UNIT 1 ENERGY AND DEVELOPMENT

Structure

1.1 INTRODUCTION

Modern industrial societies are characterised by intensive use of energy. Can you think of a day in your life without electricity or other sources of energy such as fuels for cooking and transport? Think of all the things that you use. Energy is required to produce them and reach them to you. You will agree that energy has been a crucial input in the current model of development. There is a close relationship between energy consumption and economic growth as measured by the growth of GDP and this has been demonstrated by many researchers. It is now argued that the cost and availability of energy is a major factor in promoting economic growth.

However, as the energy intensive industrial economies have expanded, their adverse impact on the environment has grown. This aspect has come under closer scrutiny in the past few decades and an understanding of the role of energy in economic development will help us develop models of environment friendly energy usage. Therefore, we begin our discussion of the energy-environment relationship by understanding the multi-faceted role of energy in economic development. We first highlight the correlation between energy and economic growth as measured by the GDP. We then examine the energy resource base at our disposal and the various energy options available to us. Finally, we analyse the carrying capacity of the Earth in relation to our energy needs.

In the next unit you will learn about energy consumption in the modern energy economies.

Objectives

After studying this unit, you should be able to:

- discuss the role of energy in economic growth;
- analyse the energy demand due to growing population and industrialisation;
- describe the energy resource base of the Earth; and
- explain how the Earth's carrying capacity is estimated.

1.2 THE ENERGY ECONOMY

The growth of an economy is measured in many ways. One of the prime indicators of economic growth is the Gross Domestic Product, or the GDP. With energy gaining centre-stage in the industrial economies, the cost and availability of energy was added as one of the major factors in the growth of GDP along with capital, labour and technical assets. Let us understand this point by looking at the trends of GDP growth vis-à-vis the growth in the use of energy and population.

The Role of Energy in Economic Growth

In pre-1750 Europe, in countries where land was relatively constant, the growth of GDP has been estimated to be about 0.5% per annum – very similar to the growth in population. From 1760 to 1820, as Britain started to use coal to fuel its early industrial age, the GDP growth rose to 1.5% with a population growth of 1% (population growth in the rest of Europe remained about 0.5%). Then from 1820 to 1913, as the industrialised world adopted the steam engine fuelled by coal, the GDP growth rose to 2.5%, the population growth was 0.5 to 1.0%, and capital growth was 1.2 to 2.6%. Study Table 1.1 for average annual percentage rates of change of world energy consumption and population from 1925 to 1972.

Table 1.1: Average annual percentage rates of change of world energy consumption and population from 1925 to 1972

	Total Energy Consumption	Population	Energy Consumption per capita
1925-1950	2.2	1.1	1.1
1950-1955	5.3	1.7	3.6
1955-1960	4.5	1.9	2.5
1960-1965	5.3	1.9	3.4
1965-1970	5.9	1.9	3.9
1970-1972	5.2	1.9	3.2
1950-1972	5.3	1.8	3.4

Source: International Energy Outlook, 2000

In the period from 1950 to 1973 when the world turned to extremely cheap petroleum, GDP growth rates doubled to around 5%. Then after petroleum prices rose dramatically between 1973 and 1979 and the world returned to coal and nuclear fuels in addition to petroleum, GDP growth rates decreased to 2-2.5% per annum (see Table 1.2).

Table 1.2: GDP growth rates of selected countries

Country	1700-1760	1760-1820	1820-1850	1850-1913	1913-1950	1950-1973	1973-1995
Austria				2.05	0.25	5.40	2.4
Belgium			2.74	2.18	1.02	4.11	2.0
Denmark			1.98	2.38	2.35	3.99	1.9
France	0.36	0.74	1.69	1.46	1.02	5.12	2.2
Italy				1.37	1.44	5.49	2.7
Germany			2.00	2.57	1.30	6.00	2.10
Japan				2.45	1.81	9.68	3.8
Sweden				2.74	2.80	3.77	1.4
UK	0.58	1.53	2.40	2.02	1.30	2.97	1.8
USA			4.59	4.13	2.80	3.72	2.4
Mean			2.57	2.34	1.61	5.03	2.98

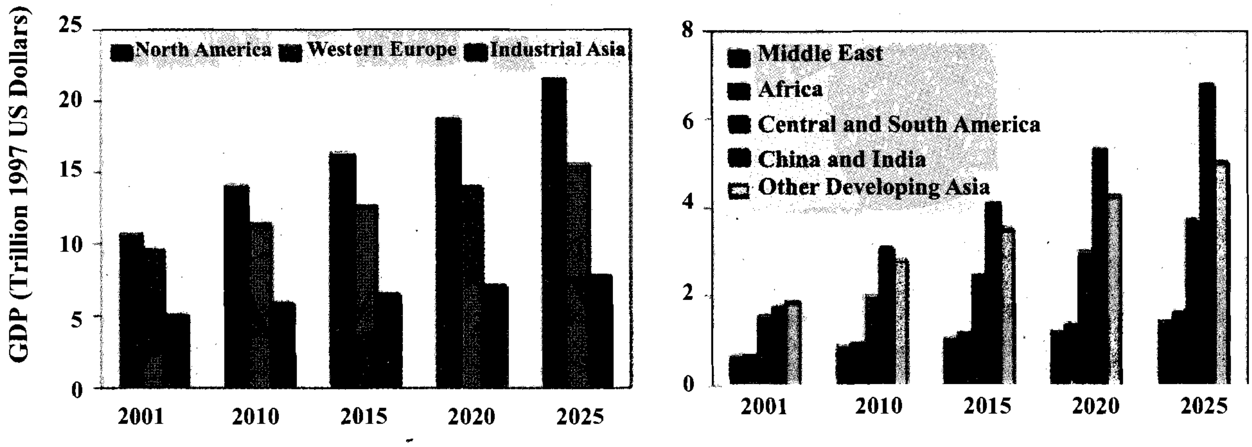


Fig.1.1: The GDP of the industrialised and the developing world by region from 2001 to 2025 (Source: International Energy Outlook, 2004)

SAQ 1

Study Tables 1.1 and 1.2 and answer the following questions:

a) What is the relationship between the population growth rate and energy consumption?

b) Explain the drop in Japan's growth rate from a high of 9.68 percent in the period 1950-73 to 3.8 percent in the period 1973-95.

c) Compare the future trends in GDP growth of North America, Western Europe, China and India. What implications does this economic growth have for energy demand and supply in these countries?

It is postulated in energy economics that low energy prices stimulate economic growth. However, if economic growth rates higher than population growth rates are desired, nations should adopt a policy of promoting the supply of energy sources at the lowest possible prices.

Energy prices are determined to a large extent by supply and demand rates of new discoveries, inter-fuel competition, environmental considerations, government intervention, and rates of depletion.

Looking at the supply/demand equation for various energy resources available for consumption, it is clear that supply/reserves/resources are adequate to meet expected demand well into the next century (see Sec. 1.4). However, governments exercise an important influence on the energy sector, in general, and on energy prices, in particular. Ensuring an adequate supply of energy remains the prime responsibility of the energy industries.

The energy sector – given its holistic importance for the economy – has traditionally been a sector of strong government involvement. Governments intervene in the energy sector for a variety of reasons and in a variety of ways. Many instances and types of intervention are explicitly designed or intended to support energy policy goals and are specific to the energy production and supply industries or to the use of energy. Other actions, designed to support broader economic, political or social objectives, also affect the supply and use of energy amongst a range of goods and services.

In practice, because the role of energy is an essential input to most economic and human activity, almost all government actions impinge on the energy supply and demand in one way or the other.

There is a vast range of measures that governments use in the pursuit of energy policy goals. These measures can be broadly classified into five main groupings:

- Economic and fiscal instruments,
- Trade instruments,
- Government administration, management and ownership,
- Energy sector regulation, and
- Energy Research and Development (R&D).

Governments can use these measures to tax or subsidise the use of energy sources and can, by these actions, encourage or discourage the use of specific fuels.

Based on the above consideration there could be two kinds of energy policies:

- one for developed countries with high standards of living and reasonably stable populations, and
- another for the developing and underdeveloped nations.

In the developed nations, major problems associated with energy consumption revolve around air pollution, global warming and traffic congestion. In the less developed and developing world obviously a policy of cheap, freely available energy should be followed. In particular, the expansion of electricity grids and gas pipeline systems should be encouraged. You will learn about these issues in detail in Unit 6 on Energy Policy.

Energy is one of the sectors of the economy where traditionally governments are most heavily involved. Many of the instruments of government intervention affect the final prices of energy to the consumer. The point to emphasise here is that policy measures by governments, which affect the final price of energy, will ultimately have a significant impact on economic growth and development. It is, therefore, imperative to understand and work for environment friendly energy efficient sustainable economies. For this, you need to understand the impact of population growth and industrialisation on energy demand, which is the subject of the next section.

1.3 ENERGY DEMAND DUE TO POPULATION GROWTH AND INDUSTRIALISATION

You have learnt in Block 4 of the course MED-001 about the trends in human population growth. The population of the developing world is predicted to increase from its current value of four billion to over eight billion by 2050, at which time it will comprise almost ninety percent of the world population. Population growth is one of the factors which drive the world-wide energy demand, especially the demand for electricity.

1.3.1 Energy Demand vis-à-vis Population Growth

The two main factors which will lead to greatly increased world-wide demand for energy (especially electricity) during the next half-century are:

- population growth, and
- per capita economic growth in the less-developed countries.

Let us explain this further. Currently, the average person in the less-developed countries consumes only one sixth of the energy consumed by an average person in Western Europe or Japan (see Fig. 1.2).

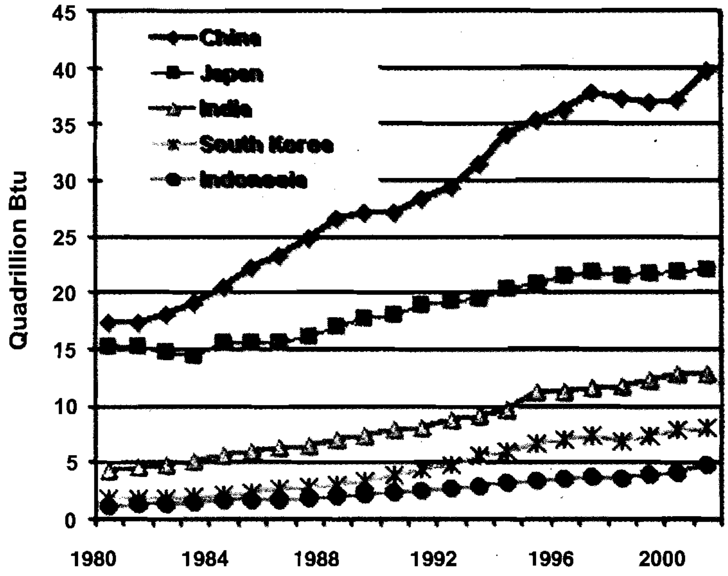
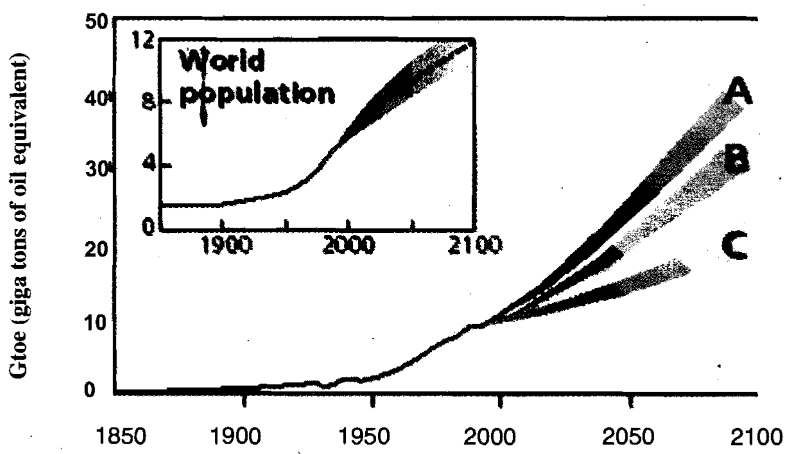


Fig.1.2: Energy consumption in selected Asian countries 1980-2001 (Source: eia.doe.gov)

Doubling of per capita energy consumption in the less developed countries over the next 50 years would correspond to only a very modest degree of economic development. Yet, combined with the predicted population increase, it would lead to a two to three-fold increase in world energy consumption.

The actual increase in demand may be expected to be even greater. For example, there will be an increased demand from economic growth in the developed as well as developing countries. Improvements will undoubtedly occur in the efficiency of energy utilisation, but in the face of the expected increases in demand, these could only have relatively minor impact (see Fig. 1.3).



A: High growth presents a future of impressive technological improvements and high economic growth.

B. Middle course describes a future witnessed through perhaps more realistic technological improvements and more intermediate economic growth.

C. Ecologically driven growth presents a 'rich and green' future.

Fig.1.3: World population and global primary energy use projections to 2100. Notice that at present the world uses roughly 9 gtoe worth of energy per year

1.3.2 Energy Demand in Industrialisation

The changing structure of production and consumption accompanying the process of development are important in determining the growth and composition of end-use energy demand. As an economy develops, it undergoes a series of structural changes. During the initial stages of economic growth, the share of agriculture in total output falls and the share of industry rises. This is the industrialisation phase of development. In the later stages of development, the demand for services begins to increase rapidly, increasing its share of GDP. This latter stage is often referred to as the 'post-industrialised' society.

The growth of heavy industry (infrastructure development) during the industrialisation phase leads to enormous increases in energy consumption. Accordingly, the **energy intensity** of GDP (**defined as energy input per dollar of GDP**) increases as the share of industry in GDP increases. As development continues, however, the demand for financial services, communications, transportation, and consumer goods (light manufacturing) grows rapidly. As a result, the share of services and consumer goods increases, eventually accounting for over one-half of total output. Light industry (involved in the production of consumer goods) and services require less energy input per unit output than heavy industry. This leads to a reduction in overall energy intensity, i.e., the energy input per unit output (see Fig. 1.4).

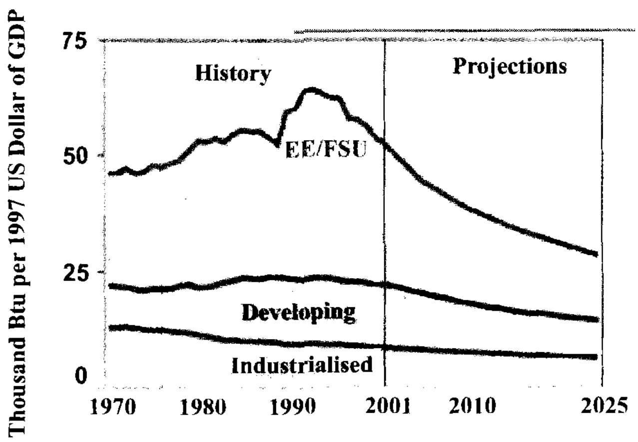


Fig.1.4: World energy intensity by region 1970-2020 (Source: IEO 2004)

Although economic development leads to declining growth rates of per capita energy demand in the industrial sector, there is substantial growth in energy demand in the transportation, residential and commercial sectors.

Fig.1.5: An illustration of energy consumption in the developed world (Picture credit: Ms. Shruti Vidyarthi)

As per capita incomes rise, consumers devote a larger proportion of their income to the purchase of durable goods such as air-conditioners, heaters, refrigerators, and automobiles. Since these items require some energy input to produce a flow of services, energy demand increases. The growth of energy demand in these sectors, however, slows as incomes continue to rise because there is a limit to which energy can be consumed for transport, residential and commercial uses. Thus, there exists a saturation effect in the demand for services that require energy input.

In a recent study of the effect of economic development on end-use energy demand, it was found that **energy demand grows at different rates in different, broadly-defined, end-use sectors (industrial, transport, residential** and **commercial)**. Specifically, it was found that per capita industrial energy demand rises very rapidly at the onset of development, accounting for the maximum energy use. The growth of energy demand in industry, however, quickly declines, and energy use in the other sectors eventually takes a majority share of total end-use energy consumption. In fact, energy demand in the transportation sector continues to grow well into the post-industrial phase of development, accounting for more than half of all energy use. A simulation of energy demand by sector for an average country based on these results is depicted in Fig. 1.6.

Given these patterns of development, we can expect energy demand in transport to acquire an increasing share of the energy consumption in the developed countries. The trends evident in Fig. 1.6, however, represent average global trends. They do not necessarily hold for any one country. It is, therefore, important to consider this, when making inferences about the future energy needs for any single country.

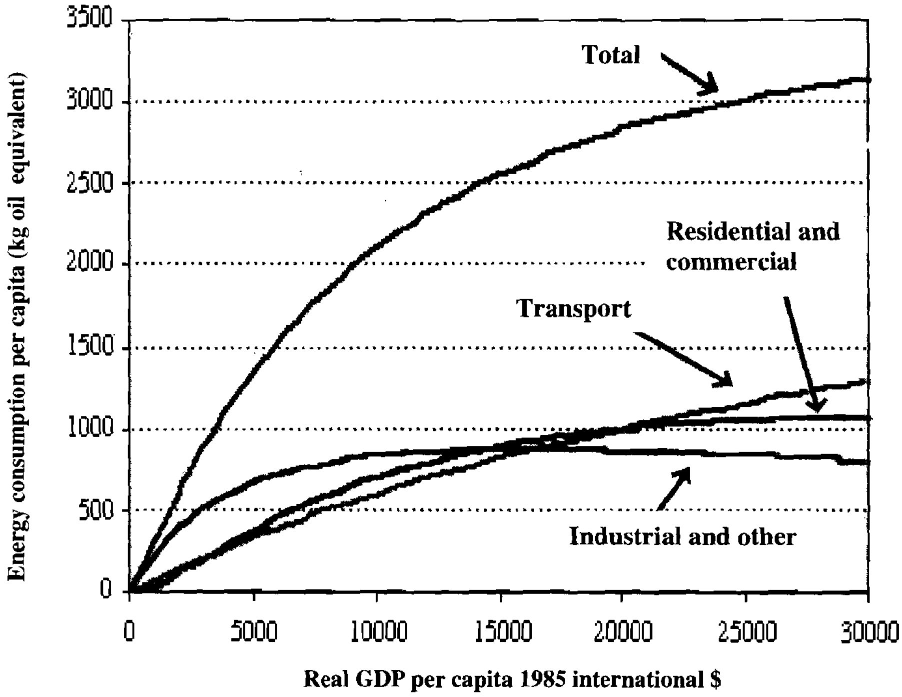


Fig.1.6: Simulated per capita end-use energy demand

1.3.3 Energy Demand in Asian Developing Economies

Developing countries are playing an increasingly important role in the world energy markets, and their consumption of commercial energy has increased substantially over the past two decades. The increase has been particularly pronounced among the developing countries of East Asia and Southeast Asia and is expected to continue into the next century. However, the quantum of future energy demand by these lower-middle-income countries will depend on a host of factors, such as:

- the expected income levels,
- real energy prices,
- the continuing trend away from traditional non-commercial energy sources to commercial fuels, and

- the speed of shift toward energy-intensive activities due to urbanisation and industrialisation, increased motorisation, and household use of electrical appliances.

The growing concerns about the environment and the global nature of environmental problems have focused attention on the pattern and trend of energy demand in the developing economies. More than half of the total carbon dioxide emissions originate in the energy sector, and a large and increasing share of the flow of emissions in future will be from lower-middle-income countries. A detailed analysis of energy demand and the possibilities of inter-fuel substitution in the major coal-producing countries, such as China and India, is very important. This is needed for a better understanding of global environmental problems and the energy needs of these economies. For a complete understanding, we also need to have an idea about the available energy resources. This is what you will learn in the next section. But first attempt this exercise.

SAQ 2

Discuss the trends in energy consumption from the 1950s onwards. How did the growth in population influence these trends?

1.4 THE EARTH'S ENERGY RESOURCE BASE

The main sources of energy available on the Earth are solar and nuclear energy, with energy from other sources being negligible in comparison. All practical sources of mechanical energy found on the Earth derive their energy originally from sunlight. These sources of energy are: **hydro energy, wind energy, tidal energy, seismic energy,** and **geothermal energy**. We now discuss each one of these briefly. In this section, we shall be using terms like ergs, joules, watts, megawatts or MW. If you do not know them, refer to Section 2.2 of Unit 2.

Energy is measured in units of joules or ergs.

1 joule = 10^5 ergs.

Solar Energy

You have learnt in the course MED-001 that the Sun is the main source of energy available on the Earth. Most of the usual sources of energy on the Earth are derived directly or indirectly from sunlight, such as the energy in wood, coal, gas, wind, river currents, fossil and water vapour. The energy from the Sun collected per unit time by a unit area at the outer surface of the Earth's atmosphere (in a plane perpendicular to the light path) is 1.40×10^6 ergs/cm^2/ s. It is called the **solar constant**. The entire area of the Earth intercepts 1.78×10^{24} ergs/s of this energy.

About 35 % of incident solar energy is reflected back into space as visible light. About 12 % is absorbed in the Earth's atmosphere on the average and is converted into thermal energy. The total energy falling on the ground per second is about 9.44×10^{23} ergs/s. You can appreciate that this is a large quantity of energy by noting that it can provide 23,600 kilowatts of sunlight per person for a world population of 4 billion. Compare this number with your average consumption of energy per day and calculate the number of days it will last for you. The Sun is not only the source of solar energy. It drives other useful sources, which we take up now.

The Sources of Mechanical Energy

All practical sources of mechanical energy found on the Earth derive their energy originally from sunlight. These sources of energy are: hydro energy, wind energy, tidal energy, seismic energy, geothermal energy, etc. The gravitational energy released by water flowing from higher to lower level is used in dams to generate energy. As you know, the use of electric generators and power lines has enabled the harnessing of a large amount of hydropower.

Wind Energy

Wind has been used since ancient times for the transportation of both people and goods across water bodies in sail boats. This utilisation of a mechanical source of energy to transport goods was a major stride forward in the evolution of the economic system. It provided human beings with the capacity to maintain order at a level far above anything known before. Wind mills were probably used as early as 1000 AD. By the thirteenth century, windmills had become fairly common. Wind mills were used to grind grain and lift water. Holland's famous wind mills made it possible to recover areas of fertile land from the sea. Lately, wind mills have been largely replaced by gasoline engines or electric motors.

Tidal Energy

Generating technologies for deriving electrical power from the ocean include tidal power, wave power, ocean thermal energy conversion, ocean currents, ocean winds and salinity gradients. Of these, the three most well-developed technologies are **tidal power**, **wave power** and **ocean thermal energy conversion**.

Wave energy conversion takes advantage of the ocean waves caused primarily by interaction of winds with the ocean surface. Wave energy is an irregular and oscillating low-frequency energy source that must be converted to a 60-Hertz frequency for linking with the electric utility grid.

Although many wave energy based devices have been invented, only a small proportion of these have been tested and evaluated. Further, only a few have been tested at sea and in ocean waves, rather than in artificial wave tanks.

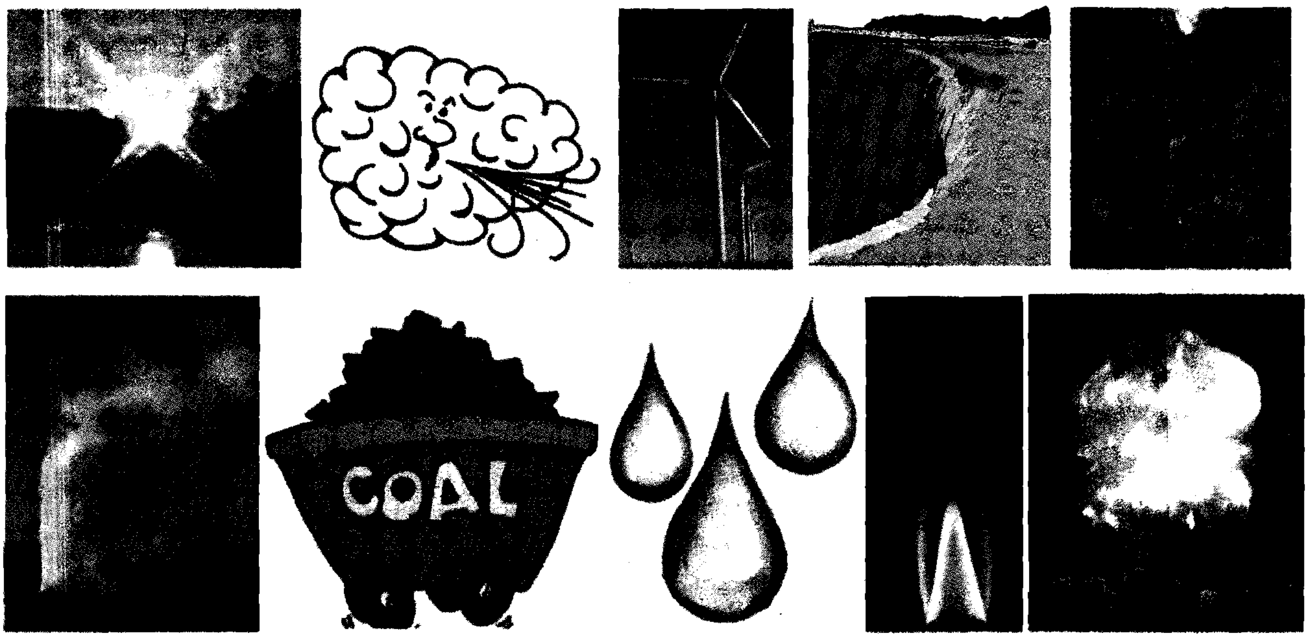


Fig.1.7: The energy resource base of the Earth

Geothermal Energy

When the Earth's surface buckles and folds or shifts longitudinally along a fault, the seismic energy may be converted into the thermal energy. The thermal energy thus developed may produce hot spots, molten rocks and volcanoes along such Earth's faults or folds. Because of the very low thermal conductivity of most rocks, volcanic heat may accumulate over the ages. Thus a considerable amount of geothermal energy may accumulate in a localised region of the Earth's crust.

Practical sources of volcanic heat usually depend upon naturally occurring hot springs, geysers or holes that eject steam under pressure. The hot water releasing from such wells comes from underground channels that establish a large area of contact with hot volcanic rocks below the surface.

At present, geothermal energy is being converted to electric power at four sites: Larderllo, Italy (since 1904) where 372 MW of electric power is being generated; Wairakei, New Zealand (since 1958) where 192 MW of electric power is being generated; Geysers, California (since 1960) with 82 MW and Japan (since 1968) with 31 MW. Iceland has plans for the utilisation of its abundant supply of geothermal energy for the development of electric power. There are a few other sites that might eventually be utilised for geothermal energy, but the power potentially available from all such sites is quite small when compared to other sources of power.

Chemical Energy in Fossil Fuels

While most of the carbon in an ecosystem is recycled, there can be a small rate of deposition of detritus in a reducing environment that can accumulate over the ages to form large fossil deposits. You have studied about this in MED-001. These deposits contain a large amount of chemical energy in the form of coal, oil, natural gas, etc.

Oil

Petroleum has been used since ancient times for space heating, cooking and lighting. The Chinese were drilling oil wells as early 1000 B.C. It is only recently, however, that energy from oil has been extensively converted to useful work. Oil yields about one third of the total raw energy produced in the world today for a rate of supply equal to 229×10^{10} watts.

The total reserves of oil in the ground are limited and the available oil will be consumed eventually. According to usual estimates, the total reserves of oil amount to about 1.2×10^{29} ergs of energy. At the rate of present use of oil, the Earth's oil reserves would last for just about two hundred years.

Coal

Coal was first mined and used in China around 1100 B.C. The early use of coal was in making ceramics, metallurgy, space heating and cooking. Nowadays coal is used extensively as fuel and in thermal power plants. The total reserves of recoverable coal in the ground are quite large, but still finite. So eventually, the supply of coal will be exhausted.

Natural Gas

The world produces 3.38×10^{26} ergs of energy in natural gas at a rate of 107×10^{10} watts. About 17% of this energy goes into producing electricity at an efficiency of about 30%. The total world reserves are estimated to be about 1.1×10^{29} ergs, about the same as the total oil reserves. So at the present rate of consumption, natural gas would last for about three hundred years.

Oil Shale

Although the total energy content in the Earth's reserve oil shale may be estimated at about 2×10^{29} ergs, much less than one-tenth can be extracted, since a large amount of energy is needed to obtain the oil from shale. Due to the cost of mining and extracting oil from the shale, oil shales will not be extensively exploited until the world's oil reserves become largely depleted.

Peat

Peat is currently consumed on a small scale, particularly for space heating. The total reserve energy in peat is about 1% of the reserve energy in coal. At the present rate of accumulation of peat, about 48×10^{10} watts of power are continuously available.

Nuclear Energy

Nuclear energy arises from the conversion of mass to energy, according to Einstein's mass energy equivalence principle $E= mc^2$. Here $c = 3.00\times 10^8$ m/s is the speed of light. The two sources of nuclear energy are: **nuclear fission** and **nuclear fusion**.

Nuclear fission occurs when the nucleus of a large atom – in particular uranium 235, plutonium 239 or uranium 233 – splits into nuclei of approximately equal masses. The total mass of the two fragments is less than the mass of the original nucleus. The deficiency in mass is released as energy. The total energy released in the fission of one uranium 235 nucleus is 190 MeV or 317×10^{-13} joules. 1 gram of Uranium 235 can yield about 8×10^{10} joules of energy.

The **fusion** of light atomic nuclei into heavier nuclei also results in a net loss of mass with a resulting release of energy. The Sun and stars obtain their energy from the fusion of light elements, especially hydrogen.

While controlled nuclear fission has been used to obtain energy in nuclear reactors, controlled thermonuclear fusion reaction has not yet been attained. The rare, expensive and radioactive (half-life of 12.5 years) tritium can be fused with deuterium at about 30 million degrees temperature, while the cheap plentiful deuterium can be fused with itself at about 300 million degrees. At such high temperatures, there are several technological problems yet to be overcome. But once this happens, we will have a cheap and everlasting source of energy. However, a word of caution may not be out of context here. There are a host of safety and environmental issues involved in the use of nuclear technologies for energy generation. You have read about some of the risks involved in the course MED-001. We will revisit these issues in Unit 4.

Fig. 1.8 shows the shares of various fuels in the total energy consumption in India in 2000.

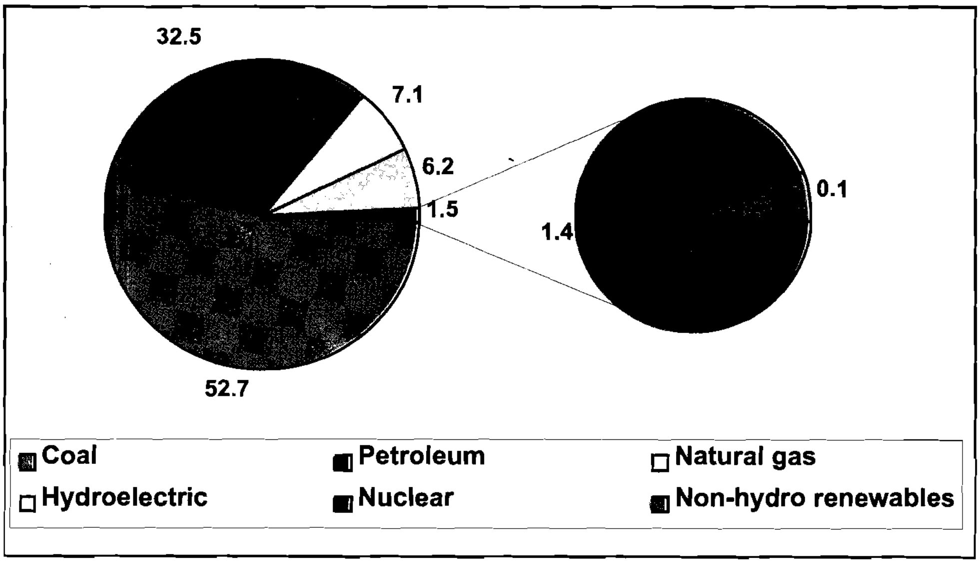


Fig.1.8: India's fuel share of energy consumption, 2000

You may now like to try an exercise to consolidate these ideas.

SAQ 3

Make a comparative chart of the amount of energy that can be tapped from various energy resources available in the world. Also mention how long each of the non-renewable energy resources is estimated to last at the current consumption trends. What suggestions can you give about the sustainable use of energy?

Resource potential and its availability is only one dimension of the energy base of the Earth. The carrying capacity of the Earth's resource base will actually determine how this resource base can support the human population.

We, as human beings are unique in our ability to modify the environment and to improve technology for food and energy production. These unique abilities combined with the inherent social nature of humans complicate the estimation of the human carrying capacity of the planet. We now discuss this aspect of energy and development.

1.5 THE CARRYING CAPACITY OF THE EARTH'S ENERGY BASE

You have learnt in MED-001 that the carrying capacity of an ecosystem is defined as the maximum population size of a species that an area can support without reducing its ability to support the same species in the future. Biological studies of population change typically demonstrate that once the carrying capacity of an ecosystem is exceeded, a severe crash or collapse of the population follows and is associated with rapid environmental degradation.

According to the United Nations Population Fund's (UNFPA) latest population report, the world population has doubled since 1960 to 6.1 billion people and is projected to increase to 9.3 billion by 2050. Along with the increase in the number of people, there is an associated increase in the demand placed on the resources of the Earth. This affects the carrying capacity of the Earth.

The long-term sustainable carrying capacity for the human species on the Earth varies with resource availability as well as culture and level of economic development. Thus, two measures of human carrying capacity arise:

- the biophysical carrying capacity, and
- the social carrying capacity.

The **biophysical carrying capacity** is the maximum population that can be supported by the resources of the planet at a given level of technology.

The **social carrying capacity** is the sustainable biophysical carrying capacity within a given social organisation, including patterns of consumption and trade.

The social carrying capacity therefore must be less than the biophysical carrying capacity as it will account for the quality of life. Besides, it can give us an estimate of the number of humans that can be supported in a sustainable manner at a **given standard of living**.

The amount of energy consumed per person per year is a useful measure of the standard of living. Per capita energy consumption is measured in kW/person and includes industrial uses, transportation, domestic uses, clothing, electronic entertainment, vacations, food production, etc. Currently there exists an extreme dichotomy in the level of energy consumption between the US, other developed countries and developing countries.

You can see this in Fig. 1.9 that depicts per capita energy consumption in different regions of the world in the year 1995. Notice that the North American per capita energy use was more than twice that of Europeans, more than 10 times that of Asians and more than 25 times that of Africans. Needless to say, these disparities have not been reduced.

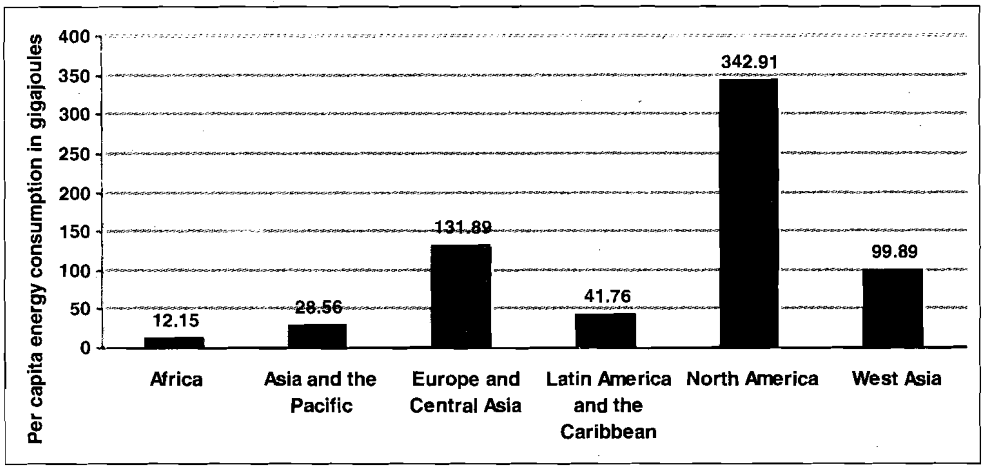


Fig.1.9: Energy consumption per capita in different regions of the world in the year 1995

In order to estimate the human population that can be sustained by the Earth, a standard of living or level of consumption must be selected or assumed. At this point, the introduction of social issues becomes important. For instance, very high global population could be supported at a very low level of food consumption, perhaps even on the brink of starvation. The result, however, could be a socially unstable situation. **A socially sustainable carrying capacity must be based on a level of consumption that meets basic human needs of food, water and space as well as provides opportunity to enjoy socio-political rights, health, education and well-being.** Another important aspect of social sustainability is equitable distribution of resources. Inequitable distribution of wealth can lead to social instability and disruption.

Estimating Sustainable Carrying Capacity

The basic resources of the planet, such as land, water, energy and *biota* are inherently limited. **Selection of one or several of these limited resources as a metric for measuring the carrying capacity of the planet is a common method of estimating global human carrying capacity**.

The use of a single resource or combination of limited resources to estimate carrying capacity includes measuring how much of that resource is available globally. For instance, global wheat harvest capacity can be estimated based on land area and water availability. It can then be used to compute the number of humans that those quantities can support.

Resource use must also be differentiated between renewable and non-renewable resources (see Table 1.3) for estimation of global carrying capacity. You know that renewable resources are driven primarily by solar energy and are regenerated through natural processes. Non-renewable resources are those with limited quantities and very low or no renewal rates. Long-term use of non-renewable resources is generally not sustainable, though some of these are renewable at reasonable rates of consumption. **A socially sustainable global carrying capacity must be based on the use of renewable resources, possibly supplemented by very low consumption of non-renewable resources**.

Recent estimates by the World Energy Council suggest that one-third of the world's oil reserves have been used and that the remainder will be significantly depleted by the end of the 21st century if current rates of consumption continue. Other studies suggest that declines in oil production will occur as early as 2010. Other non-renewable energy sources, such as coal and natural gas, will supplement as oil production potentially declines; however, these sources are also not sustainable over the long-term.

Table 1.3: Renewable and non-renewable resources

Renewable Resources	Non-renewable Resources
Solar energy (drives wind, hydropower) Freshwater Some soil used for agriculture Wood for construction Some animal species (e.g., animals for transport, insulin and vaccines)	Energy sources (e.g., oil, coal, natural gas, nuclear) Stratospheric ozone Tropical forests Biodiversity Minerals (e.g., diamonds, gold, iron)

Changes in available technology for energy and food production and distribution, and waste disposal also impact the resulting carrying capacity estimate. Of course, the advancements in fertilising agricultural land lead to increased food production, and allow for greater population growth. Some estimates of carrying capacity account for future improvement in technology, and other estimates presume that the level of technological development remains the same.

Energy Inputs

Energy availability is a useful metric that can be used to estimate carrying capacity because it can account for many different resources. Energy from the Sun is the driving force of the Earth's ecosystems. You have studied in MED-001, how solar energy generates atmospheric processes that provide wind energy and fresh water. Plants, trees, food crops, and animals all require energy from the Sun. The balance of energy consumption and production can be used to estimate the number of humans that the planet is capable of supporting in a sustainable manner.

The total amount of energy input by the Sun to the Earth is finite and can be estimated. When that energy is divided amongst the entire Earth ecosystem, it is possible to estimate at a given level of consumption, as to how many humans can be supported on the Earth. The resulting estimate is a sustainable number because it does not rely on non-renewable energy sources. Currently, about 50% of all the solar energy captured by photosynthesis is used by humans. On its own, solar energy cannot support the present human population without supplementation by non-renewable energy sources, such as fossil fuels.

Land Area

Land area can be used in different ways to estimate carrying capacity, either as a metric for other resource uses or as a measure itself. The simplest way of using land area to compute carrying capacity is to presume a population density for a given area and compute the total number of people that the region can support. Another method, the **ecological footprint** concept, uses land area as a metric for a combination of other factors. Ecological footprint takes many different resource uses and measures them by the equivalent amount of land area required for their production. The ecological footprint describes how much land is necessary to support a given population in terms of energy, food, and other resources at a certain level of consumption. The result is that developed/rich countries with high levels of resource consumption have much larger footprints than the land they actually occupy.

Food Production

Estimates of carrying capacity using food as a metric determine the total amount of food that can be produced globally and divide by a standard level of food consumption per person. The result is a global population that can be supported at a given level of subsistence assuming that food is equitably distributed around the globe. More complex methods consider changes in crop yield with increased technology, food distribution, varied world diets, and other resource supply, such as fossil fuels.

SAQ 4

List the parameters, which can be used as metrics to estimate the carrying capacity of the Earth. Explain how energy availability is used as a metric for this purpose.

Recent Carrying Capacity Estimates

When one considers the array of factors that must be estimated and the conditions that must be assumed, it is unrealistic to expect a unique figure defining the Earth's human carrying capacity. Professor Joel Cohen in his 1995 book, "How Many People can the Earth Support?" summarised estimates of human carrying capacity of the Earth beginning with estimates made as early as the 1600s. His summary is not limited to estimates that are considered socially sustainable as he includes estimates that consider only biophysical parameters.

A sustainable population of humans on the Earth implies reliance on renewable energy sources combined with socially sustainable standards of living. The standard of living and carrying capacity are inversely related. This means that as the standard of living decreases, the number of people that can be supported on the Earth increases. The current global population of 6.1 billion people exceeds the median range of socially and biophysically sustainable carrying capacity. This is made possible by consumption of non-renewable energy sources, such as fossil fuels as well as inequities in global distribution of food and energy consumption.

Energy is a useful metric for estimating carrying capacity because it can be used to estimate available renewable energy from the Sun as well as the standard of living based on energy consumption. Solar energy is the primary source of renewable energy on the Earth as it generates atmospheric processes as well as food and forest resources. Per capita energy consumption can be used to estimate resource use that defines human standards of living, including food, transportation, manufacturing, heating and cooling, housing, etc.

To sum up, the estimation of the carrying capacity of the Earth is a difficult task involving value-based decisions and assumptions. Whether the future of the Earth will have a dense population of humans with reduced biodiversity and degraded environmental qualities or a smaller human population living in a sustainable manner on diverse resource base, remains to be seen. However, current levels of energy consumption and the impending depletion of non-renewable energy sources point towards the necessity for a change in either population growth or consumption trends if the human race is to survive at anything close to its current level of subsistence. You will learn about the energy consumption patterns in the next unit. Let us now summarise what you have studied in this unit.

1.6 SUMMARY

- **Cost** and **availability** of energy at the point of usage, is a major factor in the growth of GDP. Low energy prices stimulate economic growth; nations should adopt a policy of promoting the supply of energy sources at the lowest possible prices. In the undeveloped and developing world a policy of cheap, freely available energy should be followed, in particular, for electricity grids and gas pipelines.

- Two main factors which will lead to greatly increased world-wide demand for energy (especially electricity) during the next half-century are: **population growth** and **per capita economic growth in the less-developed countries**. The predicted population increase would lead to a two to threefold increase in world energy consumption. The actual increase in demand may be expected to be even greater.

- The growth of heavy industry (infrastructure development) during the industrialisation phase leads to enormous increases in energy consumption. Accordingly, the **energy intensity** (defined as energy input per dollar of GDP) increases as the share of industry in GDP increases. As the economies develop, the growth rates of per capita energy demand in the industrial sector decline. But there is substantial growth in energy demand in the transportation, residential and commercial sectors.

- The main **sources of energy** available on the Earth are solar and nuclear energy, energy from other sources being negligible in comparison. All practical sources of mechanical energy found on the Earth derive their energy originally from sunlight. These sources of energy are: **hydro energy, wind energy, tidal energy, seismic energy, geothermal energy**, etc. While most of the carbon in an ecosystem is recycled, there can be a small rate of deposition of detritus in a reducing environment that can accumulate over the ages to form large fossil deposits. These are: **oil, coal, natural gas, oil shale and peat**. Two sources of nuclear energy are predominant: **nuclear fission** and **nuclear fusion**.

- The **carrying capacity** of an ecosystem is defined as the maximum population size of a species that an area can support without reducing its ability to support the same species in the future. The long-term sustainable carrying capacity for the human species on the Earth varies with resource availability as well as culture and level of economic development.

- Two measures of carrying capacity are: the **biophysical carrying capacity** and the **social carrying capacity**. The social carrying capacity is the sustainable biophysical carrying capacity within a given social organisation, including patterns of consumption and trade.

- The basic resources of the planet, such as land, water, energy and biota are inherently limited. A **socially sustainable global carrying capacity** must be based on the use of renewable resources, possibly supplemented by very low consumption of non-renewable resources.

- Energy is a useful **metric for estimating carrying capacity** because it can be used to estimate available renewable energy from the sun as well as standard of living based on energy consumption.

1.7 TERMINAL QUESTIONS

1. Discuss the role of energy in the economic growth of developing countries. How do policy measures adopted by governments affect energy use in a country?

2. Explain how the end-use energy demand varies with the changes in production and consumption as an economy develops.

3. Describe the features of energy demand in Asian developing countries.

4. Given the energy resource base of the Earth, what energy options are available to developing economies of the world?

5. Explain how the carrying capacity of the Earth can be estimated using various parameters. Outline the basis of a socially sustainable global carrying capacity.