Glasgow Caledonian University

School of Engineering and Built Environment

Energy Resources, Generation and Utilisation

Module Code: M2H823551

Task Exercise No: 1

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Introduction

This module, Energy Resources, Generation and Utilisation has been designed to give a broad overview of the many energy and environmental issues that face the world today, and which are leading some to believe that the introduction of renewable energy sources represents one way of meeting at least part of the world's energy demands, while also helping to save the planet. Through the delivery of the module you will study such subjects as:

- global energy uses and trends
- environmental effects associated with energy production and use
- the costs of different sources of energy
- the advantages and disadvantages of renewable energy sources, and
- the concepts of efficiency and energy savings in buildings, transportation, and power generation

The module does not give definitive answers to the problems associated with energy consumption, but instead presents accurate information and suggests how this information might be used: It is left to you, the student, to draw your own conclusions and formulate your own opinions. In the teaching material, there is an effort made to avoid a bias towards, or against, aspects of fossil fuel consumption, renewable energy or nuclear power, and a balanced approach to each technology. By the end of the module you will be able to evaluate an energy-use scenario and make a reasoned judgement of merit.

Support notes

There are 9 Task exercises. Each exercise has 4 sections, each with a task at the end that should be attempted / completed. The structure is summarised below:

Task Exercise No: 1: Global Energy use and trends

Task Exercise No: 2: Energy balance and new energy sources

Task Exercise No: 3: Global warning and carbon sequestration

Task Exercise No: 4: Negative effects of energy use

Task Exercise No: 5: Energy Production costs and the national grid

Task Exercise No: 6: Description of alternative energy sources I

Task Exercise No: 7: Description of alternative energy sources II

Task Exercise No: 8: Energy Saving in buildings

Task Exercise No: 9: Energy Saving in generation and transportation

Task Exercise No: 1

Section 1: Global energy use and trends

In this section we will explore how natural sustainable energy sources have been used by people for centuries, and, because of industrialisation over the last 200 years, how we have instead become heavily reliant on energy stores such as fossil fuels. In a global context, we will consider if the trend of increasing energy consumption is likely to continue.

Early history of energy use

The primary source of energy on the Earth is solar radiation from the Sun which sustains all life. The energy falling on the Earth varies around the globe resulting in a strong correlation between the volume of living matter (the **biomass**) and sunlight. At higher latitudes where there is less sunlight, there are generally fewer living creatures.

However, human beings are not completely constrained by the availability of solar energy because of their capacity to alter the environment to make it more suitable for life. Light and heat can be artificially generated by burning organic materials; naturally available materials can be used to construct shelter and provide thermal insulation in the form of clothing; animals can be confined and used to do work; new materials such as metals and alloys with useful properties can be synthesised from raw materials.

These are examples of how natural resources were used to support life in early history. Increasing technological development permitted other sources of energy to be exploited. Wind power played an important part in the development of human civilisation and was thought to have been first harnessed using sail boats about 5,000 years ago. The ability to move easily through the oceans allowed the rapid dispersal of people to all regions of the world. Wind mills were used to mill grain and pump water and were introduced about the same time. The Dutch used windmills extensively from the 14th century for drainage and land reclamation. The basic technology remains very similar to that of wind turbines we use today to generate electricity.

Energy can also be extracted from the movement of water. Wave and tidal power were not generally utilised in the past, but the water flow through rivers and streams is easier to exploit. One cubic metre of water weighs one tonne, and this weight of water falling with gravity can do a significant amount of work. The conventional way of capturing the energy was by fitting a waterwheel on a river with the paddles turned by the weight of the falling water or the kinetic energy of the flowing water. The mechanical energy could then be used to do useful work.

The principle was extended and controlled in the 19th century with the development of hydroelectric schemes. A dam is used to stop the natural flow; the water builds up behind the dam acquiring potential energy; then water is released through a turbine to generate electricity when required.

Geothermal energy was also used as a heat source. Since there are vast natural sources of energy that cannot, even with current technology, be exploited - this includes hurricanes, earthquakes, and volcanic eruptions.

Task 1.1

It is important to become familiar with the internet to find data, and to use Excel (or similar software) for charting. To practice, try the following exercise.

The quantity of solar radiation incident on a one metre square area of the surface of the Earth depends on the month of the year and the latitude. Find the latitude and longitude coordinates of the place where you live.   http://www.nearby.org.uk/conversions-more.cgi

Go to the NASA website. http://eosweb.larc.nasa.gov/sse/RETScreen to get the total amount of energy incident on 1 m^2 of surface area at your location for each month of the year.

Produce a graph of the monthly variation using Excel. Calculate the total energy for the year. On average, how many joules (J) is incident on 1 m^2 of surface each second?

The industrial revolution

The invention of the steam engine heralded the beginning of the industrial revolution. Machines were produced to take over many manual tasks leading to standardised mass production. Increasing iron production and the development of roads, bridges and railways to move products and raw materials allowed industrialisation to spread and grow rapidly. Since the machines needed a huge amount of energy, and the energy source was coal. Coal is plentiful and cheap and there was an enormous increase in production in the UK over the course of the 19th century and early 20th century, giving rise to the soot and grime that were characteristic of that age.

With the development of the petrol and diesel engines in the late 19th century, the more convenient oil became the fuel of choice and almost all machinery was converted to run off oil. Virtually the only remaining uses for coal was home heating and for electricity generation as distribution networks were set up to make power available in the home.

The consumption of oil increased dramatically over the 20th century, with the growth of transportation. The motor car represented individual freedom and once production was mechanised and mass produced on assembly lines by Henry Ford from 1908, the car became affordable and millions were manufactured and sold.

Since a car is hardly an efficient method of travelling - the machinery is so elaborate that to convey a single person weighing 100 kg, it is necessary to move machinery weighing 1,000 kg (1 tonne). Energy is used 'fighting' the contact frictional force and air resistance.

Aeroplanes represented complete freedom and commercial flights 'took off' in the 1950s. Air travel is even less efficient because an aeroplane works against gravity when ascending to cruising altitude. Oil consumption increased faster with the growth in air travel. Consideration of transport efficiency should be a factor in choosing a mode of transport. There is evidence that energy consumption in the US and Europe is now levelling as we enter the age of communication. The increased freedom of being able to communicate at any time (the internet and moving from fixed to mobile phones) is equally dramatic but is not associated with a huge increase in energy use.

Industrialisation started in the late 18th century in Britain and still continues today. Some developed regions of the world have achieved a higher degree of industrialisation and consequently have a higher standard of living.

Developing nations such as China and India, lag behind, but aspire to the level of affluence of the developed countries. It is unreasonable to deprive citizens of developing countries of the right to strive for a higher standard of living (regardless of negative arguments concerning wealth), and this is recognised in climate change agreements such as the Kyoto treaty (examined later in the course). As a country progresses along the path of increasing industrialisation, more and more energy is required to sustain development, and, as we will see, this makes it difficult to predict future global energy consumption.

Task 1.2

Using the information taken from the following websites:

(i) Wikipedia

https://en.wikipedia.org/wiki/Energy_efficiency_in_transport

(ii) Urban transport and energy efficiency in Africa

https://www2.giz.de/wbf/4tDx9kw63gma/SUT_module5h.pdf

(iii) Transport emissions in South Africa

http://awsassets.wwf.org.za/downloads/wwf_2016_transport_emissions_in_south_africa.pdf

(iv) Take Global Warming Seriously

http://www.ucsusa.org/our-work/global-warming/science-and-impacts/global-warming-impacts#.WaAB-T6GPcs

(iv) InterAcademy Council

http://www.interacademycouncil.net

(and any others you find yourself), produce a table of the fuel efficiencies associated with different modes of transportation.

Predicting future demand

We have seen that there are many sources of energy derived from fossil fuels, and many different uses for the energy. We will now accurately quantify the numbers so that we might identify the trend (and as a secondary goal, better understand where energy saving and efficiency measures would have the greatest effect).

The **trend** is the result of the statistical analysis of a time series applied to data over a limited time domain to reveal any relationship that exists. If the relationship continues to hold, the trend can be used to predict how the system will develop into the future. The procedure is not entirely straightforward, as we see in Fig. 1.1, because complex 'systems' will always change over time. The best way of predicting the trend is to try and fully understand the underlying processes at work: It is normally insufficient merely to rely on visual extrapolation.

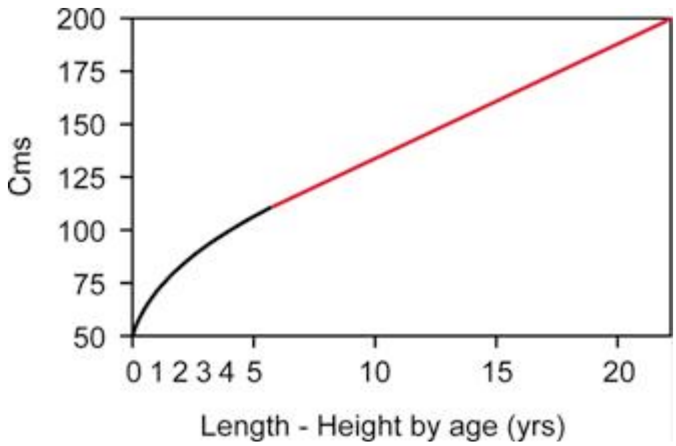


Figure 1.1: The WHO mean length-height data for infant girls (black line). If we extrapolate the trend (red line), most girls are destined to exceed 6'6" by the age of 20. This clearly is wrong. A linear projection is inappropriate in this case.

Fig. 1.2, overleaf shows a projection of this type for the world consumption of primary energy ('primary' meaning the total energy contained in the raw material - not all of this will be used or be useable) based on the expectation that nothing with change over the next 25 years.

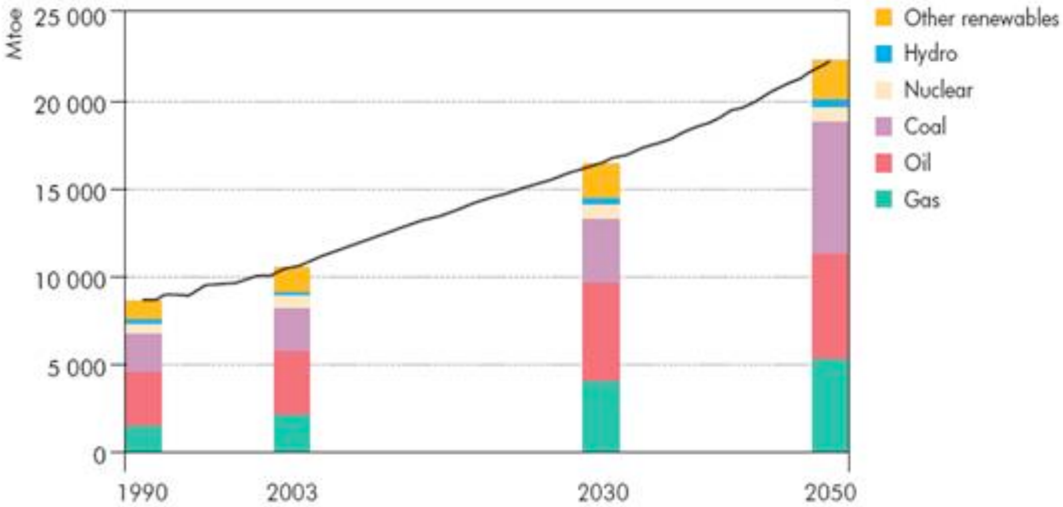


Figure 1.2: Projection of future primary energy demand in terms of equivalent tonnes of oil. [Energy Technology Perspectives (c) OECD/IEA, 2014]

From 1980 to 2014, the growth was 54% and is anticipated to increase at a slightly faster rate - this is reflected in the rising line of the projection. In reality of course, there is a limited supply of fossil fuels and this will affect demand; also the pressure over environmental concerns is also liable to curb energy consumption. Rising cost will also affect demand. It is therefore very unlikely that energy demand will rise in exactly that way.

On the other hand, the demand is unlikely to fall. Although the US and European countries may well reduce energy use over this period, energy consumption in developing countries will probably spiral. The economies of China and India are developing rapidly and are likely to skew any linear projection.

For these reasons, we cannot easily predict demand, but we can certainly define limits. The upper limit of energy demand (effectively a worst case scenario) can be estimated by an idealised calculation - we can assume that every person in the world in 2050 will have attained the standard of living now enjoyed in developed countries, and that this will be sustained in the least-energy-wasteful way possible.

The per capita (yearly, per head) primary energy consumption in units of **toe (tonnes of oil equivalent)** in major developed countries in 2015 ranged from 2.6 (Portugal) to 8.3 (Canada), with the UK sitting at 3.8. If one were to assume that just through improving the efficiency of energy use and cutting out careless consumption, the same standard of living can eventually be achieved for 2.0 toe per capita, then the projection for primary energy demand between now to 2050 as the entire world population moves steadily to the same level of energy use is shown in Fig. 1.3.

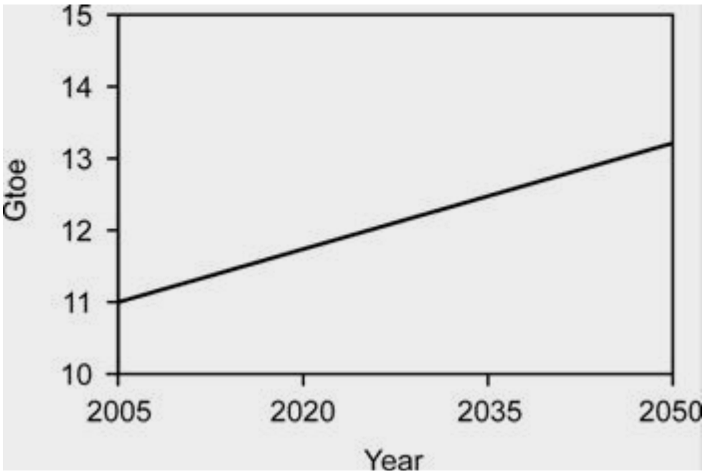


Figure 1.3: Projection of future primary energy demand based on the assumption that the entire world population eventually achieves the same standard of living and consumes 2.0 toe per capita.

The projection for 2050 is much less than that of Fig. 1.2, but is dependent on effective measures being taken to use energy more efficiently. However, we have neglected the possibility that the world population will increase between now and 2050. This will affect the prediction.

Task 1.3

Assume a world population in 2017 of 7.5 billion, rising by 1% annually. Calculate the population by 2050 using a spreadsheet. Chart the results.

What is the effect on the primary energy demand in 2050 assuming a uniform 2.0 toe by that time?

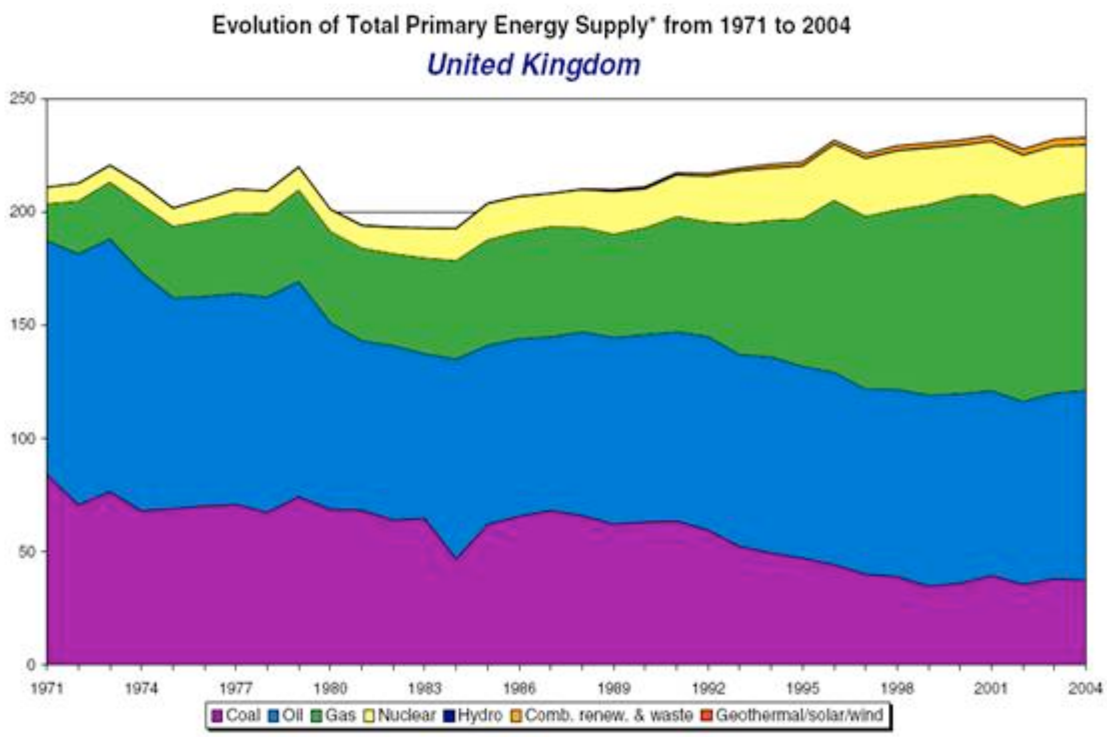
Predicting future demand

We have seen that to reduce energy demand, population growth must stabilise and energy has to be used more effectively. Since not all primary energy is used in the same way. It is desirable to break down energy use by sector to see how it is being currently used, and thereby understand the role energy plays in society (and economic development).

Formally, sectors arise from the subdivision or grouping of related components of an economic system into groups. In terms of energy use, it is convenient to identify the domestic or residential, commercial, industrial (including agriculture), and transportation sectors. This kind of division is useful because each sector requires its own specific policies and regulatory action to effect a reduction in energy consumption.

Fig. 1.4 shows the primary energy use in the UK (noting that the 2004 total is 3.8 toe multiplied by the population), and energy consumption by sector. The energy consumption is lower because of losses converting primary energy into useable energy. Refer to the IEA's Key World Energy Statistics report 2016
https://www.iea.org/publications/freepublications/publication/KeyWorld2016.pdf
for global information, and Energy Consumption in Sub-Saharan Africa. Further information can be obtained from Sub-Saharan Africa Power trends.

https://www2.deloitte.com/za/en/pages/energy-and-resources/articles/sub-saharan-africa-power-trends.html



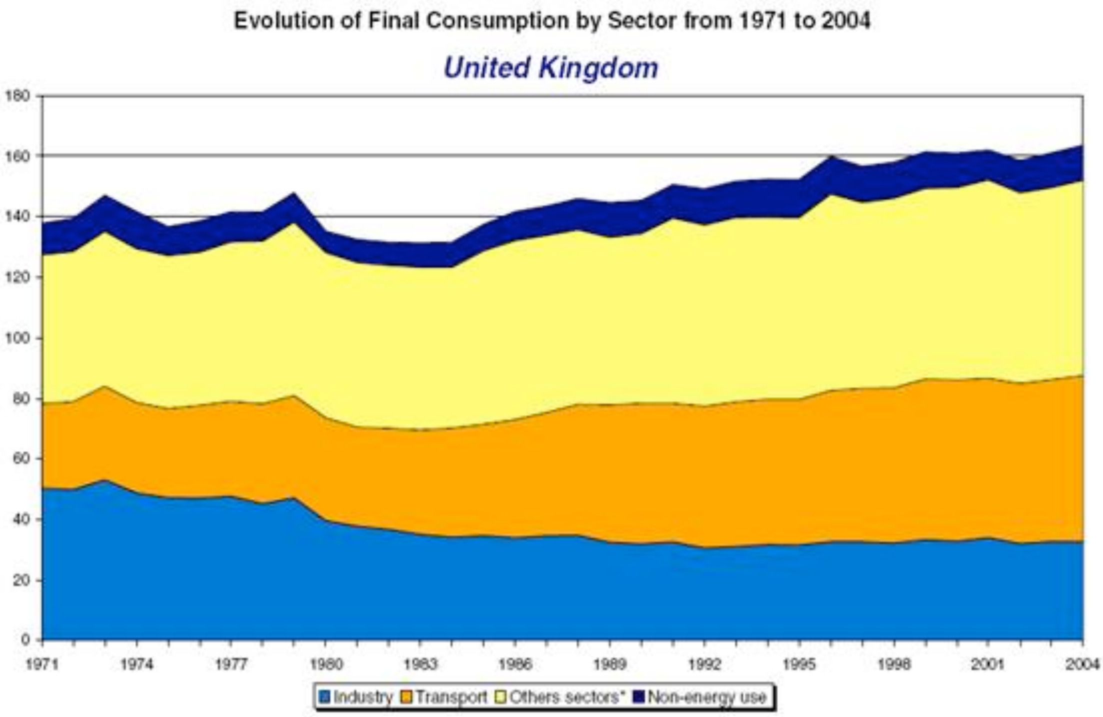


Figure 1.4 How energy was used in the UK from 1974-2004.
[Energy Technology Perspectives (c) OECD/IEA, 2008]

Of course energy use in these sectors can be sub-divided further. **Domestic** refers to all residential homes. In this sector energy use is generally divided as follows: 40% space heating and cooling; 15% water heating; 12% lighting; 10% refrigeration; 6% laundry; 17% appliances.

Commercial refers to shops, supermarkets and non-manufacturing businesses. Industrial is associated with manufacturing and is energy intensive because of the high degree of automation and mechanisation. Energy used for transportation can be divided between the distinct modes of transport (through alternative categorisations are possible). Fig. 1.5 shows a particular division for the UK.

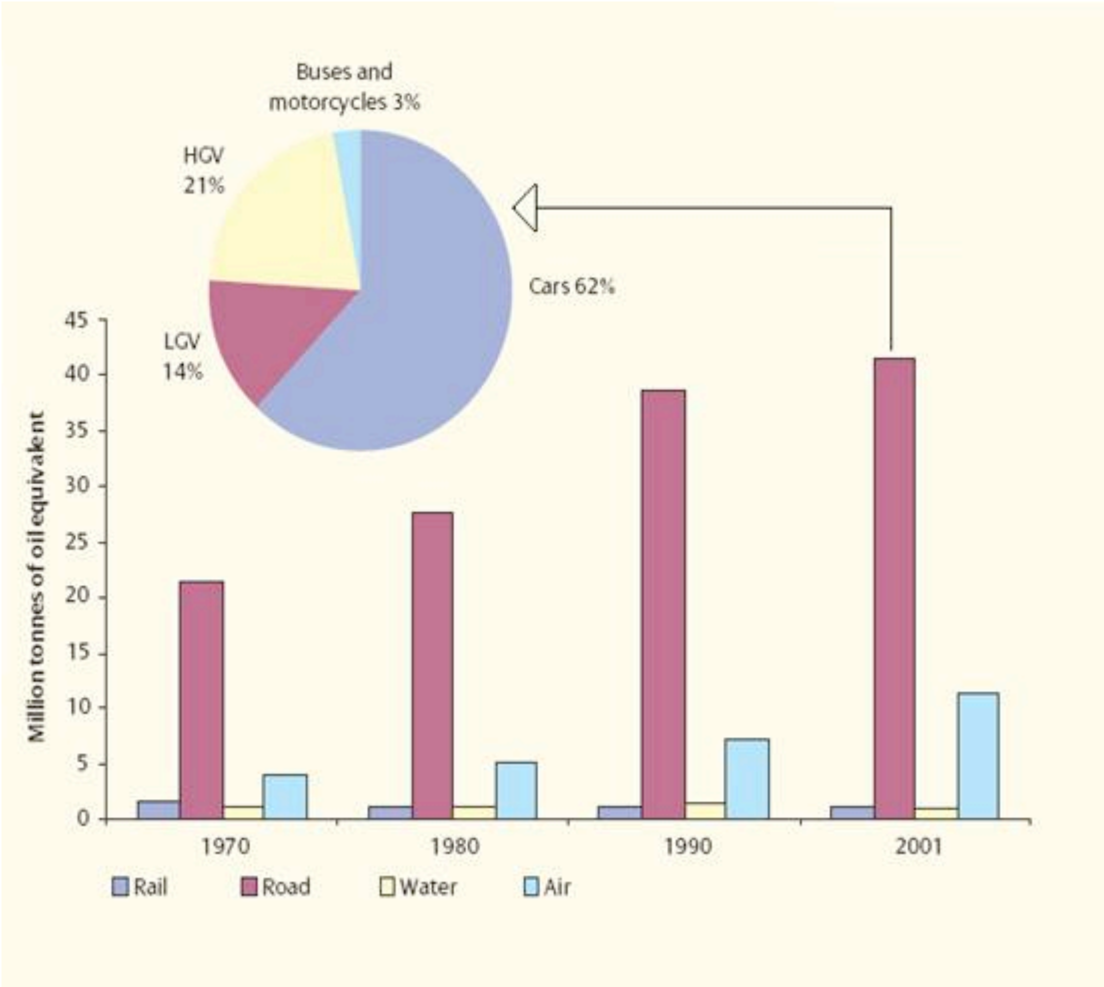


Figure 1.5: Division of energy use by mode of transport.
[Data obtained from http://www.bis.gov.uk/

Ultimately, in spite of the convenience of division of use by sector, the amount of energy consumed depends on the individual and the choices he or she makes. The term **carbon footprint** is used to quantify our use of energy in terms of its effect on the environment (which we will consider in detail later). We are not concerned with environmental effects here though, only in the quantity of raw material consumed. You should bear in mind that one tonne of oil (1 toe) energy can produce between 0.6 and 1.2 tonnes of carbon depending on the fossil fuel type used for generation. The output from a carbon footprint calculator can therefore be converted into a measure of the rate at which we use energy compared to the national average and the desirable goal of 2.0 toe *per capita*.

Task 1.4

Estimate the amount of energy you personally use by determining your carbon footprint using one of the following websites:

www.carbonfootprint.com
www.bestfootforward.com/footprintlife.htm
www.foodcarbon.co.uk
www.carboncalculator.co.uk

Do you think these calculations are accurate (and consistent) or alarmist?

How does the result relate to the national average in your country.

(in the UK, 3.8 toe *per capita*)?

Notes

Units of energy

The basic unit of energy is the **joule (J)**. One joule is actually a very small quantity of energy: To raise a cup of tea to your lips expends 1 to 5 J. Most tasks use thousands or millions of joules, and in these cases energy is best represented in scientific notation or using multipliers as shown in the table on the left: To avoid calculation errors, a shorthand notation of some sort is essential when dealing with numbers with a string of zeroes.

Also important is the rate at which energy is produced or consumed. One **watt (W)** describes energy produced at the rate of 1 joule per second ($J\ s^{-1}$). Thus an electrical generator with 1 kW output will produce 1 kW x 3,600 J of energy in one hour (because there are 3,600 seconds in one hour). This is **3.6 MJ** and is called a **kiloWatt hour (kWh) -** the **unit** used to meter and charge electricity. Note that Energy (in J) = power (in W) x time (in s)

(Divide by 3,600,000 to convert to units of electricity). For example, a 100 W light bulb running for 10 hours will consume 1 unit of electricity.

The primary energy content of 1 tonne of oil is considered to be 42 GJ, equivalent to 11,667 units of electricity.

Unit	**Scientific notation**	**Value**
1 kJ	1.0 x 103 J	1,000 J
1 MJ	1.0 x 106 J	1,000,000 J
1 GJ	1.0 x 109 J	1,000,000,000 J
1 TJ	1.0 x 1012 J	1,000,000,000,000 J

Unit	**Scientific notation**	**Value**
1 min	6.0 x 101 s	60 s
1 hr	3.6 x 103 s	3,600 s
1 day	8.64 x 104 s	86,400 s
1 year	3.15 x 107 s	31,536,000 s