since in reality these countries are effectively exporting their manufacturing and heavy industry requirements to other parts of the world where wage costs are lower. Indeed, there is evidence that many advanced 'consumer' nations are simply exporting their 'dirty' energy-intensive industries to countries in which environmental legislation is much weaker, with the result that in gross terms environmental pollution is increasing.

The ratio of energy used to GDP is known as the *energy intensity* of an economy. It is a measure of the output of an economy compared with its energy inputs, in effect a measure of the efficiency with which energy is used. Manufacturing nations, with old or relatively poor infrastructures, like many of the East European and former Soviet Union (FSU) countries, often exhibit very high *energy intensities*, while the more energy-efficient 'post-industrialized' nations have much lower intensities. The link between infrastructure and *energy intensity* is very strong indeed. In developing countries, development of an infrastructure leads to growth in energy-intensive manufacturing industries. In industrialized economies, *energy intensity* is strongly influenced by the efficiency of the infrastructure and capital stock such as power stations, motor vehicles, manufacturing facilities and end-user appliances. The energy efficiency of capital stock is, in turn, influenced by the price of energy relative to the cost of labour and the cost of borrowing capital. If energy costs are high in relation to these other costs, then it is much more likely that investments will be made in energy-efficient technologies. Conversely, if energy prices are low, then little incentive exists for investment, or indeed research, in more energy-efficient technologies.

While energy intensity is strongly influenced by the price of energy, it is also affected by factors which are not directly attributable to price effects. For example, changes in technology and changes in the composition of world trade can influence energy intensity. Geographical location has a strong influence; cold northerly countries tend to exhibit high energy intensities. Other factors include changes in fashion and preferences. For example, if the practice of cycling to work becomes popular with enough people, then it is possible that this will influence the energy intensity of an economy. In short, there are many factors which influence energy intensity.

1.5 Environmental Issues

A full investigation of the environmental problems facing the Earth, although very interesting, is well beyond the scope of this book. However, because environmental considerations, in particular the perceived threat of global warming, are influential in shaping the energy policy of many countries, it is essential that the issue be discussed in some detail. Indeed, it is the threat of climate change, above any other issue, which is changing the attitudes towards energy consumption. Although there is much scientific debate on the precise nature and extent of the twin threats of global warming and ozone depletion, the fact remains that these threats are generally perceived to be real, with the result that both national and international energy policies are now being driven by an environmental agenda. It is therefore important to have an understanding of pertinent environmental issues. Ignorance of the facts relating to environmental issues is surprisingly widespread amongst politicians, professionals and the public at large. Concepts such as global warming and ozone depletion are often confused and interchanged. Indeed, some individuals committed to environmentally green lifestyles exhibit very woolly thinking when it comes to the science of the environment. This section is, therefore, written with the sole intent of presenting the relevant facts and explaining the pertinent issues relating to global warming and ozone depletion.

1.5.1 Global Warming

There is growing scientific evidence that greenhouse gas emissions caused by human activity are having an effect on the Earth's climate. The evidence suggests that the Earth's climate has warmed by 0.8°C since 1882 [10], and that the pace of this warming is increasing. Globally, the 1990s were the warmest years on record, with seven of the ten warmest years being recorded in that decade [10]. Indeed, in 1998 the global temperature was the highest since 1860 and this was the twentieth consecutive year with an above normal global surface temperature. Figure 1.3 illustrates the steady rise in global temperature that has occurred over the past 125 years.

The effects of the rise in global temperature have been wide ranging and profound. Perhaps the most visible effect of global warming has been the rapid decrease in glaciation experienced over the past 50 years. This phenomenon is well illustrated in Figure 1.4, which shows the change in the Alaskan Muir and Riggs glaciers between 1941 and 2004. The Muir glacier, parts of which were more than 65 m thick in 1941,

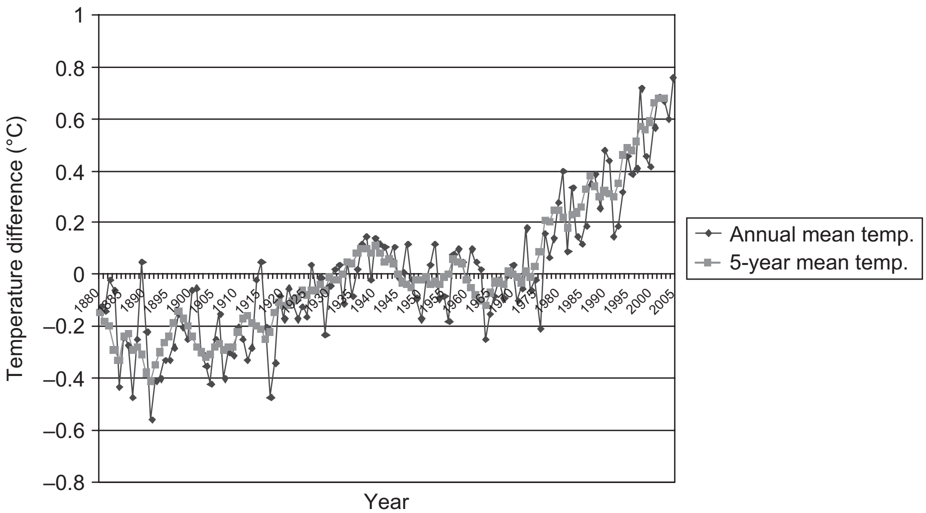

FIG 1.3 Global mean surface air temperature anomaly [10].