

For example if $T_o = 273 + 127 = 400^\circ\text{K}$ ie the input temperature is 127°C and $T = 273 + 27 = 300^\circ\text{K}$, ie the output temperature is 27°C

$$\epsilon_i = 1 - \frac{300}{400} = 0.25, \text{ and efficiency is } 25\%$$

In practice, due to friction and other losses the efficiency of thermal machines is lower than the maximum value.

Second-law efficiency

There are often different methods of performing the same task, for example, heating a living space. Let us assume that this is done by delivering an amount of heat Q to a building at 30°C by a gas furnace which has an efficiency of 60%. The same task can be done by a heat pump (a Carnot cycle run in reverse) capable of extracting a quantity of heat Q from the atmosphere using work W delivered by a motor. The theoretical minimum energy consumption W of the heat pump is

$$W = Q \left(1 - \frac{T}{T_o}\right)$$

If the outdoor temperature is 5°C

$$T = 273 + 5 = 278^\circ\text{K} \text{ and } T_o = 273 + 30 = 303^\circ\text{K}$$

then

$$W = Q \left(1 - \frac{278}{303}\right) = \frac{Q}{12}$$

Using the furnace for the same task, the amount of heat necessary would be Q_o . A new efficiency can then be defined as

$$\epsilon_{ii} = \frac{\text{theoretical minimum energy consumption for a particular task}}{\text{actual energy consumption for a particular task}}$$

This is sometimes called the Second Law Efficiency. Thus

$$\epsilon_{ii} = \frac{W}{Q_o} = \frac{W}{Q} \frac{Q}{Q_o} = \frac{1}{12} \times 0.6 = 0.05$$

Source: Goldemberg, J, Johansson, T B, Reddy, A K N and Williams, R H, *Energy for a Sustainable World*, John Wiley and Sons, Chichester, UK (1988).

Chapter 3

Energy and Development

The aggregate monetary value of all goods and services produced in a year for a whole country or region is called the Gross National Product (GNP). Often another indicator is used – the Gross Domestic Product (GDP).¹

The GNP per capita is the average monetary value of goods and services, ie income available to each person in a given country.

$$\text{GNP/capita} = \frac{\text{GNP}}{\text{population}}$$

As it is an average, GNP/capita glosses over distributions of income, which are sometimes considerable. It is, however, an easily measured indicator and has come to be widely used by economists and planners as a proxy for *development*.

It is for this reason that the World Bank divides countries in three aggregates:

- high-income countries (annual GNP/capita above US\$ 6000);
- middle-income countries (annual GNP/capita between US\$ 651 and US\$ 6000); and
- low-income countries (annual GNP/capita below US\$ 650).

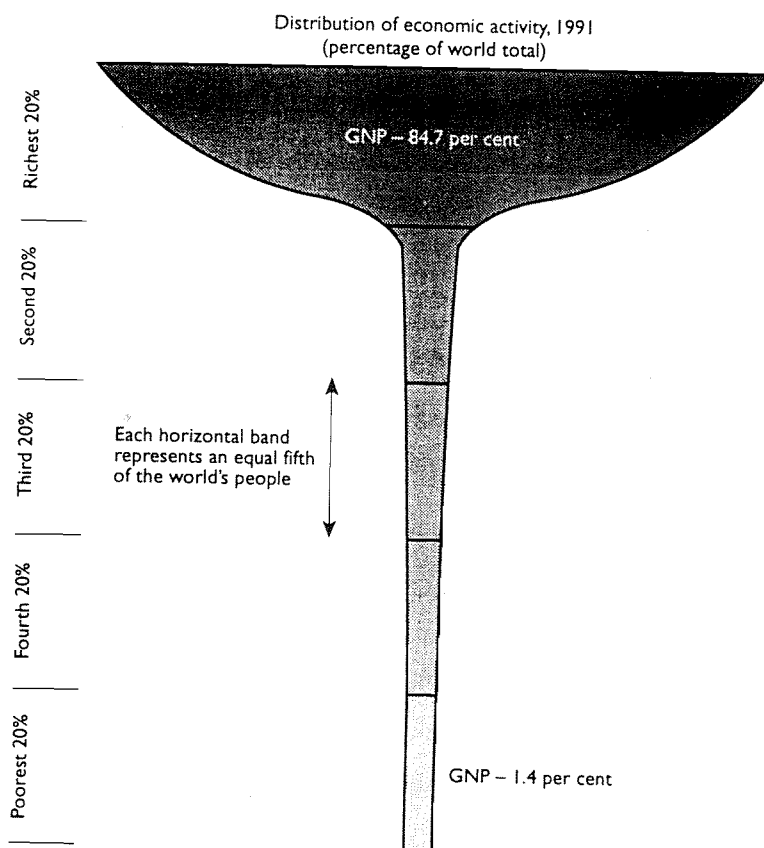
¹ The definitions of GDP and GNP are:

- Gross Domestic Product (GDP): the total output of goods and services for final use produced by an economy, by both residents and non-residents.
- Gross National Product (GNP): the total domestic and foreign value added claimed by residents, calculated without making deductions for depreciation. It comprises GDP plus net factor income from abroad, which is the income residents receive from abroad for factor services (labor and capital), less similar payments made to non-residents who contribute to the domestic economy.

A complete list of countries in each category is given in Appendix 3. A list of which countries are considered developing (LDCs) or industrialized is given in Appendix 4. In general, it is the high-income countries which are industrialized but East European countries, some of the Republics of the ex-Soviet Union and some middle-income countries are also included in this category.

Disparities in Income Distribution

GNP changes dramatically among countries as shown in Figure 3.1 in which countries are divided into five categories: those comprising the poorest fifth of the population represent 1.4 per cent of the world's GNP and the countries where the richest fifth live represent 84.7 per cent. Another way of displaying this type of information is through a Lorenz Curve Diagram (see Box on Global distribution of income).

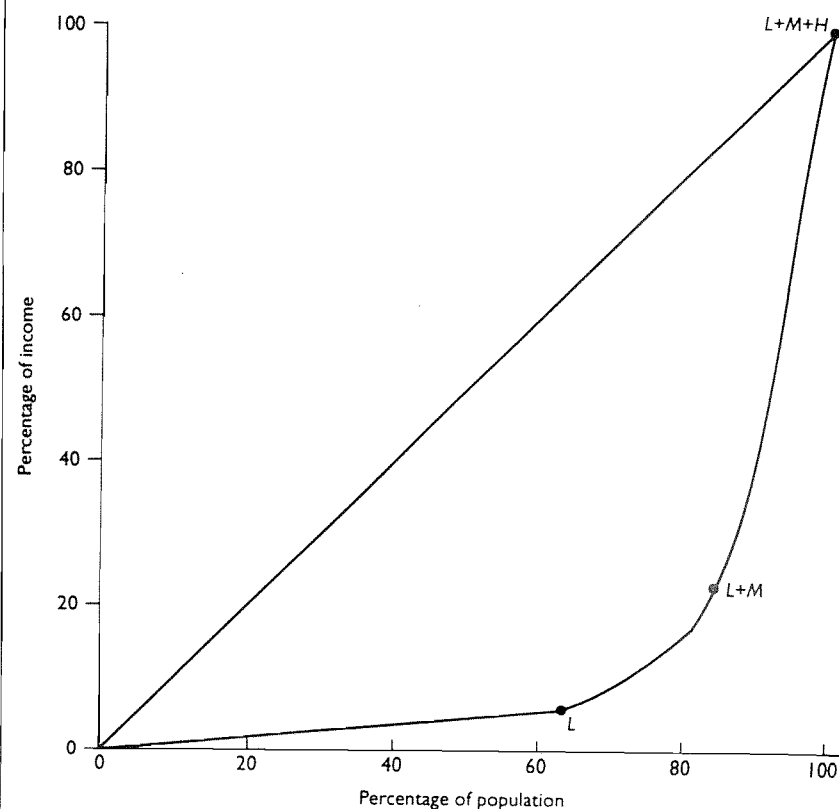


Source: UNDP, *Human Development Report*, Oxford University Press, Oxford, UK (1994).

Figure 3.1 Global economic disparities

Global distribution of income

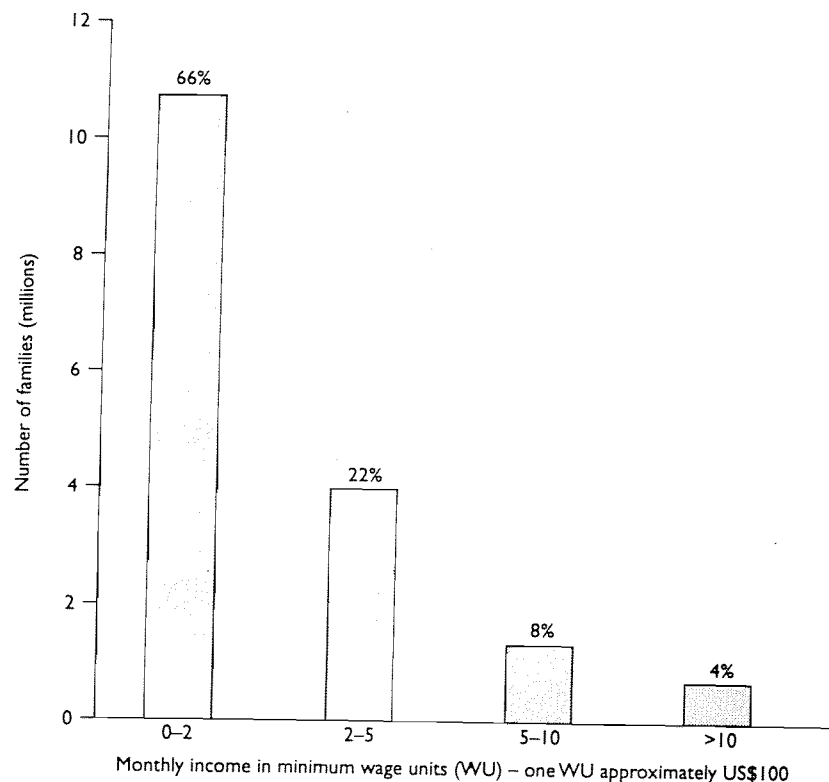
Figure 3.2 shows a Lorenz curve. If the income distribution was uniformly equal, 25 per cent of the world's population would have 25 per cent of the income, 50 per cent would have 50 per cent, and so on. The 45° line would represent this situation. The actual distribution is shown by the curved line, which is plotted by first indicating the low-income country share (L), then adding the middle-income shares (L+M), then adding the high-income shares (L+M+H). Clearly, the global distribution of income is skewed. Low-income countries have 61 per cent of the world's population but only 5 per cent of global income; middle-income countries have 23 and 13 per cent, respectively; while high-income countries have 17 and 82 per cent, respectively.



Source: Adapted from data contained in World Bank Reports, Washington DC, US.

Figure 3.2 Lorenz curve for income distribution

Even more striking than such global information is the disparity of income inside a given country. An example is given in Figure 3.3 for Brazil in 1970: 66 per cent of the population had a monthly income of between 0 and 2 wage units (WU), and 4 per cent above 10 units.



Source: Vanin, V R Graça, G M C and Goldemberg, J, *Ciencia e Cultura*, 33 (4), 477-486 (1981).

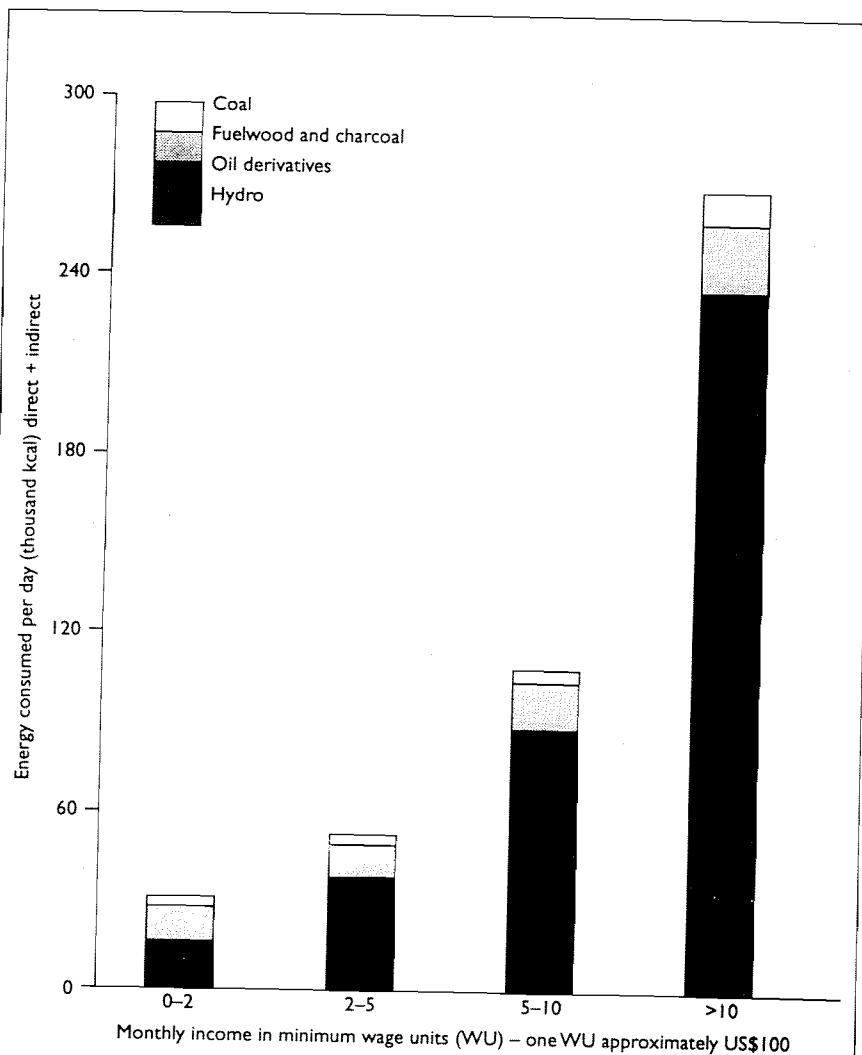
Figure 3.3 Number of families in different income brackets: Brazil 1970

The promotion of economic growth is the stated aim of any candidate to public office in developing countries and the performance of political leaders is judged by their success. Economic growth, however, cannot be measured by the income per capita in such countries because they are all dual societies, consisting of small islands of affluence surrounded by a sea of poverty. The élite minorities and the poor masses differ so much in their per capita incomes, needs, aspirations and ways of life that, for all practical purposes, they live in two separate worlds. Consequently, the élite and the poor differ fundamentally in their use of energy. The élite emulate the ways of life prevalent in industrialized countries and have similar patterns of luxury-oriented energy use. In contrast, poor people are preoccupied with finding enough energy for cooking and other essential activities.

For the poor, development means satisfying the basic human needs, including access to jobs, food, health services, education, housing, running water, sewage treatment, etc. The lack of access of the majority of people to such services is a fertile ground for political unrest, revolution, and the hopelessness and despair that lead to emigration to industrialized countries in search of a better future.

Much of the energy for agriculture, transportation and domestic activities in developing countries comes from human beings and draft animals. Other sources include biomass in the form of fuelwood, animal wastes and agricultural residues. Fuelwood, in fact, is the dominant source of energy in rural areas, and cooking is the most energy-intensive activity. These biological sources of energy are often described as 'non-commercial' because they are not the object of commercial transactions: in rural areas, the women and children usually gather twigs and branches for cooking fuel instead of buying wood.

Figure 3.4 shows as an example of how energy is consumed by different income/capita groups in Brazil. For families with income higher than 10 WU, oil derivatives represent 65 per cent of total energy consumption while for families between 0 and 2 WU they represent 35 per cent. On the other hand, for high-income families, fuelwood and charcoal represent 8 per cent while for poor families they represent 40 per cent.



Direct energy: Energy over which a person has direct control, such as driving an automobile, electricity, etc.

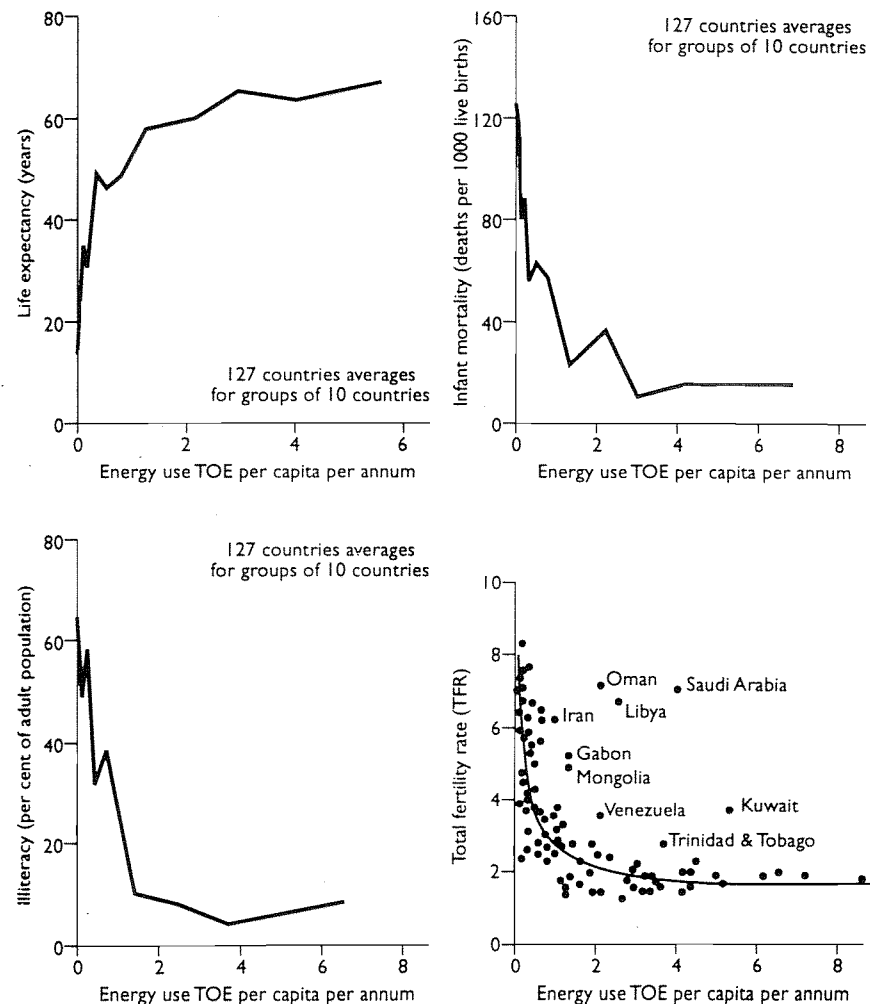
Indirect energy: Built into the products used and on which the person has no direct control of the amount consumed.

One half of the energy used is direct and the other half indirect. People with incomes between 0 and 2 wage units consume 20×10^3 kcal/day while people with income greater than 10 wage units consume 280×10^3 kcal/day, that is, 14 times more.

Source: Vanin, V R, Graça, G M C and Goldemberg, J, *Ciência e Cultura*, 33 (4), 477-486 (1981).

Figure 3.4 Total energy consumed per family: Brazil 1970

The importance of energy in development is illustrated in Figure 3.5, which shows four social indicators for a number of countries – illiteracy rate, infant mortality, life expectancy and total fertility rate – as a function of per capita commercial energy consumption.



Sources: World Energy Council, *Energy for Tomorrow's World*, Kogan Page Ltd, London, UK (1993) and Goldemberg, J, 'Energy for a Sustainable World Population', in Polunin, N and Nazim, M (eds), *Population and Global Security*, United Nations Population Fund (UNFPA), Geneva, Switzerland (1994).

Figure 3.5 Life expectancy, infant mortality, literacy and total fertility rate as a function of commercial energy consumption per capita

In the majority of the developing countries, where commercial energy consumption per capita is below 1 ton of oil equivalent (TOE) per year, illiteracy, infant mortality and total fertility rate are high, while life expectancy is low. Surpassing the 1 TOE/capita barrier seems, therefore, an important instrument for development and social change. A low energy consumption is not, of course, the only cause of poverty and underdevelopment but it is a good proxy for many of its causes, such as poor education, bad health care and the hardship imposed on women and children. As commercial energy consumption per capita increases to values of above 2 TOE (or higher) in industrialized countries, social conditions improve considerably. Average consumption per capita in OECD countries, in 1990, was about 5 TOE a year, as shown in Table 2.5.

Energy, in itself, is of little interest but it is an essential ingredient of socio-economic development and economic growth. The objective of the energy system is to provide energy services, for instance lighting, comfortable indoor temperature, refrigerated storage, transportation and appropriate temperatures for cooking. The energy chain to deliver these services begins with the collection or extraction of primary energy which, in one or several steps, is converted into energy carriers suitable for the end-use(s). These energy carriers are used in energy end-use equipment to provide the desired energy services.

For example, to have lighting, light bulbs are needed which are fed with electricity, which comes from a grid that carries electricity produced in a power plant burning coal that came from a mine (see Figure 3.6). In another example, gasoline comes from a truck and/or pipeline which brings it from a refinery, where oil from an oil well is processed.

In all these stages there are usually significant losses, particularly in developing countries where both commercial and non-commercial energy is presently being used very inefficiently. The poor often do not have access to technology and/or cannot afford it; they have to depend on their own labor, animal power, or fuelwood and other types of biomass which have a high price in terms of human time, labor, health and gender impact, which is usually more severe on women.

In addition, it is important to remember that the energy needs of developing countries are not the same as those of industrialized countries due to differences in climate (eg space heating is not required in most of the South) and also because the satisfaction of basic human needs and the building of an infrastructure must be given paramount attention in the South.

The energy crises of the 1970s have led to a revolution in the technology of energy end-use. New technologies, commercially available at that time or subsequently, made it feasible to provide energy services with a smaller energy input than was possible with the technologies in widespread use. This meant that there could be a 'delinking' between GDP growth and energy growth, which did in fact take place in the industrialized countries in the 1970s and 1980s.

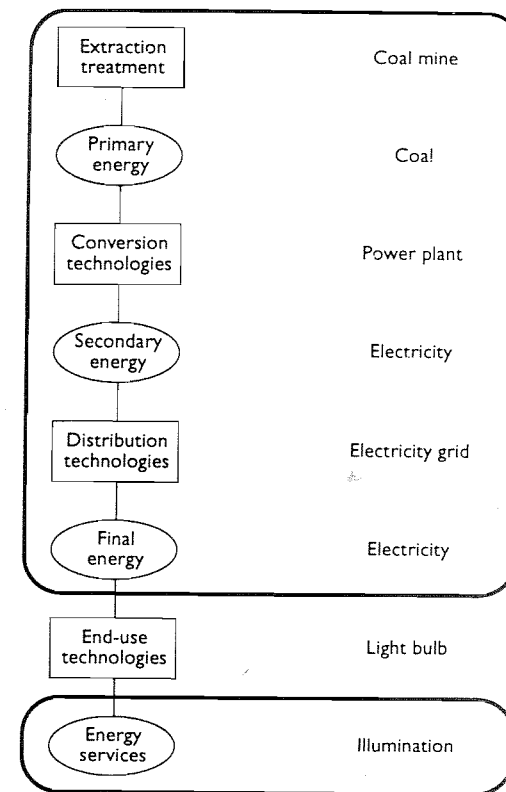


Figure 3.6 The energy system: from extraction to energy services

Many of these new technologies are also of fundamental importance to developing countries, to the extent that emphasizing energy efficiency in development planning would make it possible to provide not only the energy required for basic needs but also considerable further improvements in living standards.

To indicate in a very dramatic way the potential importance of energy efficiency for developing countries, an energy scenario (really a 'thought experiment') was constructed² for a hypothetical developing country with a mix of energy-using activities similar to that for Western Europe in the 1970s (excluding space heating, which is not needed in most developing countries).

² Goldemberg, J, Johansson, T B, Reddy, A K N and Williams, R H, *Energy for a Sustainable World*, John Wiley and Sons, Chichester, UK (1988).

The per capita energy use associated with each activity in the scenario is the product of any given activity level and an energy intensity corresponding in energy efficiency to either the best technology currently available on the market or to an advanced technology that could be commercialized in about ten years. The resulting final total energy use per capita, obtained by summing over all activities, is only about 20 per cent higher than the final energy use in 1980! This indicates the enormous potential of the use of advanced technologies in developing countries.

The Human Development Index (HDI)

As seen above, a number of social indicators such as longevity, literacy and total fertility rate seem to be closely correlated to per capita energy consumption.

A more complex social indicator is sometimes used when trying to establish such correlations – the Human Development Index (HDI) which was designed to correct some of the shortcomings of the use of per capita income as a measure of development.

The HDI is a composite of:

- longevity – measured by life expectancy;
- knowledge – measured by a combination of adult literacy (two-thirds weight) and mean years of schooling (one-third weight); and
- standard of living – measured by purchasing power, based on real GDP per capita adjusted for the local cost of living (purchasing power parity – PPP).

Each of these indicators is given a value between 0 and 1, and the resulting numbers are averaged in an overall index. For example, if the minimum for life expectancy is 25 years and the maximum 85 years, the longevity component for a country where life expectancy is 55 years would be 0.5. A similar procedure is used for knowledge and standard of living.

A plot of HDI as a function of per capita commercial energy consumption per year for a large number of countries is given in Figure 3.7.

It is apparent from Figure 3.7 that, for an energy consumption above 1 TOE/capita per year, the value of HDI is higher than 0.8 and essentially constant for all countries. One TOE/capita/year seems, therefore, the minimum energy needed to guarantee an acceptable level of living as measured by the HDI, despite many variations across countries of consumption patterns and lifestyles. A similar HDI for countries with different income per capita means that a lower income is compensated by a greater longevity and increased knowledge.

The Energy Cost of Satisfying Basic Human Needs

Several attempts have been made to quantify people's minimum energy needs. One of them starts from the assumption that a normally active young adult in a temperate climate needs a dietary energy allowance of 2500 kcal per day, which roughly corresponds to a continuous energy flow of 100 watts (called a unit of 'human equivalent power' – HEP). Then the notion that satisfying basic needs would require the work of hypothetical slaves consuming energy at a rate corresponding to HEP is introduced, and the number of slaves required to meet various basic human needs is estimated. Table 3.1 lists the resulting basic energy needs.

Table 3.1 Basic energy needs of hypothetical society relying on slaves

| Type of activity | Number of slaves per capita | Daily energy needs per capita (watt) | (kcal) |
|------------------|-----------------------------|--------------------------------------|--------|
| Food | 3 | 300 | 6,000 |
| Shelter | 3 | 300 | 6,000 |
| Clothing | 1 | 100 | 2,000 |
| Travel | 2 | 200 | 4,000 |
| Leisure | 6 | 600 | 12,000 |
| Total | 15 | 1,500 | 30,000 |

Source: Haffner, E, 'Optimum Power Requirements of Civilised Humans' (unpublished), Hampshire College, Amherst, Mass, US (1979).

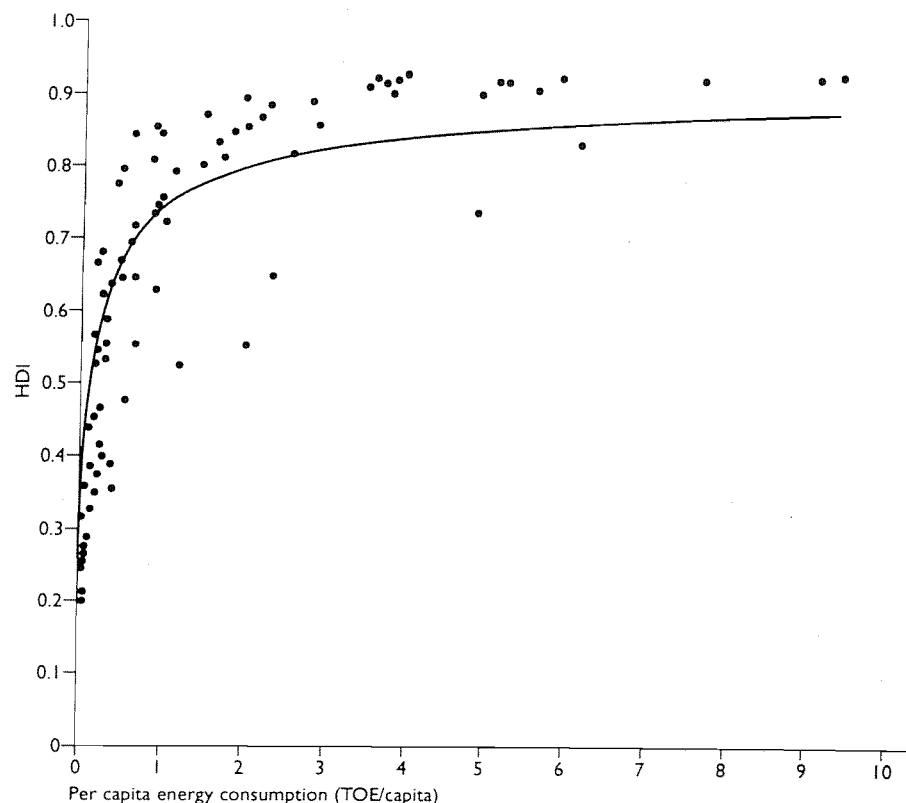
A more sophisticated approach to the question of basic human needs has been made by the Bariloche Foundation with its Latin American World Model.³ The Bariloche study explores possible physical limits to establishing a society in which basic human needs are satisfied and, on the basis of a simple econometric model, investigates the possibility of doing so with current economic resources.

The target levels assumed in the Latin American World Model are:

- 3000 kcal and 100 grams of protein per person per day;
- One house (50 square meters of living area) per family; and
- 12 years of basic education (ie, school enrolment of all children between 6 and 17 years).

The quantitative definition of a representative package of basic human needs is difficult for various reasons. For one, basic needs vary with climate, culture, region, period in time, age and sex. For another, there is not a single

³ Fondation Bariloche, *Catastrophe or New Society – A Latin American World Model*, International Development Research Centre (IDRC), Ottawa, Canada (1976).



Sources: Suarez, C E, 'Energy Needs for Sustainable Development', in Goldemberg, J and Johansson, T B (eds), *Energy As an Instrument for Socio-Economic Development*, UNDP, New York, US (1995)

Figure 3.7 HDI versus annual energy consumption per capita, 1991–1992

level of basic needs but a hierarchy. There are needs, such as a minimum of food, shelter and protection from fatal diseases, that have to be met for survival. Satisfaction of higher-level needs such as basic education make 'productive survival' possible. Top-level needs such as travel and leisure arise when people try to improve their quality of life beyond 'productive survival'. Obviously, needs perceived as basic vary according to living conditions in any given society. Despite the difficulties involved in defining and ranking human needs, the three quantitative measures considered in the Latin American World Model may be regarded as a basic core for 'productive survival'.

The final result of the Latin American World Model is the GNP per capita needed to satisfy basic human needs: this monetary income has been converted to energy units using appropriate elasticity coefficients for the sectors

considered. Thus the amount of commercial energy needed to satisfy basic human needs is obtained.

It is well known, however, that a large number of people in rural areas in LDCs do not have access to commercial energy due to lack of purchasing power or other reasons. These people depend for survival on non-commercial energy sources, principally firewood, dung and agricultural wastes which they gather at a negligible monetary cost. In many LDCs, non-commercial energy accounts for a significant proportion of total primary energy consumption and 7.5×10^3 kcal/day per capita is considered to be a representative figure.

Adding this number to the cost of commercial energy to meet basic needs yields the total energy cost of satisfying basic human needs which, as shown in Table 3.2, ranges between 27.8×10^3 and 36.4×10^3 kcal/day per capita, ie between 1.0 and 1.3 TOE/capita.

Table 3.2 Basic needs: per capita energy consumption

| Region | Year | Commercial energy (kcal/day) | Non-commercial energy (kcal/day) | Total energy (kcal/day) |
|---------------|------|------------------------------|----------------------------------|-------------------------|
| Latin America | 1992 | 24.2×10^3 | 7.5×10^3 | 31.7×10^3 |
| Africa | 2008 | 20.3×10^3 | 7.5×10^3 | 27.8×10^3 |
| Asia | 2020 | 28.9×10^3 | 7.5×10^3 | 36.4×10^3 |

Source: Krugmann, H and Goldemberg, J, 'The Energy Cost of Satisfying Basic Human Needs', *Technological Forecasting and Social Change*, 24, 45–60 (1983).

Energy and GNP

The ratio of energy consumption (E) to GNP is defined as the *energy intensity* (I) of the economy:

$$I = E / (\text{GNP})$$

As a first approximation, the growth of national income occurs through an increase in population, number of houses, automobiles, domestic appliances, etc, with a consequent proportional increase in energy consumption; therefore I is a constant K and

$$E = K(\text{GNP})$$

The energy intensity is usually expressed in TOE per thousand US dollars of GNP for a given year of reference.

Long-term time series of the energy intensity for a number of countries have shown that I is not really constant but changes over time, reflecting the

combined effects of changes in the structure of the economic product built into the GNP as well as changes in the mix of sources of energy and the efficiency of energy use.

From the definition of energy intensity, we can obtain percentage changes as follows:

$$I = E / (\text{GNP})$$

$$\log I = \log E - \log(\text{GNP})$$

$$\frac{\Delta I}{I} = \frac{\Delta E}{E} - \frac{\Delta(\text{GNP})}{(\text{GNP})}$$

Table 3.3 gives numbers for $\Delta I/I$ in the period 1981–1991 for a few regions of the world, using GDP instead of GNP.

Table 3.3 Primary energy, GDP and energy intensity changes (1981–1991) (per cent/year)

| | $\frac{\Delta E}{E}$ | $\frac{\Delta(\text{GDP})}{(\text{GDP})}$ | $\frac{\Delta I}{I}$ |
|---------------|----------------------|---|----------------------|
| South Asia | 6.5 | 5.2 | +1.3 |
| East Asia | 7.7 | 6.6 | +1.1 |
| Latin America | 2.9 | 1.8 | +1.1 |
| Africa | 4.1 | 2.7 | +1.4 |
| OECD | 1.4 | 3.7 | -2.3 |

Source: *Energy in Developing Countries – A Sectorial Analysis*, OECD/IEA, Paris (1994).

In OECD countries, the energy intensity is *decreasing* at a rate of about 2.3 per cent a year; in developing countries it is *increasing* at a rate of between 1.1 and 1.4 per cent a year. If the GDP grows, the only method of offsetting the resulting energy growth is to decrease the energy intensity. In the OECD, this has occurred and growth of energy consumption in the period 1981–1991 was only 1.4 per cent while GDP grew by 3.7 per cent. An increasing energy intensity works in the opposite direction. In Latin America, for example, GDP has grown only 1.8 per cent per year but energy growth was 2.9 per cent per year in the period 1981–1991, since the energy intensity grew by 1.1 per cent.

Since E is not strictly proportional to GNP, it is sometimes useful to relate E and GNP through the equation:

$$E = K(\text{GNP})^\gamma, \text{ where } \gamma \text{ and } K \text{ are constant}$$

In this case the income elasticity⁴ of energy consumption, γ , can be calculated as follows:

$$\log E = \gamma \log K + \gamma \log(\text{GNP})$$

$$\frac{\Delta E}{E} = \gamma \frac{\Delta(\text{GNP})}{(\text{GNP})}, \text{ since } K \text{ is a constant}$$

therefore,

$$\gamma = (\Delta E/E) / (\Delta(\text{GNP})/(\text{GNP}))$$

If $\gamma = 1$ energy consumption grows proportionally with GNP;

If $\gamma < 1$ energy consumption grows less rapidly than GNP;

If $\gamma > 1$ energy consumption grows more rapidly than GNP.

For example, if energy consumption grows by 4 per cent a year and, in the same period, GNP has grown 5 per cent a year:

$$\gamma = 4/5 = 0.80$$

If GNP grows at only 3.2 per cent a year:

$$\gamma = 4/3.2 = 1.25$$

A price elasticity (β) for energy consumption (E) can also be defined as:

$$E = P^\beta$$

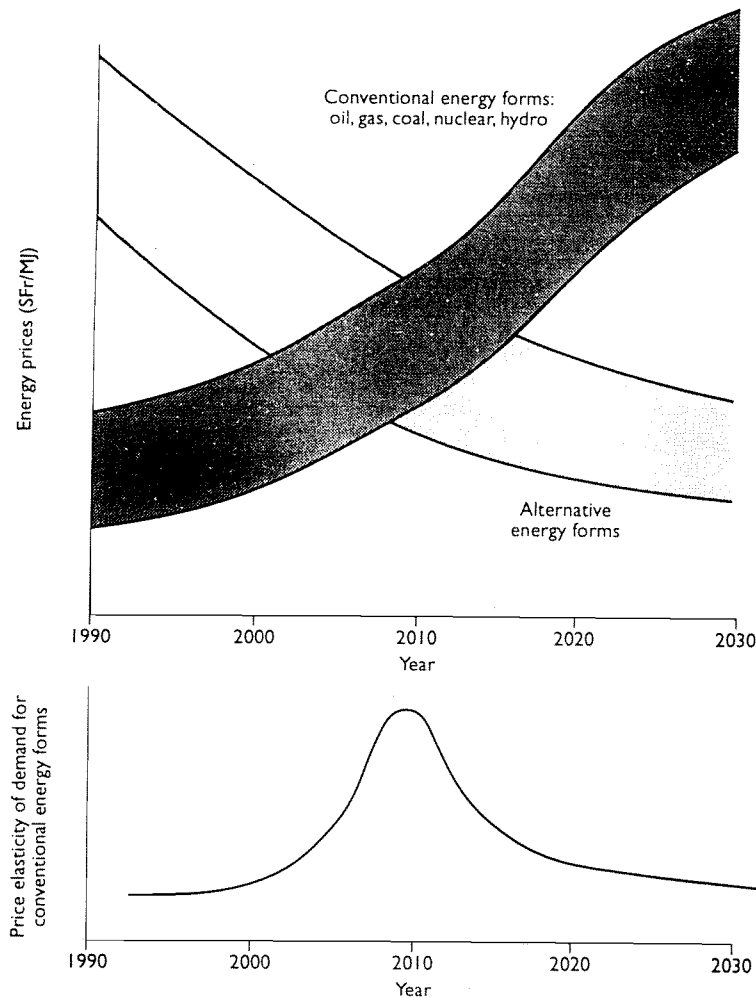
$$\beta = (\Delta E/E) / (\Delta P/P)$$

where P is the price of energy.

Figure 3.8 indicates the type of behavior expected for the price elasticity of demand for conventional energy forms in the next few decades in Switzerland, according to a study made by the Swiss Development Corporation. This study assumes that the price of conventional energy sources will grow until the year 2010; the price elasticity will also grow, even if energy becomes more expensive up to the point that alternative energy forms become cheaper than conventional ones. From then on, consumption of conventional energy forms will begin to level off and the price elasticity will decrease.

⁴ Elasticity is a general concept that applies to any functional relation between two variables $y = f(x)$

$$\gamma = \frac{\text{per cent variation in } y}{\text{per cent variation in } x} = (\Delta y/y) / (\Delta x/x)$$



Source: Sustainable Energy Development in Switzerland, The Swiss Development Corporation, Zurich, Switzerland (1995).

Figure 3.8 Evolution of price elasticity in Switzerland

Some relevant economic definitions

General

According to some economists, since the end of the 18th century the study of economics has expanded from:

- political economy to
- development economics.

Traditional or classical economics is concerned with the efficient least-cost allocation of scarce productive resources and the optimal growth of these resources over time in order to produce an ever-expanding range of goods and services.

Political economy goes beyond traditional economics and is concerned with the relationship between politics and economics. 'Politics' is understood here to mean the role of the 'power' of certain groups of economic interest or political leaders to influence the allocation of productive resources either for their own benefit, or for a wider group.

Development economics is the political economy of societies in which income per capita is widely different for different social groups and addresses 'the economic and political processes necessary for affecting rapid structural and institutional transformation of entire societies in a manner that will most efficiently bring the fruits of economic progress to the broadest segments of their populations'.

'Classical' economics has traditionally been divided into three broad categories: micro-economics, macro-economics and international economics:

- *Micro-economics* focuses on the behavior and activities of individual economic units – primarily producers and consumers. For example, micro-economics tries to explain how an enterprise decides the price of a given product, what level of production will maximize its profits and how to minimize costs of labor, raw materials and other inputs. It tries to address the basic questions of what and how much to produce, and assumes that the answer is determined by the aggregate preferences of all consumers as revealed by their demand for different goods and services.
- *Macro-economics* looks at the economy as a whole in terms of aggregate or macro-economic variables such as consumption, saving, investment, the money supply, gross domestic product, employment and the overall price level. For example, macro-economics tries to explain why sometimes only 3 per cent of the work force is unemployed and, on other occasions, 7 per cent or higher, or why the productive capacity of the economy is sometimes fully used (in numbers of workers, factories, machines and know-how) while on other occasions it is partially idle. It also tries to explain why GNP grows at 2 per cent or 4 per cent a year, and why the level of prices goes up or down.
- *International economics* examines the trading and monetary relationships between nation states both as producers of exports and consumers of imports, and thus represents a mixture of elements of both.

In classical economics, consumers are assumed to be *sovereign* in their preferences, and producers respond to sovereign consumer preferences and are interested in *profit maximization*. They are assumed to compete with each other on equal terms. *Consumer sovereignty*, *perfect competition* and *profit maximization* are the pillars of classical economic analysis.

The ultimate rationale for these ideas comes from Adam Smith's notion of the 'invisible hand' which postulates that if each individual consumer, producer and supplier of

resources pursues his or her own self interest, they will, 'as if by an invisible hand', promote the overall interests of society.

Unfortunately, the facts of economic life in both developed and developing countries have proved over and over again that:

- Consumers are rarely sovereign.
- Producers, whether private or public, have great power in determining what goods and services are produced, and for whom. The ideal of perfect competition has little relation to reality.

The so-called 'invisible hand' often acts not to promote the general welfare of all, but to lift up those who are already well-off while keeping down that vast majority of the population which is striving to free itself from poverty, malnutrition and illiteracy.

Source: Todaro, M T, *Economic Development in the Third World*, Longman, London and New York (1977).

Specific to energy

There are several figures of economic merit that can be used to measure the cost-effectiveness of energy efficiency investments: the simple payback, the cost of saved energy (CSE), the internal rate of return (IRR) and the lifecycle cost (LCC) or annualized lifecycle cost (ALC).

The *simple payback* is the ratio of the initial investment to the first year's savings. Despite the simplicity of this index, it is the least desirable one to use, because it contains no information regarding the expected lifecycle of the investment and the time value of money. As an example, the payback is less than 2 to 4 years when the discount rates are about 50 per cent to 25 per cent. The discount rate gives a measure of the value of the money. If the discount rate is 10 per cent, one dollar today will be worth 1.1 dollars after one year; conversely, a discount rate of 50 per cent implies that a dollar saved ten years from now is worth 0.017 dollars today.

The *cost of saved energy* is an index which permits a ready comparison between investments in energy-efficient and energy-supply alternatives. The CSE is the annual repayment cost for a hypothetical loan taken out to pay for the investment in energy-efficiency improvement, divided by the expected annual energy savings.

The *internal rate of return* is an alternative approach to the economics of energy efficiency to treat the alternative options as investment opportunities and try to get the consumer to make economic decisions the way corporate investors do – by calculating the IRR associated with the extra investment required to improve energy efficiency. The IRR is the real rate of return realized from the dollar value of the energy savings resulting from an energy-efficient investment.

The *lifecycle cost* is the total discounted present value of all future costs associated with providing a particular energy service over a specified period.

The *annualized lifecycle cost* is the total annualized cost associated with the provision of this energy service: the operating cost (mainly fuel) plus the annualized cost of the initial investment, as defined for the CSE concept.

Source: Goldemberg, J, Johansson, T B, Reddy, A K N and Williams, R H, *Energy for a Sustainable World*, John Wiley and Sons, Chichester, UK (1988).

Chapter 4

Energy and the Environment: the Facts

The environment in which we live changes continuously due to 'natural causes' over which we have little control. The seasons of the year are the most evident of these changes, primarily in geographical locations with high latitudes (north and south). There are many other variations, such as the inclination of the Earth's axis, sunspots on the surface of the Sun and those with their origin in the Earth itself, such as volcanic eruptions, earthquakes, typhoons, floods and forest fires.

Life on Earth has shown a surprising resilience in withstanding changes in the environment, and humanity in particular has adapted well to changing climate after the last glaciation some 10,000 years ago when most of the northern hemisphere was covered by ice and snow. All the natural changes in our environment, except natural disasters, occurred slowly over long periods of time, typically centuries.

Until recently, humanity's actions have been of negligible importance in changing the environment, except perhaps in denuding large forest areas in Europe, China and Central and South America.

After the industrial revolution at the end of the 18th century, however, and particularly in the 20th century, anthropogenic aggression towards the environment has become more important due to population growth and the enormous increase in personal consumption mainly in the industrialized countries. What characterizes these environmental changes caused by humanity is that they take place in a short period of time (typically decades). As a result, many new problems or areas of interest in the environmental field have become the object of study and great concern, mainly the ones indicated in Table 4.1.

Table 4.1 Main environmental problems

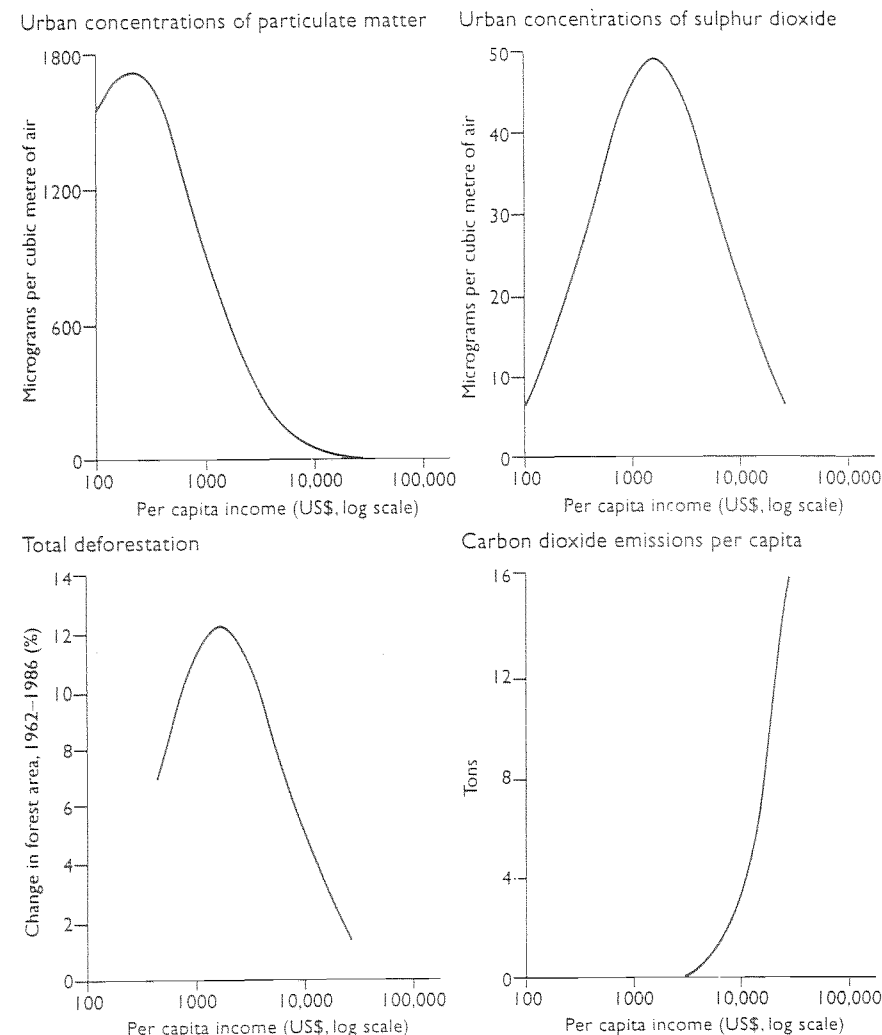
| Environmental problem | Main source of problem | Main social group affected |
|---|--|----------------------------|
| Urban air pollution | Energy (industry and transportation) | Urban population |
| Indoor air pollution | Energy (cooking) | Rural poor |
| Acid rain | Energy (fossil-fuel burning) | All |
| Ozone depletion | Industry | All |
| Greenhouse warming and climate change | Energy (fossil-fuel burning) | All |
| Availability and quality of fresh water | Population increase, agriculture | All |
| Coastal and marine degradation | Transportation and energy | All |
| Deforestation and desertification | Population increase, agriculture, energy | Rural poor |
| Toxic chemicals and hazardous wastes | Industry and nuclear energy | All |

Broadly speaking, all these problems have a multitude of causes such as population increase, the growth and changing patterns of industry, transportation, agriculture and even tourism. The way energy is produced and used, however, is at the root of many of these causes. One can go further and try to establish cause and effect relationships between energy and environmental problems.

For example, air pollution and acid rain are largely due to the burning of fossil fuels and urban transportation. Greenhouse warming and climate change are due mainly to the burning of fossil fuels. Deforestation and land degradation are due, in part, to the use of fuelwood for cooking.

Such problems are also an important cause of the loss of biodiversity. In some other environmental situations, energy does not play a dominant role but, nevertheless, is important in an indirect way, as in coastal and marine degradation which is due, in part, to oil spills. In the case of environmental hazards and disasters, the role of nuclear energy is paramount as clearly demonstrated by the Chernobyl nuclear accident.

We shall discuss these problems in some detail, trying to identify in which ways energy production and use are involved, thus allowing energy policies to be proposed that can reduce or prevent environmental changes. One way to do this is to plot, for many countries as a function of energy consumption per capita, a variety of environmental quality indicators, such as urban concentrations of particulate matter and sulphur dioxide (SO_2), total deforestation, and carbon dioxide emissions per capita (Figure 4.1). Such information does not exist in this form but as a function of per capita income which will be used as a proxy for energy consumption per capita. This approach glosses over differences in income within each country, which are often considerable.



Source: Shafik, N and Bandyopadhyay, S, 'Economic Growth and Environmental Quality', Working Paper WPS904, The World Bank, Washington, DC, US (1992).

Figure 4.1 Environmental indicators at different country income levels

As we shall see later (under Trends in Energy Intensity in Chapter 6, p. 75) the energy intensity $I = E/\text{GDP}$ of most countries is distributed around an average value of 0.4 TOE/US\$ 1000. An energy consumption of 1 TOE per capita per year, which seems essential to overcome the worst problems of underdevelopment corresponds, therefore, to a yearly income of US\$ 2500 per capita.

Table 4.2 gives the trends of these indicators as income changes.

Table 4.2 Trends in pollution as a function of per capita income

| Indicator | Worsens as income increases | Improves with very high income | Observation |
|---|-----------------------------|--------------------------------|-------------------|
| Urban concentration of particulate matter | X | X | Bell-shaped curve |
| Urban concentration of sulphur dioxide | X | X | Bell-shaped curve |
| Total deforestation | X | X | |
| Carbon dioxide emissions | X | | |

We shall now present the outstanding facts regarding the environmental problems most closely related to energy:

- urban air pollution;
- indoor air pollution;
- acid rain;
- greenhouse warming and climate change;
- desertification and deforestation; and
- coastal and marine degradation.

Urban Air Pollution

Urban air pollution is probably the most visible undesirable product of civilization; even in the 16th century, British Parliament sessions in London had to be postponed due to severe pollution 'episodes'. One of the most serious of these occurred in 1952 when very heavy fog was responsible for 4000 deaths, and more than 20,000 cases of illness. Such disasters led to the passing of the UK Clean Air Act of 1956, establishing limits on the emission of pollutants and acceptable levels of air quality. Other legislation followed in the UK, North America, many other western European countries and Japan. As a result, monitoring, regulatory and assessment agencies on environmental quality were set up with highly beneficial consequences.

The five main urban air pollutants are:

- sulphur oxides (SO_x , mainly SO_2);
- nitrogen oxides (NO_x and mainly nitric oxide (NO) and nitrogen dioxide (NO_2));
- carbon monoxide (CO);
- suspended particulate matter – SPM (including lead); and
- ozone.

Table 4.3 gives the symptoms resulting from exposure to such pollutants as well as permissible levels as established by the World Health Organization (WHO).

Table 4.3 World Health Organization (WHO) health effects criteria for major air pollutants

| Pollutant | Symptoms | WHO exposure criteria |
|-----------------------------------|--|---|
| Sulphur dioxide | <ul style="list-style-type: none"> ■ Respiratory irritation, shortness of breath, impaired pulmonary function, increased susceptibility to infection, illness in the lower respiratory tract (particularly in children), chronic lung disease and pulmonary fibrosis. ■ Increased toxicity in combination with other pollutants. | 500 $\mu\text{g}/\text{m}^3$ for 10 min; 350 $\mu\text{g}/\text{m}^3$ for 1 hour |
| Respirable particulate matter | <ul style="list-style-type: none"> ■ Irritation, altered immune defense, systemic toxicity, decreased pulmonary function and stress on the heart. ■ Acts in combination with SO_2; effects depend on the chemical and biological properties of the individual particles. | No health effects criteria |
| Oxides of nitrogen | <ul style="list-style-type: none"> ■ Eye and nasal irritation, respiratory tract disease, lung damage, decreased pulmonary function and heart stress. | 400 $\mu\text{g}/\text{m}^3$ for 1 hour; 150 $\mu\text{g}/\text{m}^3$ for 24 hours |
| Carbon monoxide | <ul style="list-style-type: none"> ■ Interferes with oxygen uptake into the blood (chronic anoxia). ■ Can result in heart and brain damage, impaired perception, asphyxiation; or in lower doses, weakness, fatigue, headaches and nausea. | 100 mg/m^3 for 15 min; 60 mg/m^3 for 30 min; 30 mg/m^3 for 1 hour; 10 mg/m^3 for 8 hours |
| Lead | <ul style="list-style-type: none"> ■ Kidney disease and neurological impairments. ■ Primarily affects children. | 0.5–1.0 $\mu\text{g}/\text{m}^3$ for 1 year |
| Photochemical oxidants (eg ozone) | <ul style="list-style-type: none"> ■ Decreased pulmonary function, heart stress or failure, emphysema, fibrosis, and aging of lung and respiratory tissue. | 150–200 $\mu\text{g}/\text{m}^3$ for 1 hour; 100–120 $\mu\text{g}/\text{m}^3$ for 8 hours |

Source: Tolba, M K, et al (eds), *The World Environment 1972–1992*, UNEP, Chapman and Hall, London, UK (1992).

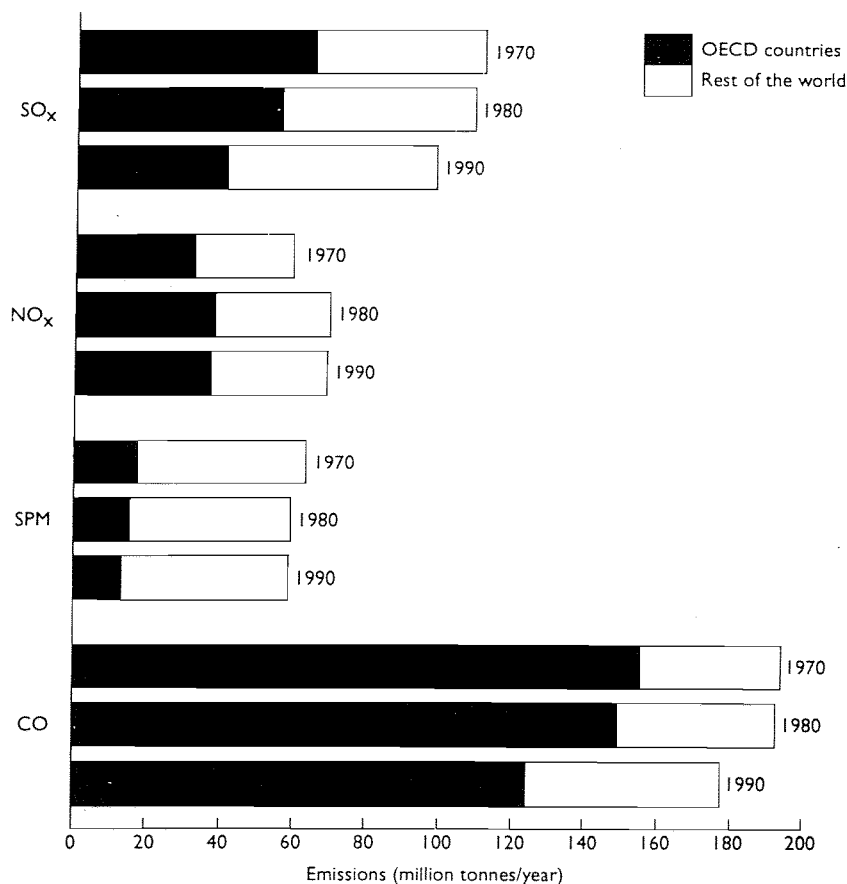
Table 4.4 indicates the amounts of the main urban pollutants (except ozone) emitted into the atmosphere in 1990.

Table 4.4 Pollutants emitted in 1990

| Pollutant | Quantity (million tons) | Percentage emitted in industrialized countries |
|---------------|-------------------------|--|
| SO_x | 99 | 40 |
| NO_x | 57 | 52 |
| CO_x | 177 | 71 |
| SPM | 57 | 29 |

Source: Tolba, M K et al (eds), *The World Environment 1972–1992*, UNEP, Chapman and Hall, London, UK (1992).

Emissions of all these pollutants have been slowly decreasing in the past 20 years, with the exception of NO_x which has increased (Figure 4.2).



Source: Tolba, M K et al (eds), *The World Environment 1972–1992*, UNEP, Chapman and Hall, London, UK (1992).

Figure 4.2 Human-made emissions of common air pollutants

Energy systems are the main source of sulphur dioxide emissions (90 per cent of total emissions). Emissions in developed regions have decreased over the past two decades, while those in developing regions have increased.

In industrialized regions, industry and transportation, rather than power stations, are the main sources of CO emissions. Combustion of fossil fuels and the burning of wood as fuel contribute about one-third of total human-made emissions. In developing regions, inefficient combustion in primitive stoves, furnaces and boilers is a main source (Table 4.5).

Table 4.5 Estimates of CO releases

| Source | Amount (10 ⁶ t/yr) |
|--|----------------------------------|
| Fossil fuel combustion | 190 |
| Wood burning as fuel | 20 |
| Forest clearing, savanna burning, oxidation of methane | 460 |
| Total | 670 |

Sources: Tolba, M K et al (eds), *The World Environment 1972–1992*, UNEP, Chapman and Hall, London, UK (1992).

Lead in the air is considered to be a serious health hazard at concentrations of even a few millionths of a gram per cubic meter. Emissions have been reduced dramatically in the past few years, mainly because the amount of lead additives in gasoline has been reduced. In the UK, for example, a decline of 50 per cent was observed in 1985/1986 when the lead content of gasoline was reduced from 0.4 to 0.15 g per litre.

Ozone, at concentrations of about 100 ppb, is a major air pollutant that damages vegetation, can harm lungs and is the main agent responsible for smog formation. Ozone is formed in the atmosphere from volatile hydrocarbon compounds (such as gasoline) and NO_x with energy provided by sunlight.

Indoor Air Pollution

There are three types of problems related to indoor air pollution:

- 'Traditional' – due to cooking generally indoors which produces smoke, particulates, carbon monoxide and other gases affecting mainly the rural poor. More than one billion people in developing countries are victims of this type of pollution.
- 'Occupational' – leading to illnesses, such as silicosis, mercury poisoning and others, victimizing miners and industrial workers.
- 'Modern' – affecting people living in modern, airtight buildings due to radon and asbestos from building materials, and formaldehyde emitted from insulating foam.

We shall restrict our discussion to the 'traditional' type of pollution which is closely linked to the fuelwood crisis.

In 1989, the total production of wood, ie wood felled or harvested from trees regardless of its use, was about 3500 million cubic meters, evenly distributed between industrial wood and fuelwood (Table 4.6).

Table 4.6 Production of wood, 1989 (to nearest million cubic metres)

| | Industrialized countries | Less-developed countries | World total |
|-----------------|--------------------------|--------------------------|-------------|
| Fuelwood | 268 | 1538 | 1786 |
| Industrial wood | 1274 | 403 | 1677 |
| Total | 1542 | 1941 | 3463 |

Source: Tolba, M K et al (eds), *The World Environment 1972–1992*, UNEP, Chapman and Hall, London, UK (1992).

In the industrialized countries, most of the wood (82 per cent) is not burned but is used for industrial purposes; in the less-developed countries, 80 per cent is used for fuelwood. Wood and other biomass fuels comprise 40–60 per cent of the total energy resource for many developing Asian, Latin American and African countries. Domestic cooking accounts for over 60 per cent of total national energy use in sub-Saharan Africa and exceeds 80 per cent in several countries. In addition, some poor families spend 20 per cent or more of disposable income on the purchase of wood and charcoal fuels, or devote more than 25 per cent of total household time to collecting wood.

Between 30 and 40 per cent of the world's population relies on fuelwood for cooking; the Food and Agriculture Organization (FAO) estimated in 1981 that 1100 billion people were in a 'deficit situation' concerning fuelwood and that 400 million cubic meters were needed to make up for this shortfall. By the year 2000, the world fuelwood deficit will probably reach 960 million m³ a year due to population growth – the energy equivalent of 240 million tons of oil per year, worth about US\$ 40 billion. Since most of this fuelwood is for use in developing countries, which cannot afford the foreign exchange needed to replace fuelwood by petroleum, the crisis is likely to continue.

Biomass burning for cooking by the poor has been identified by the World Health Organization as the major indoor air pollution health problem in the world today; WHO estimates that almost 1.5 billion people live in unhealthy air. High levels of woodsmoke exposure – often ten or more times the recommended WHO limits – have been reported in emission studies throughout developing countries. This, in turn, has been linked to acute respiratory infection (ARI), in particular pneumonia, along with a number of other ailments.

Women – who generally perform over 90 per cent of domestic chores including cooking – and their children are the segment of the population most continuously exposed to indoor air pollution. The resulting pollution levels in homes and cooking huts represent the equivalent particulate dosage of smoking several packs of cigarettes a day. ARI is, in fact, the leading health hazard to children in developing nations and is responsible for an estimated 4.3 million deaths a year. Among all endemic diseases, including diarrhea, ARI is the most pervasive cause of chronic illness.¹

¹ Kammen, D M, 'From Energy Efficiency to Social Utility: Lessons from Cookstove Design, Dissemination and Use', in Goldemberg, J and Johansson, T B (eds), *Energy As an Instrument for Socio-Economic Development*, UNDP, New York, US (1995).

Table 4.7 shows that WHO daily exposure guidelines are usually not followed, by a large margin, in a number of developing countries,

Table 4.7 Indoor air concentrations

| Typical exposure in some developing countries* | Pollutant | WHO daily exposure guidelines |
|--|--------------------|-------------------------------|
| 1–20 mg/m ³ | SPM | 0.12 mg/m ³ |
| 10–50 mg/m ³ | CO | 10 mg/m ³ |
| 0.1–0.3 mg/m ³ | NO ₂ | 0.15 mg/m ³ |
| 1–20 µg/m ³ | benzo-alpha-pyrene | 0.001 µg/m ³ ** |

Notes: * India, Nepal, Nigeria, Kenya, Guatemala and Papua New Guinea.

** Concentration causing a cancer link out of 100,000 people after a life-time exposure.

Source: World Health Organization (WHO), Geneva (1990).

The living conditions that expose people to high levels of indoor air pollution have been well documented in Africa. The majority of sub-Saharan Africans live in rural areas. In Kenya, for example, only about 20 per cent of the population lives in towns and cities. Family homes generally consist of small, multi-purpose buildings, where the same room or few rooms are used for cooking, sleeping and working. In many cases the total indoor volume is less than 40 m³; in an extreme case of Masai homes in Kenya, indoor air volumes in the cooking area can be consistently less than 20 m³. Also rural cooking houses often have minimal ventilation.

Different fuel and stove combinations have widely different indoor levels of emission, not only because stoves are more efficient and therefore take less time to cook, but also because fuels are so different, as indicated in Table 4.8.

Table 4.8 Indoor emissions of traditional stoves

| Fuel and stove combination | No of measurements | (CO) (ppmv) |
|------------------------------|--------------------|-------------|
| Dung/traditional stove | 25 | 220–760 |
| Wood/traditional stove | 38 | 140–550 |
| Charcoal/traditional stove | 14 | 230–650 |
| Charcoal/improved stove | 22 | 80–200 |
| Kerosene fuel and stove | 8 | 20–65 |
| WHO 1-hour exposure standard | | 46 |

Source: Kammen, D M, 'From Energy Efficiency to Social Utility: Lessons from Cookstove Design, Dissemination and Use', in Goldemberg, J and Johansson, T B (eds), *Energy As an Instrument for Socio-Economic Development*, UNDP, New York, US (1995).