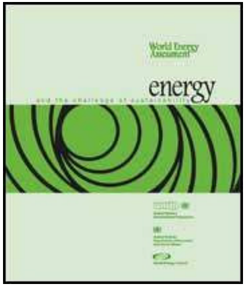

World Energy Assessment - Energy and the Challenge of Sustainability (UNDESA - UNDP - WEA - WEC, 2000, 517 p.)

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PART I. ENERGY AND MAJOR GLOBAL ISSUES

Chapter 1. An Introduction to Energy

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Life is but a continuous process of energy conversion and transformation. The accomplishments of civilisation have largely been achieved through the increasingly

efficient and extensive harnessing of various forms of energy to extend human capabilities and ingenuity. Energy is similarly indispensable for continued human development and economic growth. Providing adequate, affordable energy is essential for eradicating poverty, improving human welfare, and raising living standards world-wide. And without economic growth, it will be difficult to address environmental challenges, especially those associated with poverty.

But energy production, conversion, and use always generate undesirable by-products and emissions - at a minimum in the form of dissipated heat. Energy cannot be created or destroyed, but it can be converted from one form to another. The same amount of energy entering a conversion process, say, natural gas in a home furnace, also leaves the device - some 80-90 percent as desirable space heat or warm water, the rest as waste heat, most through the smokestack. Although it is common to discuss energy consumption, energy is actually transformed rather than consumed. What is consumed is the ability of oil, gas, coal, biomass, or wind to produce useful work. Among fossil fuels the chemical composition of the original fuel changes, resulting in by-products of combustion, or emissions.

This chapter provides a brief introduction to energy's importance for human life and economic functioning, and paints a broad picture of the current energy scene. (More extensive data on energy trends appear in the annexes to this report.) Chapters 2, 3, and 4 examine in greater detail the links between energy and important global challenges, including social issues, health and the environment, and energy security. Chapter 11 analyses prospects for achieving widespread and sustainable prosperity and for reconciling high levels of energy services with environmental protection.

What is sustainable energy development?

In its 1987 report, *Our Common Future,* the World Commission on Environment and

Development defines sustainable development as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs"(p. 8). The report further describes sustainable development "as a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are all in harmony and enhance both current and future potentials to meet human needs and aspirations" (p. 46). In its broadest sense, the report notes, "the strategy for sustainable development aims to promote harmony among human beings and between humanity and nature" (p. 65).

The relationship between energy production and use and sustainable development has two important features. One is the importance of adequate energy services for satisfying basic human needs, improving social welfare, and achieving economic development - in short, energy as a source of prosperity. The other is that the production and use of energy should not endanger the quality of life of current and future generations and should not exceed the carrying capacity of ecosystems.

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Throughout the 20th century, the ready availability of commercial energy fuelled global economic development. But much of the developing world continues to rely on non-commercial energy sources, mainly fuelwood, and has limited access to modern energy such as electricity and liquid fuels. Lack of capital and technological capacity hinders the development of adequate supplies, with deleterious effects on economic and social development.

Because they affect affordability and economic competitiveness, energy prices need to be taken into account when analysing options for sustainable energy development. Moreover, energy supplies should be secure and reliable. For that reason, attention should be given to:

- **The dependence on energy supplies from politically unstable regions or unevenly distributed locations.**
- **The possible disruption of energy supplies due to severe accidents.**
- **The sociocultural environment in which energy systems operate.**
- **The eventual exhaustion of finite energy resources such as coal, crude oil, natural gas, and uranium, for which alternative options must be developed.**

Finally, the development and introduction of sustainable energy technology must occur in a socially acceptable manner, with a broad range of citizens participating in decision-making.

No energy production or conversion technology is without risk or waste. Somewhere along all energy chains - from the extraction of resources to the provision of energy services - pollutants are produced, emitted, or disposed of, often with severe impacts on human health and the environment. The combustion of fossil fuels is responsible for most urban air pollution, regional acidification, and risks of human-induced climate change. The use of nuclear power has created a number of concerns about the safety of nuclear installations, the storage and disposal of high-level radioactive waste, and the proliferation of nuclear weapons. The manufacturing of photovoltaic panels generates toxic waste, and in some developing countries the use of biomass contributes to desertification and biodiversity losses.

As noted, to be considered sustainable, energy systems must not overload the carrying capacity of ecosystems. Nor should the use of finite resources compromise the ability of future generations to meet their energy service requirements. Efficient use of resources, clean conversion processes, and the timely development of inexhaustible supply options - such as renewable forms or nuclear energy based on breeding or fusion - are therefore the principal strategies for sustainable energy development.

Evolution of the energy system

From the perspective of society, energy is not an end in itself. The energy system is designed to meet demands for a variety of services such as cooking, illumination, comfortable indoor climate, refrigerated storage, transportation, information, and consumer goods. People are interested not in energy, but in energy services.

An energy system comprises an energy supply sector and the end-use technology needed to provide energy services (see figure 1 the overview and figure 6.1). The energy supply sector involves complex processes for extracting energy resources (such as coal or oil), for converting these into more desirable and suitable forms of energy (such as electricity or gasoline), and for delivering energy to places where demand exists. The end-use part of the system transforms this energy into energy services (such as illumination or mobility).

Energy services are the result of a combination of technology, infrastructure (capital), labour (know-how), materials, and energy carriers. All these inputs carry a price and, within each category, are partly substitutable for one another. From the perspective of consumers, the important issues are the economic value or utility derived from the services. The energy carrier and the source of that carrier often matter little. Consumers are generally unaware of the upstream activities of the energy system. The energy system is service driven (from the bottom up), whereas energy flows are driven by resource availability and conversion processes (from the top down). Energy flows and driving

forces interact intimately (see below). Thus the energy sector should never be analysed in isolation. It is not sufficient to consider only how energy is supplied; the analysis must also include how and for what purposes energy is used.

Modern energy systems rely on manufactured or processed fuels and sophisticated conversion equipment. Traditional energy usually means unprocessed fuels close to their primary form and low-technology conversion devices (or no technology). Low-technology energy conversion usually implies low efficiency and high pollution. Thus technology is a critical link between the supply of energy services and access, affordability, and environmental compatibility. Technology is more than a power plant, an automobile, or a refrigerator. It includes infrastructure such as buildings, settlement patterns, road and transportation systems, and industrial plants and equipment. It also includes social and cultural preferences as well as laws and regulations that reflect the compatibility of technology options with social preferences and capabilities and cultural backgrounds.

The overall efficiency of an energy system depends on individual process efficiencies, the structure of energy supply and conversion, and energy end-use patterns. It is the result of compounding the efficiencies of the entire chain of energy supply, conversion, distribution, and end-use processes. The weakest link in the analysis of the efficiency of various energy chains is the determination of energy services and their quantification, mostly due to a lack of data on end-use devices and actual patterns of their use.

In 1997 the global efficiency of converting primary energy (including non-commercial energy) to final energy, including electricity, was about 70 percent (279 exajoules over 399 exajoules). The efficiency of converting final energy to useful energy is lower, with an estimated global average of 40 percent (Nakicenovic and others, 1990; Gilli, Nakicenovic, and Kurz, 1995). The resulting average global efficiency of converting primary to useful energy is the product of these two efficiencies, or 28 percent. Because detailed statistics do not exist for most energy services and many rough estimates enter the efficiency

calculations, the overall efficiency reported in the literature spans a wide range, from 15 to 30 percent (Olivier and Miall, 1983; Ayres, 1989; Wall, 1990; Nakienovic and others, 1990; Schaeffer and Wirtshafter, 1992; and Wall, Scuibba, and Naso, 1994).

Technology is a critical link between the supply of energy services and access, affordability, and environmental compatibility.

Specific energy services are supplied by various combinations of energy and technology. In this context, technology is often viewed as capital and know-how. To a large extent, energy and technology, capital, and know-how can substitute for one another. Replacing less efficient and dirty technology with more efficient and cleaner technology is the substitution of capital and know-how for energy. Capital investment, however, typically involves energy embedded in materials, manufacturing, and construction, as well as labour and know-how.

The core business of the energy sector has traditionally involved delivering electricity to homes and businesses, natural gas to industries, and gasoline to gas stations. In the past, electricity supply - especially electrification of unserved areas - was a matter of sociopolitical development strategy. As a matter of state importance, energy supply was often directed by a regional utility under essentially monopolistic conditions. More recently, energy sector liberalisation has turned strategic goods into commodities, changing the sector from selling kilowatt-hours or litres of gasoline to selling energy services. With competition among suppliers, energy companies will become increasingly active in providing energy services, which may also include end-use technologies.

Demand for energy services

The structure and size of the energy system are driven by the demand for energy services. Energy services, in turn, are determined by driving forces, including:

- **Economic structure, economic activity, income levels and distribution, access to capital, relative prices, and market conditions.**

- **Demographics such as population, age distribution, labour force participation rate, family sizes, and degree of urbanisation.**

- **Geography, including climatic conditions and distances between major metropolitan centres.**

- **Technology base, age of existing infrastructure, level of innovation, access to research and development, technical skills, and technology diffusion.**

- **Natural resource endowment and access to indigenous energy resources.**

- **Lifestyles, settlement patterns, mobility, individual and social preferences, and cultural mores.**

- **Policy factors that influence economic trends, energy, the environment, standards and codes, subsidies, and social welfare.**

- **Laws, institutions, and regulations.**

The structure and level of demand for energy services, together with the performance of end-use technologies, largely determine the magnitude of final energy demand. The amount of final energy per unit of economic output (usually in terms of gross domestic product, or GDP), known as the final energy intensity, is often used to measure the effectiveness of energy use and the consumption patterns of different economies.

Economies with a large share of services in GDP and a large share of electricity in the final energy mix usually have lower final energy intensities than do economies based on materials and smokestack-based industries and fuelled by coal and oil. The final energy demand mix, the structure and efficiency of energy supply (resource extraction, conversion, transmission, and distribution), domestic resource availability, supply security, and national energy considerations then determine primary energy use.

Global primary energy use expanded by about 2 percent a year in 1970-98 (table 1.1). This growth rate fell to just under 1 percent a year in 1990-98 as a result of regional differences in socioeconomic development. First, the severe economic collapse of transition economies in Eastern Europe and the former Soviet Union reduced income by 40 percent and primary energy use by 35 percent between 1990 and 1998. Second, the rapid growth experienced by developing countries in the 1980s slowed in the early 1990s and slowed even more during the financial crisis of 1997-98. Third, among OECD regions, energy growth exceeded the long-term global average only in Pacific OECD countries. In North America, despite continued economic expansion and the availability of inexpensive energy services throughout the 1990s, total energy use grew by just 1.4 percent a year (the same as the OECD average). If corrected for weak economic performance in transition economies and the 1997-98 financial crisis, global energy use would have continued to grow by 2 percent a year throughout the 1990s.

Energy use by developing countries has increased three to four times as quickly as that by OECD countries - the result of life-style changes made possible by rising incomes and higher population growth. As a result the share of developing countries in global commercial energy use increased from 13 percent in 1970 to almost 30 percent in 1998. On a per capita basis, however, the increase in primary energy use has not resulted in more equitable access to energy services between developed and developing countries. (Annex C provides energy data and trends related to the discussion in this chapter, disaggregated by country and region.)

In Africa per capita energy use has barely increased since 1970 and remains at less than 10 percent of per capita use in North America (annex table C2). The same is true for Asia despite a near-doubling in per capita energy use since 1970. In essence this means that most Africans and Asians have no access to commercial energy. Latin America saw little improvement, while China and especially the Middle East made above-average progress in providing access to modern energy services. Energy use in non-OECD Europe and the former Soviet Union has been affected by economic restructuring, which in the former Soviet Union led to negative per capita growth in energy use between 1971 and 1997. Per capita energy use stayed nearly constant in North America, while substantial growth occurred in the Pacific OECD.

TABLE 1.1. COMMERCIAL PRIMARY ENERGY USE BY REGION, 1970-98[a]

Region	1970 (exajoules)	1980 (exajoules)	1990 (exajoules)	1998 (exajoules)	1998 as share of world total (percent)	Annual growth rate, 1970-98 (percent)	Annual growth rate, 1970-80 (percent)	Anr gro ra 198 (per
North America	74.7	85.6	93.4	104.3	29.4	1.2	1.4	0.
Latin America	5.7	9.2	11.3	15.1	4.3	3.6	4.9	2.
OECD Europe[b]	51.6	61.9	66.5	70.1	19.7	1.1	1.8	0.
Non-OECD Europe[c]	3.6	6.1	6.5	4.8	1.3	1.0	5.3	0.
Former	31.8	47.2	58.5	37.5	10.6	0.6	4.0	2.

Soviet Union	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Middle East	3.0	5.6	10.6	15.4	4.3	6.0	6.4	6.
Africa	2.9	5.6	8.9	11.0	3.1	4.8	6.6	4.
China	9.8	17.8	28.5	36.0	10.1	4.8	6.2	4.
Asia[d]	6.0	10.6	18.8	28.1	7.9	5.7	5.9	5.
Pacific OECD[e]	14.1	19.4	26.0	32.8	9.2	3.0	3.2	3.
World total	**203.2**	**269.0**	**328.9**	**354.9**	**100.0**	**2.0**	**2.8**	**2.**
OECD countries	140.4	166.9	185.9	207.2	58.4	1.4	1.7	1.
Transition economies	35.4	53.3	65.0	42.3	11.9	0.6	4.2	2.
Developing countries	27.4	48.8	78.0	105.5	29.7	4.9	5.9	4.

a. Excluding commercial biomass. b. Includes Czech Republic, Hungary, and Poland. c. Excludes the former Soviet Union. d. Excludes China. e. Australia, Japan, Republic of Korea, and New Zealand.

Source: BP, 1999.

Regional energy use is even more inequitable when viewed in terms of per capita electricity use. The difference between the least developed countries (83 kilowatt-hours

per capita) and the OECD average (8,053 kilowatt-hours per capita) is two orders of magnitude (see annex table C.2).

The link between energy use and economic activity is neither static nor uniform across regions. In the past, energy and economic development were closely related. But this relationship does not necessarily hold at higher levels of economic development. During 1960-78 changes in primary energy use and GDP grew at the same rate in OECD countries (figure 1.1). Thereafter, a change in elasticity between energy and economic activity suggests that the often-postulated one-to-one relationship between primary energy use and economic activity can be changed, at least temporarily. Because of its versatility, convenience, cleanliness (at point of use), and productivity-enhancing features, the increase in electricity use has outpaced GDP growth in all regions - often by a large margin. In addition, the efficiency of converting electricity from final energy to energy services is the highest of all fuels.

Energy transformation is the fastest-growing sector in all countries except transition economies, generally followed by transportation. Electricity generation dominates energy transformation, reflecting the continued importance of electricity for economic development. Oil refining, coal transformation (coking), gasworks, centralised heat production, transmission, and distribution losses account for the rest of the energy used by energy transformation.

Energy trade patterns and globalisation

The growing share of traded goods and services in gross world product reflects a continued shift towards integrated global commodity markets. This share approached 43 percent in 1996, up from 25 percent in 1960. The value share of energy in trade peaked in 1979 at almost 14 percent, then fell to 3-5 percent in the 1990s.

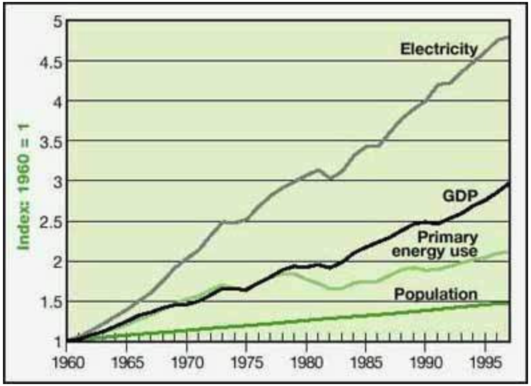

FIGURE 1.1. CHANGES IN GDP, POPULATION, PRIMARY ENERGY USE, AND ELECTRICITY USE IN OECD COUNTRIES, 1960-97

Source: IEA, 1999.

Still, the world energy system has become more integrated, as evidenced by the rising share of energy crossing borders before reaching final consumers. Energy trade slipped to 40 percent of primary energy use in 1985 (down from 50 percent in 1970) but rebounded after the collapse in oil prices in 1986. By the end of the 20th century this share was approaching 55 percent.

The fast-growing Asian economies contributed significantly to this increase. Their energy imports tripled between 1985 and 1997, reaching 13 percent of world energy imports. The share of OECD countries in global energy trade dropped 6 percentage points thanks to stepped-up intraregional trade and increased domestic production of oil (accounting for 13 percent of domestic oil production in 1990, up from 6 percent in 1985) and gas (30 percent of domestic gas production in 1985). OECD countries in Europe cut their share of global imports from 25 percent in 1985 to 16 percent in 1997, while North America

doubled its share to 8 percent over the same period.

Global energy trade remains dominated by crude oil and oil products. Despite steady growth in coal trade and accelerated penetration of natural gas in the 1990s, the share of crude oil and oil products in trade only fell from 90 percent in 1971 to 77 percent in 1997. While trade in coal, natural gas, and even oil products expanded largely unaffected by world oil market prices, trade in crude oil definitely responds - though with a lag - to market price changes. Thus crude oil remains the world's swing fuel, with Middle Eastern countries as the swing supplier despite the fact that the Middle East has the lowest production costs.

Crude oil and oil products

Developing countries have almost doubled their share of crude oil and oil product imports since 1979. While other major importers such as Western Europe and Japan have reduced or held steady their share of the global oil trade, the U.S. thirst for oil has reached an all-time high, accounting for 25 percent of global oil trade. In 1998 some 46 percent of oil trade originated in the Middle East - up from 38 percent in 1985. The region is on track to regain market shares of well above 50 percent. Its low production costs (on average, less than $5 a barrel) exposes investments in oil production capacity elsewhere to above-average risks. It appears that Organisation of the Petroleum Exporting Countries (OPEC) countries have regained their monopoly power lost in 1986, and can control oil market prices in either direction.

For importing countries, concerns about oil import dependence and supply security appear to have given way to market forces and high expectations that new exploration and development will bring new oil to the market at a rate commensurate with demand. Moreover, in the wake of globalisation and non-polarisation, quasi-open access to OPEC oil has accelerated the shift of oil from a strategic good to a commodity, further lowering

supply security concerns.

Still, the world oil market remains fragile. In March 1999 OPEC countries cut production by 85 million tonnes a year, or 2.5 percent of world oil production. This was in addition to an earlier cut of 125 million tonnes. As a result of strong world oil demand, including that from the rebounding Asian economies and the surging U.S. economy, market prices almost tripled within about a year. (World market prices for API Gravity 2 oil were $9.39 a barrel in December 1998 and $27.55 a barrel in March 2000.)

The impact of oil market prices or of high dependence on oil imports (or both) on the economies of several developing countries is shown in figure 1.2. In several countries oil imports absorb a large share of export earnings. The low oil market prices of the mid-1990s benefited these economies relative to 1985 (the year before oil prices collapsed) and 1990 (when prices soared during the Gulf war). The pattern for Haiti differs from those of the other countries in figure 1.2. There the share of export earnings spent on oil imports has more than doubled since 1985. The 1999 hike in oil prices will likely absorb similar shares of export earnings as in 1985 and 1990.

Coal

World coal production runs about 4,500 million tonnes, equivalent to some 2,230 million tonnes of oil equivalent (Mtoe), 210 Mtoe of which corresponds to steam coal trade. In recent years coal exports have grown by 4 percent a year. There is no indication that demand will outstrip supply in the foreseeable future. Production capacity is well developed, and new market entrants (Colombia, Kazakhstan, Russia, Venezuela) are eager to join the trade.

Over the past 20 years a quasi-unified coal market has emerged in which the United States has assumed the role of marginal supplier. Indeed, U.S. capacities are among the world's highest-cost supplies. Everything else being equal, prices tend to gravitate towards the

production costs of the marginal producer. Because productivity advances determine the cost of U.S. production, U.S. productivity levels determine the world price of coal.

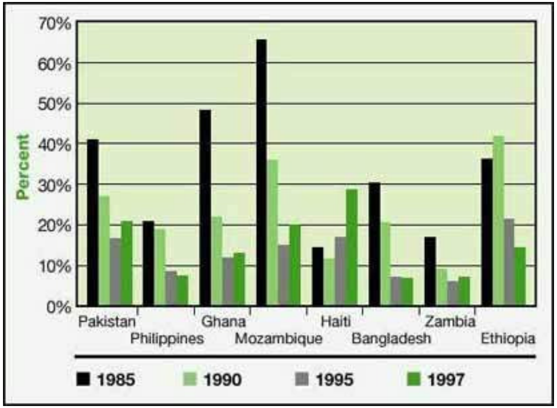

FIGURE 1.2. OIL IMPORTS AS A SHARE OF EXPORT EARNINGS IN VARIOUS DEVELOPING COUNTRIES, 1985-97

Source: World Bank, 1999.

Since 1990 electricity rates have declined steadily, especially in countries where electricity market deregulation has been or is about to be introduced.

Natural gas

Unlike oil and coal markets, natural gas has yet to play a significant role in global markets. Some 20 percent of global gas crosses borders before reaching final consumers. About 75 percent of that gas is traded by pipe between essentially neighbouring countries. Hence natural gas trade has developed primarily at the regional level or between adjacent regions. Pipeline transmission is capital-intensive and allows little flexibility in the choice of buyers and sellers. Still, pipeline gas is traded between production and consumption sites more than 4,000 kilometres apart. Three major regional gas trade markets have emerged:

- **The almost fully integrated North American market, characterised by accelerated growth of Canadian exports to the U.S. market (from 26 Mtoe in 1990 to 79 Mtoe in 1998). There have also been minor exchanges between Mexico and the United States.**

- **The European market, with the following principal suppliers: the former Soviet Union (with a pipeline producing 108 Mtoe in 1998), Norway (pipeline producing 38 Mtoe), and the Netherlands (pipeline producing 33 Mtoe), and Algeria with minor liquefied natural gas supplies from Libya (pipeline and liquefied natural gas producing 47 Mtoe). Gas trade expanded by 2.7 percent a year in 1990-98.**

- **The Asian gas market is dominated by liquefied natural gas (which increased from 47 Mtoe in 1990 to 77 Mtoe in 1998). The main suppliers are Indonesia, Malaysia, Australia, Brunei, the United Arab Emirates, and Qatar. Japan, the Republic of Korea, China, and Taiwan (China) are the main customers.**

A gas market has also begun to develop in Latin America, with exports from Bolivia to Argentina and Argentina to Chile.

Energy prices and taxes

Energy prices influence consumer choices and behaviour and can affect economic development and growth. High energy prices can lead to skyrocketing import bills, with adverse consequences for business, employment, and social welfare. Energy exporters benefit from high energy prices. High energy prices also stimulate exploration and development of additional resources, foster innovation, and encourage efficiency improvements.

While some impacts of energy prices are fairly steady, others are more transient. For example, higher absolute prices have had little impact on economic development in Japan and OECD countries in Europe relative to the much lower prices in the United States and some developing countries. The price hikes of the 1970s affected economic growth in all energy-importing countries, however. Thus it appears that economies are more sensitive to price changes than to price levels. But even price changes appear not to cause the turbulence of the past. The recent near-tripling in world oil market prices has, at least in OECD countries, not yet had any impact on economic development.

Energy prices, which include taxes, must be clearly distinguished from costs, average costs from marginal costs, and contract markets from spot markets. Two types of exchange modes - contract markets and spot markets - prevail in most major energy markets. Contracts are long-term trade agreements between exporters and, in the case of oil, refineries. Contracts account for about 80 percent of traded oil. The prices associated with these contracts are usually not disclosed. Contract prices are quasi-fixed for the contract period but include certain adjustment mechanisms that account for major market changes.

The remaining 15-20 percent of international oil is traded in spot markets. Spot sales are more or less instantaneous sales of entire cargoes. Initially, spot market transactions served as a mechanism to clear markets for a small share of production that was not contracted or became available for other reasons - say, seasonal market fluctuations. The

spot market has since become the principal mechanism for setting oil prices as well as an essential ingredient for managing risk.

Steam coal prices are less volatile than oil, which is one reason coal remains a popular fuel for electricity generation. In addition, coal can be significantly cheaper than natural gas and oil. While internationally traded energy prices are an important factor in the approximately $450 billion business (at $20 a barrel), the energy bills presented to users are considerably higher than the trade prices because most countries tax energy use. In general, OECD taxes on residential energy use are higher than those on industry. In some developing and transition economies taxes are higher for industry, usually as a cross-subsidy to provide energy services to the poor. Energy taxes and subsidies are an important tool for governments pursuing energy development objectives.

Since 1990 electricity rates have declined steadily, especially in countries where electricity market deregulation has been or is about to be introduced. Market liberalisation has a more profound impact on the electricity rates of industry than of households. Prices for light oil at the national level largely mirror movements in the global market price for oil. Light oil prices are much lower in India and other developing countries than in OECD countries, reflecting government subsidies.

Energy investments

Capital investment is a prerequisite for energy development. Energy system development and structural change are the results of investments in plants and equipment as well as in energy system infrastructure. Difficulties in attracting capital for energy investments may impede economic development, especially in the least developed countries. Although energy investments account for only a small share of the global capital market, the provision of the capital required to finance the growing needs of the energy sector cannot be assumed, especially in developing countries.

Market size and product mobility often favour investments in oil exploration and development over, for example, natural gas or energy efficiency.

General features

The challenges of raising funds for energy investments include the perceived risk to investors and the uncertainty on rates of return. Returns on energy investments do not always compare well to those on other infrastructure investments. During 1974-92 electricity projects supported by the World Bank achieved average rates of return of 11 percent a year - while returns to urban development projects were 23 percent and to transport projects, 21 percent (Hyman, 1994). Also important is the allocation of funds within the energy sector. Rate of return considerations discriminate against small-scale, clean, and innovative energy supplies and against investments in energy efficiency. Market size and product mobility often favour investments in oil exploration and development over, for example, natural gas or energy efficiency.

Investments in energy plants, equipment, and infrastructure must be viewed in the context of economic growth, savings, and the size and degree of liberalisation of capital markets. The current average global savings rate is about 22 percent of GDP - 21 percent in developed countries and 24 percent in developing countries. In transition economies recent declines in GDP have been matched by reduced savings, keeping the savings rate at about 20 percent (World Bank, 1999). Although energy investments as a share of total investments vary greatly among countries and between stages of economic development, an average of 1.0-1.5 percent of GDP is invested in energy. This share is expected to remain relatively stable.

Thus current energy investments amount to $290-430 billion a year. But such investments do not include investments in end-use devices and appliances, energy efficiency improvements in buildings, and so on. Including these investments doubles capital requirements.

Energy investments have long lives. Investments in electricity generating plants, refineries, and energy-related infrastructure made in the next 10 years will likely still be in operation in 2050 and beyond. Hence there is a fair amount of inertia with regard to the rate of change that can be introduced in the energy system. For example, the current global average conversion efficiency for coal-fired electricity generation is 34 percent and for gas-fired electricity generation, 37 percent. The best commercially available coal and gas power plants have much higher efficiencies: 43-48 percent for coal and 55-60 percent for natural gas.

Given the longevity of the existing capital stock, it is unlikely that the global average will reach, say, 45 percent for coal-fired electricity by 2050 unless the most efficient plants are adopted universally. But most efficient does not always mean least cost - low-cost domestic coal can be burnt more economically in a medium-efficient plant than in a high-efficient but more capital-intensive alternative.

The efficiency of electricity generation also varies widely among regions. The Middle East introduced coal for electricity generation in the early 1980s and, because most coal is imported, adopted the latest coal combustion technology. As a result the region's average conversion efficiency exceeds that of OECD countries. Another aspect affecting efficiency is the introduction of sulphur and nitrogen oxide abatement equipment, which tends to reduce efficiency (as in Asia and Africa).

Capital flows

The globalisation of economic production has led to an acceleration of capital flows.

Indeed, capital markets have been growing faster than GDP for some time, and this trend is unlikely to change. Annual global energy investments account for about 7 percent of international credit financing, which is about $3.6 trillion (Hanke, 1995). With capital markets growing relative to GDP, and assuming relatively stable future energy investment ratios, capital market size does not appear to be a limiting factor for energy sector finance.

Scarce public funds, especially in developing countries, are sought by many needy projects ranging from rural development, education, and health care to energy supply. Because energy supply, more than any other alternative, is often seen as more readily capable of generating revenues early on, energy investments are increasingly viewed as a private sector affair. Yet private funds are not flowing into most developing countries.

Foreign direct investment approached $400 billion in 1997, up from $50 billion in 1984, and accounted for 1.8 percent of OECD GDP (up from 0.6 percent in 1984; figure 1.3). Foreign direct investment in energy projects is estimated at 5-15 percent of the total (Victor, 2000). Foreign direct investment is generally commercially motivated, with the sponsor of investments expecting not only to recover the initial capital but also counting on competitive returns. This cannot always be guaranteed in developing countries with potentially fragile governments or the absence of free markets. Indeed, 25 countries received 89 percent of global foreign direct investment in 1996, and only 10 of these are developing countries - none are among the 47 least developed countries. Brazil, China, and Mexico are the only developing countries to receive more than 2 percent of the world total.

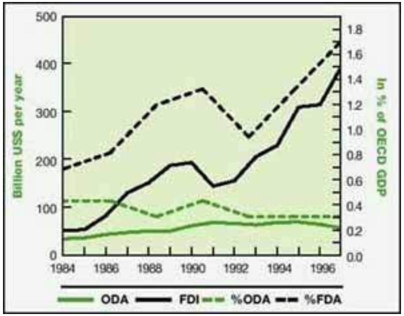

FIGURE 1.3. FOREIGN DIRECT INVESTMENTS AND OFFICIAL DEVELOPMENT ASSISTANCE, 1984-97, IN US$ AND AS SHARE OF OECD GDP

Source: World Bank, 1999.

In contrast to foreign direct investment, official development assistance is meant as development aid in the form of grants. Official development assistance increased from $34 billion in 1984 to $69 billion in 1995 but slipped to $56 billion in 1997, or 0.25 percent of OECD GDP - a far cry from the 0.7 percent target agreed to by developed countries (see figure 1.3).

Against these recent developments in international financial and capital flows, prospects for financing energy projects in developing countries generally look bleak. Most foreign investors lack confidence in the ability of developing country energy projects to provide stable (and competitive) returns until the investment has been recovered. Hence, until the economic risk to foreign investors can be eliminated (through deregulated energy and financial markets, steady revenue generation through bill collection, firm policies on profit transfers, and the like), developing countries will have to continue to finance their energy development from domestic savings.

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Chapter 2. Energy and Social Issues

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ABSTRACT

Poverty is the most fundamental reality of developing countries - and the energy consumption patterns of poor people tend to add to their misery and aggravate their poverty. A direct improvement in energy services would allow the poor to enjoy both short-term and long-term advances in living standards. Required are energy strategies

based on increasing the use of energy carriers other than biomass, or on using biomass in modern ways. Poverty alleviation and development depend on universal access to energy services that are affordable, reliable, and of good quality.

It has been noted that "poverty has a woman's face". Energy and women are linked in many diverse ways, particularly through the nature of the (predominantly biomass) energy resource base, the characteristics of the household and community economy, the features of energy policy, and the position of women in families and communities. Energy can be a vital entry point for improving the position of women in households and societies.

Many of today's global problems arise from the availability and use of natural resources, which depend on the size of the human population putting pressure on them. But population is more than just an external factor influencing energy consumption. Energy consumption patterns can also influence population growth through their effect on the desired number of births in a family and the relative benefits and costs of fertility.

Energy is linked to urbanisation through its implications for land use, transportation, industry, construction, infrastructure, domestic appliances and products, biomass consumption, and gender. Energy strategies can be designed to improve the urban environment - particularly for transport, industrialisation, mitigation of heat island effects, and construction.

Although energy devices (houses, vehicles, appliances) have become much more efficient in industrialised countries, the number and use of these devices have increased markedly. If appliances and their use (the material basis of lifestyles) are taken as determinants of energy consumption, then strategies can be devised based on reducing the number and use of energy-intensive appliances.

Almost every industrialised country has poor and disadvantaged populations. But the

energy aspects of poverty are radically different for industrialised and developing countries. Energy exacerbates poverty in industrialised countries - for example, through the disconnection of energy services or the absence in cold countries of universal affordable warmth.

There are two-way linkages between energy and poverty, women, population growth, urbanisation, and lifestyles. That is, these global issues determine energy consumption, and energy systems influence the issues. Current energy consumption patterns are aggravating these global issues, leading to unsustainability. But energy can also help solve major global problems - particularly those related to poverty, women, population growth, urbanisation, and lifestyles. To realise this potential, energy must be brought to centre stage and given the same importance as the other major global issues.

Human society cannot survive without a continuous use, and hence supply, of energy. The original source of energy for social activities was human energy - the energy of human muscle provided the mechanical power necessary at the dawn of civilisation. Then came the control and use of fire from the combustion of wood, and with this, the ability to exploit chemical transformations brought about by heat energy, and thereby to cook food, heat dwellings, and extract metals (bronze and iron). The energy of flowing water and wind was also harnessed. The energy of draught animals began to play a role in agriculture, transport, and even industry. Finally, in rapid succession, human societies acquired control over coal, steam, oil, electricity, and gas. Thus from one perspective, history is the story of the control over energy sources for the benefit of society.

Modern economies are energy dependent, and their tendency has been to see the provision of sufficient energy as the central problem of the energy sector. Indeed, the magnitude of energy consumed per capita became an indicator of a country's 'modernisation' and progress. Energy concerns have long been driven by one simple preoccupation: increasing the supply of energy. Over the past few decades, however,

serious doubts have arisen about the wisdom of pursuing a supply-obsessed approach. Attention is shifting towards a more balanced view that also looks at the demand side of energy. But access to, and the use of, energy continues to be a necessary and vital component of development.

In the supply-driven approach, the appetite for energy often exceeded the capacity of local sources of supply. The energy supplies of some countries had to be brought from halfway round the world. Efforts to establish control over oil wells and oil sea routes have generated persistent tensions and political problems. This situation has also shaped national policies for foreign affairs, economics, science, and technology - and influenced the political map of the world. The security of energy supplies was a major geostrategic issue throughout the 20th century.

At the same time, the magnitude and intensity of energy production and use began to have deleterious impacts on the environment. By the late 1960s the gravity of the environmental problems arising from toxic substances had become clear. Awareness of the environmental issue of acid rain followed. The problems of urban air pollution have been known for a long time. Climate change discussions intensified in the mid-1970s. All these problems are directly related to the quality and quantity of fuel combustion.

Then came the oil shocks of 1973 and 1979, along with price increases that led to economic disruption at international, national, and local levels. The oil shocks thrust the energy problem into the range of awareness of individuals. Some oil-importing developing countries suffered serious balance of payments problems, and in some cases landed in debt traps. The development of indigenous fossil fuel resources and power generation faced the hurdle of capital availability. And more recently, the accumulation of greenhouse gases in the atmosphere resulting from energy consumption has focussed attention on the threat of climate change, with the possibility of far-reaching consequences. In parallel, the lack of control over energy resources has highlighted the importance of national and local

self-reliance (as distinct from self-sufficiency).[1]

What human beings want is not oil or coal, or even gasoline or electricity per se, but the services that those energy sources provide.

Thus, quite apart from the critical issues related to the supply of fossil fuels, the political, social, and economic institutions dealing with energy have failed to overcome a new series of grave problems - problems of economics (access to capital), empowerment (self-reliance), equity, and the environment. Many of the human-made threats to the species and the biosphere, indeed to civilisation's future, are energy-related. Awareness of the energy dimensions of these issues has arisen more recently, but the underlying energy bases of the issues are still imperfectly appreciated by decision-makers, perhaps because this understanding has not been disseminated widely.

This chapter is devoted to the main linkages between energy and social issues. It shows that energy strategies have impacts on major issues related to poverty, women, population, urbanisation, and lifestyles. Data on infant mortality, illiteracy, life expectancy, and total fertility as a function of energy use are shown in figure 2.1, which is not meant to suggest that there is a causal relation between the parameters represented.[2]

These linkages imply that energy has to be tackled in such a way that social problems are at least not aggravated - which is what conventional energy strategies tend to do, because they are so preoccupied with energy supplies that they ignore these problems completely or deal with them inadequately. Because of its linkages to social problems, energy can contribute to their solution. Unfortunately, energy and the major problems of today's

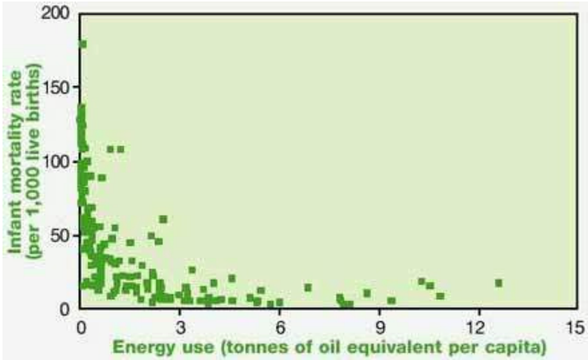
world are not being dealt with in an integrated way by national and international policy-makers.

Towards a new approach to energy for human uses

Another approach is called for: one that recognises that the satisfaction of social needs by energy is best achieved by treating neither energy supply nor energy consumption as ends in themselves. After all, what human beings want is not oil or coal, or even gasoline or electricity per se, but the services that those energy sources provide. Thus it is important to focus on the demand side of the energy system, the end uses of energy, and the services that energy provides.

In fact, one can identify a rather small set of the most important of these energy services. They include the basic services of cooking, heating, lighting, space conditioning, and safe storage of food. In addition, the provision of clean water and sanitation, which is facilitated by energy, affects public health in cities as well as rural areas. Societies also require services such as transportation, motive power for industry and agriculture, heat for materials processing (steel, cement, and so on), and energy for commerce, communication, and other economic and social activities.

FIGURE 2.1a. COMMERCIAL ENERGY USE AND INFANT MORTALITY IN INDUSTRIALISED AND DEVELOPING COUNTRIES



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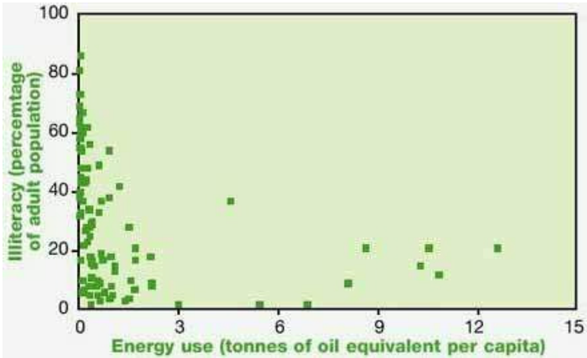

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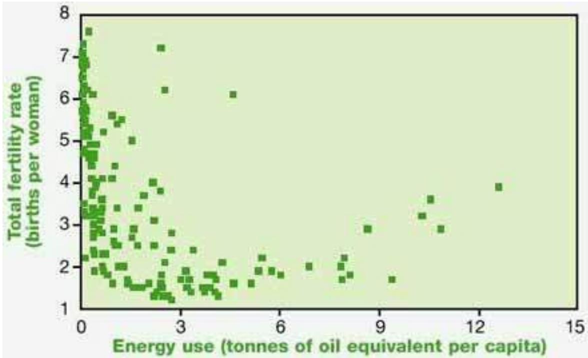

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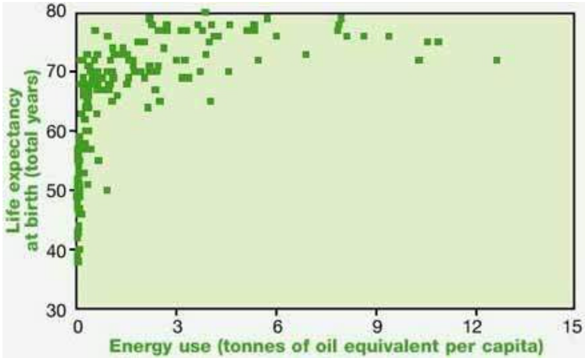

Figure

Note: Data on commercial energy use are for 1994; data on social indicators are for 1995.

Source: World Bank, 1997.

The demand-side, end-use-oriented energy services approach stresses another difference. The end user cares less about the original sources or fuels used to provide the service than about crucial attributes of the final energy carrier from a social standpoint. Among the most important attributes are energy's accessibility (particularly for the poor, women, and those in remote areas), affordability, adequacy, quality, reliability, safety, and impact (particularly on the immediate environment).

The traditional supply-side approach tends to forecast energy demand on the basis of projections of past and present economic and demographic trends. It tends to ignore the large variety of scenarios that are feasible considering the opportunities and potentials offered by changes in energy demand, improvements in energy efficiency, shifts from traditional energy sources to modern energy carriers, and dissemination of new energy technologies.

To best serve humanity, the energy system should help achieve the goals laid down at the 1992 United Nations Conference on Environment and Development (the so-called Earth Summit) in Rio de Janeiro, and in other UN contexts. These goals include the promotion of economically viable, socially harmonious, environmentally safe, and strategically secure societies. Meeting these goals requires five crucial components: economic efficiency, equity (particularly for the poor, women, ethnic minorities, and those in remote areas), empowerment or self-reliance, environmental soundness, and peace. Together these components can be taken as some of the most essential measures of sustainable development.

The Earth Summit led to greater awareness that development needs to be sustainable if it is to serve humanity's short- and long-term goals. More than 150 governments committed themselves to the protection of the environment through the Rio Declaration and Agenda 21. Government representatives considered that key commitments related to energy would be covered under the United Nations Framework Convention on Climate Change

(UNFCCC), which was signed on this occasion. Agenda 21 makes this important statement:

> **Energy is essential to economic and social development and improved quality of life. Much of the world's energy, however, is currently produced and consumed in ways that could not be sustained if technology were to remain constant and if overall quantities were to increase substantially. The need to control atmospheric emissions and other gases and substances will increasingly need to be based on efficiency in energy production, transmission, distribution and consumption, and on growing reliance on environmentally sound energy systems, particularly new and renewable sources of energy. (UN, 1993b, ch. 9.9)**

The Framework Convention on Climate Change, which has been ratified by 164 countries, defines an ecological target - without linking this target to social impacts! - that implies the implementation of energy measures. The Intergovernmental Panel on Climate Change (IPCC) also has presented scientific assessments of data related to climate change and prospects for inputs, adaptation, and mitigation of climate change and their relationship to energy issues.

Since the Earth Summit many other initiatives have been taken at various levels to promote sustainable energy through increased energy efficiency, support for renewable energy sources, and integrated energy resource planning. There are now good examples, significant benchmarks, and success stories all around the world of efforts in these areas. But these efforts are dispersed. Though they provide a good starting point, they cannot meet the tremendous energy challenges facing humanity during the 21st century.

Energy issues tend to get sidelined in many international forums. Such major global issues as poverty, women, population, urbanisation, lifestyles, undernutrition, environment, economics, and security tend to get higher priority than energy. But missing from most discussions of these issues is the important linkage between each of them and global and

local energy systems. It is too little appreciated that achieving progress in these other arenas can be greatly assisted by manipulation of energy systems.

Even when this linkage is mentioned, the discussion focuses on how these global issues determine energy consumption patterns. Energy is treated as the dependent variable. Very little attention is directed at understanding whether current energy patterns are aggravating these issues, and almost no attention is given to how alternative energy strategies can contribute to their solution.

Thus a fresh conceptual framework is required. The framework elaborated in this chapter, and depicted in figure 2.2, concerns the linkage between energy, on the one hand, and poverty, women, population, urbanisation, and lifestyles, on the other.[3]

The linkage between energy and food security is also crucial, particularly because it concerns the important social problem of undernutrition that is so widespread and serious, especially in developing countries. Despite this, the energy-undernutrition dimension is not addressed in this chapter, primarily because of space considerations. Moreover, the energy-undernutrition link has been treated adequately in other contexts, particularly in *Energy after Rio: Prospects and Challenges* (UNDP, 1997a), which explains how energy strategies can play a powerful role in increasing the supply of food as well as building an environment in which food is absorbed more effectively.

Indoor air pollution is a major by-product of the traditional use of biomass, which diminishes the quality of life, especially for women and young children.

As humankind enters the new millennium, it is important to highlight energy's critical

relationship to major global problems. The timeliness of the challenge derives from three critical elements that are converging to make the world thirstier for energy services: aspirations for a higher living standards, booming economies in large regions, and population growth.

The assessment that follows draws together a number of diverse elements that are relevant to sustainable development, and for which issues of supply and demand of energy are significant. It goes on to show new options for using energy more efficiently, and also how both renewable and fossil sources of energy can be used in cleaner, more efficient ways to help create a more sustainable future. In fact, the global goal for energy can be stated very simply: sustainable development of the world. Energy services therefore are a necessary condition for sustainable development.

Energy and poverty in developing countries

Poverty is the most fundamental reality of developing countries.[4] Poverty refers to an individual's (or family's) lack of access - associated primarily with inadequate income - to basic human needs such as food, shelter, fuel, clothing, safe water, sanitation, health care, and education. Poverty is manifested as the inability to achieve a minimum standard of what is needed for material well-being. Human poverty also entails the denial of opportunities and choices most vital to human development - including a long, healthy, creative life, a decent standard of living, dignity, self-esteem, the respect of others, and the things that people value in life.

Dimensions of poverty

Poverty is usually conceptualised and measured in terms of the proportion of people who do not achieve specified levels of health, education, or body weight. Operationally, however, poverty standards are typically expressed in a single dimension: the monetary

resources that would enable an individual to consume either a fixed bundle of basic goods and services (absolute poverty[5]), or a fraction of the bundle of goods and services that a reference group is able to, or actually does, consume (relative poverty).

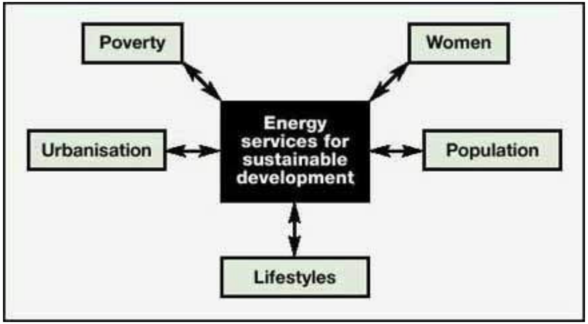

FIGURE 2.2. ENERGY AND SOCIAL ISSUES

UNDP's human poverty index goes beyond mere income poverty. It measures deprivation in three essential dimensions of human life: longevity (or vulnerability to death at an early age), knowledge (access to reading and communication), and a decent standard of living in terms of overall economic and social needs (percentage of people without access to safe water and health services and the percentage of underweight children under five).

Whether measured directly with a range of indicators of basic human outcomes, or indirectly with a single monetary dimension, poverty is indisputably among the world's largest, most urgent, and most fundamental problems. Its pervasiveness - as revealed by the extent to which elementary minimum needs are not satisfied - is undeniable. Whether food, shelter, health, education, or employment is considered, living standards of the majority in most developing countries are pathetically low. They represent a full-time struggle for survival - a type of existence largely unknown, and perhaps even

unimaginable, in industrialised countries. This struggle is quite apart from associated psychological reactions of deprivation and feelings of hopelessness and social disempowerment, often accompanied by deep feelings of personal need.

In perhaps the most ambitious and careful attempt yet undertaken to measure absolute poverty in developing countries, it has been estimated that, as of 1993, roughly 1.3 billion people in developing countries - 30 percent of their total population - consumed less than $1 a day worth of goods and services.[6]

Statistics on the inability of people in developing countries to satisfy basic human needs corroborate the enormous scale of poverty and highlight its breadth and complexity. For example, an estimated 20 percent of people in developing countries do not have access to health services, 30 percent lack access to safe water, and 61 percent lack access to sanitation (UNDP, 1996). And infant and child mortality rates in developing countries are more than 5 times higher than in industrialised countries, the proportion of children below age five who are underweight is 8 times higher, the maternal mortality rate is 14 times higher, and the proportion of births not attended by trained health personnel is 37 times higher.

Significant and widening disparities in human development and poverty are also found within countries between the rich and the poor, between rural and urban areas, between regions, between different ethnic groups, and between women and men. And income and development inequalities are greater within developing countries than within industrialised OECD countries. The richest 10 percent account for nearly half of national income or consumption in Brazil and South Africa. In contrast, the richest 10 percent in countries such as Germany, Japan, Norway, Switzerland, and the United States account for about 25 percent of their country's national income and spending. Industrialised countries not only have higher human development and lower poverty indexes; they are also more equitable than developing countries. But there has been overall progress in human

development over the past 30 years, as indicated by an examination of measures such as UNDP's Human Development Index (HDI). On average, a child born in a developing country today can expect to live 16 years longer than a child born in 1970. Adult literacy rates since then have increased by nearly half (UNDP, 1998).

Because efficient devices tend to have higher first costs, the poor invariably end up with less efficient devices that consume more energy for a given level of service.

Yet these favourable aggregate trends mask slow progress or even setbacks in many countries, especially among the poorest people. For example, life expectancy in Africa is still 20 years lower than in East Asia or Latin America and the Caribbean. And adult literacy rates in South Asia (51 percent) are shockingly lower than in Southeast Asia (90 percent) or in nearly all industrialised countries (UNDP, 1998).

The alleviation, if not eradication, of poverty is among the world's largest, most urgent, and most fundamental challenges - and not merely for humanitarian reasons. Societies with grave inequalities and disparities tend to be unstable. Large populations below the poverty line are explosive material for social upheavals. Thus poverty has politically unsustainable characteristics. It merits urgent consideration and immediate action.

The energy-poverty nexus

Energy services are a crucial input to the primary development challenge of providing adequate food, shelter, clothing, water, sanitation, medical care, schooling, and access to information. Thus energy is one dimension or determinant of poverty and development,

but it is vital. Energy supports the provision of basic needs such as cooked food, a comfortable living temperature, lighting, the use of appliances, piped water or sewerage, essential health care (refrigerated vaccines, emergency and intensive care), educational aids, communication (radio, television, electronic mail, the World Wide Web), and transport. Energy also fuels productive activities, including agriculture, commerce, manufacture, industry, and mining. Conversely, lack of access to energy contributes to poverty and deprivation and can contribute to economic decline.

The energy dimension of poverty - energy poverty - may be defined as the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe, and environmentally benign energy services to support economic and human development. The numbers are staggering: 2 billion people are without clean, safe cooking fuels and must depend on traditional biomass sources; 1.7 billion are without electricity. Increased access to such energy services will not, in itself, result in economic or social development. But lack of adequate energy inputs can be a severe constraint on development. Universally accessible energy services that are adequate, affordable, reliable, of good quality, safe, and environmentally benign are therefore a necessary but insufficient condition for development.

The energy ladder and household decisions about fuel choice

Poor people tend to rely on a significantly different set of energy carriers than the rich. The poor use proportionately more wood, dung, and other biomass fuels in traditional ways, and less electricity and liquefied petroleum gas (LPG). To illustrate this point, evidence from Brazil is shown in figure 2.3.

The observation that roughly 2 billion people depend mainly on traditional fuels for cooking is significant in part because indoor air pollution is a major by-product of the traditional use of biomass. This pollution diminishes the quality of life, especially for

women and young children.

Households use fuel for a variety of activities, including cooking, water heating, lighting, and space heating. Different energy carriers can be used for each of these activities. For instance, firewood, dung, charcoal, coal, kerosene, electricity, and LPG can be used for cooking; and kerosene and electricity for lighting.

These carriers (for a particular activity) form what is commonly referred to as an 'energy ladder' for that activity. Each rung corresponds to the dominant (but not sole[7]) fuel used by a particular income group, and different income groups use different fuels and occupy different rungs (Hosier and Dowd, 1987; Reddy and Reddy, 1994). Wood, dung, and other biomass fuels represent the lowest rung on the energy ladder for cooking. Charcoal and coal (when available) and kerosene represent higher steps up the ladder to the highest rungs, electricity and LPG.

The ordering of fuels on the energy ladder also tends to correspond to the efficiency of the associated systems (the fraction of energy released from the carrier that is actually used by the end-use device) and their 'cleanliness'. For example, the cook-stove efficiencies of firewood (as traditionally used), kerosene, and gas are roughly 15, 50, and 65 percent, respectively. As one proceeds up the energy ladder, the emission into the air of carbon dioxide, sulphur dioxide, and particulates also tends to decline.

Households seem to make choices among energy carrier options on the basis of both the household's socioeconomic characteristics and attitudes and the attributes of alternative carriers. Income is the main characteristic that appears to influence a household's choice of carrier (Leach, 1992; Reddy and Reddy, 1994).

Relevant attributes of energy carriers include accessibility, convenience, controllability, cleanliness, efficiency, current cost, and expected distribution of future costs. Because

different fuels require different appliances - stoves, lamps, and so on - with varying costs and durability, fuel costs have both fixed and variable components.

The importance of this distinction between fixed and variable costs is magnified by three factors: the presence of quasi-fixed costs, such as fixed monthly charges for a natural gas or electricity hookup; the need to make large 'lumpy' purchases of some fuels, such as tanks for storing propane gas; and the need to make sometimes sizeable security deposits, either to guarantee the payment of monthly bills or the return of equipment such as LPG cylinders or canisters. Despite the fact that they are refundable, security deposits impose a present cost on households, the magnitude of which depends upon the return on those funds in their next best use, or their 'opportunity cost'.

The division of costs into fixed, quasi-fixed, and variable components affects household decisions about fuel choice. The outcome of these decisions depends on the household's preparedness to forgo present consumption for future benefits. The degree to which a household discounts future benefits may be determined in part by its level of wealth and its liquidity. Households may apply high discount rates to fuel consumption decisions, because of the high cost of either diverting resources from other uses or of borrowing funds to cover up-front capital costs. Thus they will tend to prefer fuel carriers that involve lower up-front or first costs. Poor people use much higher discount rates than the rich when making energy carrier decisions (Reddy and Reddy, 1994). Lack of reliable income may force them to think almost solely in terms of the first cost, rather than the life-cycle cost. Because efficient devices tend to have higher first costs, the poor invariably end up with less efficient devices that consume more energy for a given level of service. Fuel costs may be determined either in a market or implicitly in terms of the opportunity cost of time spent gathering the fuel, such as firewood.

Energy strategies for alleviating poverty in developing countries

The poor pay more money, or spend more time for energy services, than those who are better off. This has a powerful implication. The economic hardship endured by poor households is understated when their income (consumption expenditure) is evaluated in terms of its command over the basket of goods and services purchased by households with average income or consumption expenditures.

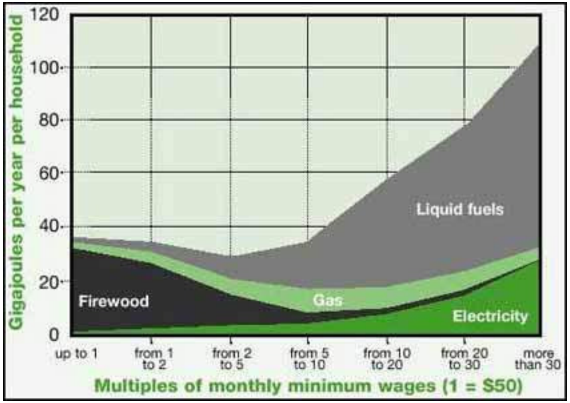

FIGURE 2.3. AVERAGE ENERGY DEMAND BY INCOME SEGMENT IN BRAZIL, 1988

Source: De Almeida and de Oliveira, 1995.

Further, in many places, poor households could achieve the same level of energy services at much less daily cost if they could move up the energy ladder to LPG or electricity. Demonstration projects have shown that the price that the poorest household is prepared to pay for electric lighting is near the full cost because the alternative of kerosene lamps involves much higher expenditures.

Substitution of energy carriers or devices that enable greater efficiency would confer

sizeable gains in purchasing power on poor urban households. This analysis of the expenditure patterns of households in different income groups suggests that such an increase in effective resources would be devoted almost entirely to better satisfying basic needs for food, shelter, clothing, health, education, and additional fuel. Thus cost-effective improvements in energy efficiency have considerable potential to reduce poverty in all of its key dimensions.

It appears that the energy consumption patterns of poor people tend to add to their misery and aggravate their poverty for the following reasons:

- **Because the poor pay more for daily energy needs, they are less likely to accumulate the wealth needed to make the investments that are necessary to make use of cheaper and more efficient fuels and appliances.**

- **The use of biomass compromises the health of household members, especially when it is burned indoors without either a proper stove to help control the generation of smoke or a chimney to draw the smoke outside. Thus in addition to its relatively high cost, the use of biomass fuel may promote higher medical care expenditures and diminish the poor's ability to work productively (chapter 3).**

- **Biomass also has deleterious environmental consequences outside the household. These effects are reinforced by the fact that biomass users are less likely to boil the water they drink, for reasons of cost or custom. Insofar as the use of biomass in urban areas promotes deforestation, reliance on biomass may also tend to increase its future cost, further diminishing the living standards of the poor (Leach, 1992; Dasgupta, 1993).**

The linkages between energy and poverty have implications for strategies to alleviate poverty. The standard poverty alleviation strategies of macroeconomic growth, human capital investment, and wealth redistribution do not directly address the energy-poverty

nexus in developing countries. If patterns of energy use among the poor depress their nutrition, health, and productivity, the poor are likely to absorb the benefits of economic growth only very slowly. Education will continue to increase their earning capacity, but by less when kerosene rather than electricity is the main illuminant, when lighting is poor, and when access to knowledge though radio and television is limited. The situation is worsened when traditional biomass is the dominant cooking fuel: school attendance flags because of the burden of collecting it and the respiratory illness caused by cooking with it.

Dramatic increases in living standards in developing countries can theoretically be achieved with small inputs of energy.

In contrast, strategies that, in addition to standard poverty alleviation strategies and rural development, include direct improvement of energy services allow the poor to enjoy both short-term and self-reinforcing long-term advances in their living standards. Such strategies should promote increased use of energy carriers other than biomass, or use of biomass in modern ways.

In fact, this approach suggests that major advances in poverty alleviation can be achieved with relatively small inputs of energy, as evidenced from the so-called 1 kilowatt per capita scenario (Goldemberg and others, 1985). This scenario was based on a 'thought experiment' in which the following question was explored: If all developing countries achieved a level of energy services comparable to that of Western Europe in the 1970s,[8] and if they deployed the most efficient energy technologies and energy carriers available in the 1980s, what would be the per capita energy consumption corresponding to this vastly improved standard of living?

The surprising answer was that, provided that the most energy-efficient technologies and energy carriers available are implemented, a mere 1 kilowatt per capita - that is, a 10 percent increase in today's energy per capita - would be required for the populations of developing countries to enjoy a standard of living as high as that of Western Europe in the 1970s. In other words, dramatic increases in living standards in developing countries can theoretically be achieved with small inputs of energy.[9]

Energy and poverty in industrialised countries

Almost every industrialised country has its poor and disadvantaged, but the energy aspects of their poverty are radically different from those for developing countries. The poor in industrialised countries are not energy poor in an absolute sense. Indeed, the direct use of energy by the poor in the United States for homes and automobiles is 1.65 times the average use in developing countries for all purposes, including the indirect use of energy for industrial and commercial purposes and public transportation. The high energy expenditures of the poor relative to those in developing countries are also not an indicator of affluence. These expenditures are essential to meet basic needs in the industrialised country context. The poor in industrialised countries consume much more energy than their counterparts in developing countries because of the much wider use of energy-intensive technologies.

Despite this apparent energy affluence of the poor in industrialised countries relative to the masses in developing countries, their economic plight cannot be ignored. The poor in industrialised countries spend a larger fraction of their income on energy relative to the average. Energy patterns clearly exacerbate poverty in industrialised countries - just as they do in developing ones. This linkage is not taken into account in conventional energy planning and policy-making. Rather, conventional energy strategies adopt the 'energy trickle-down' approach to social welfare and implicitly assume that if energy supplies are increased, these problems will take care of themselves. In industrialised countries the

problem is not that the poor do not have access to enough energy to satisfy their needs, but rather that their circumstances require them to consume too much energy and therefore to spend too large a fraction of their income on it. If they cannot meet this expenditure, their access to energy is disrupted.

An alternative energy strategy is needed that addresses the energy-poverty link in industrialised countries and makes the poor less vulnerable to the high costs of energy. The most promising approach is to make available to the poor more energy-efficient technologies for space heating, household appliances, and transportation services.

A central challenge for many developing countries is the expansion of access to electricity for the poor. In contrast, maintaining access is the critical issue in some medium-income countries and economies in transition, as well as in OECD countries. The uninterrupted availability of access to vital energy services is particularly important to the poor, highlighting the health and other hazards associated with the lack of heating and light. Disconnection can be life-threatening. It is part of the general question of how the poor should be protected during the liberalisation and privatisation that are sweeping electric utilities around the world. There is increasing recognition of the importance of dealing with material hardship (lack of access to energy) rather than just income poverty in both industrialised and developing countries.

Energy and women

***Poverty has a woman's face. Of the approximately 1.3 billion people living in poverty, 70% are women.* (UNDP, 1997a. p. 12)**

***Compared to men, women in developing countries spend long hours working in survival activities...[This] time spent...is largely invisible in current methods of reporting energy patterns and statistics.* (UNDP, 1997a, p. 15)**

In developing countries, biomass accounts for about one-third of all energy and nearly 90% in some of the least-developed countries. About two billion people rely mainly or exclusively on traditional fuels (mostly biomass) for their daily energy needs. **(UNDP, 1997a, pp. 36-37)**

Human energy conservation must be central to any energy strategy, as it is a major component of energy used at the domestic level. The traditional division of labour allocates most tasks to women in the household. **(Viklund, 1989, p. 10)**

Energy and women are linked in many diverse ways.[10] These linkages vary spatially, over time, across classes, between urban and rural areas, and between countries. Some of these variations are common to women, men, and children of a given era, class, or country. But certain features of the relationship between energy and women are worth considering.

Factors determining energy-women linkages

Four main factors influence the nature of linkages between energy and women: the nature of the (energy) resource base, the characteristics of the household and community economy, the features of energy policy, and the position of women in families and communities.

Resource base. The survival and lives of most people in the developing world depend on the biomass resource base, rather than on coal, oil, or nuclear energy. Their consumption of energy (other than human energy and animate energy sources) is for survival needs, primarily cooking. For these needs, most people depend on biomass sources such as fuelwood, crop residues, and animal dung.

But this biomass resource base is being degraded.[11] As a result, in the course of a single

generation, the time and effort required to meet minimum household energy needs have increased. Because many households rely on biomass fuels that are gathered or received as payment for services rendered, national energy accounts tend to under-represent the importance of biomass fuels as energy sources.

Likewise, labour and human investment (contributed primarily by women) added to this resource base are not fully understood or recognised. In fact, only fairly recently has it become accepted that deforestation in most areas is not caused by household use of fuel-wood. Nonetheless, the cost (human effort and financial outlay) involved in securing household energy needs has escalated to such an extent that many households have been forced to shift to less efficient and less clean fuels. The health impacts on women and children of exposure to high concentrations of particulate matter, carbon monoxide, and hundreds of other pollutants emitted when biomass fuels are burned have been investigated and documented in some depth during the past 20 years (see chapter 3).

Household and community economy. Energy choices depend on the extent to which the local economy is based on subsistence agriculture or on raising livestock. A further issue is the degree of monetisation of the economy, and whether wages are paid in cash or in kind - for instance, in grain or, more pertinently, in crop residues. Each of these variables may influence the choices made - whether fuel is gathered or bought, whether improved (more efficient and less polluting) stoves are adopted, and what type of fuel is used.

Like the resource base, the local economy is dynamic, particularly now that macroeconomic factors are bringing about vast changes in microeconomies. These factors will determine the disposable income of households, as well as the opportunity costs of depending on the labour and time of women and children to supply household energy needs.

Energy policy. The linkages between women and energy are also shaped by the prevailing

energy policy, especially its degree of sensitivity to the needs and priorities of (rural) women. Particularly in many developing countries, energy policy is designed in such a way that energy resources are not equally available to all. Industrial, commercial, urban, and male users receive priority service and attention in energy policies. At the bottom of the list are agricultural, domestic, rural, and female users. The structure and functioning of the energy sector also cater to those in the favoured categories.

The effect of these biases and predilections is evident in the rural areas of most developing countries. Even well-intentioned initiatives such as rural electrification often begin and end with a 'pole in every village'. Few affordable, viable options have been developed for the domestic sector, where much of women's work occurs.

Position of women in families and communities. One can see evidence in many places of a highly degraded biomass energy resource base. Yet investments to improve kitchens, stoves, and cooking fuels either do not figure in the hierarchy of household expenditures or appear very low on the list. Why?

A partial answer is that the livelihoods of people living in such environments are also under threat. In other words, they have other, even more urgent priorities. But another and crucial part of the answer is related to the position of women in families and communities.

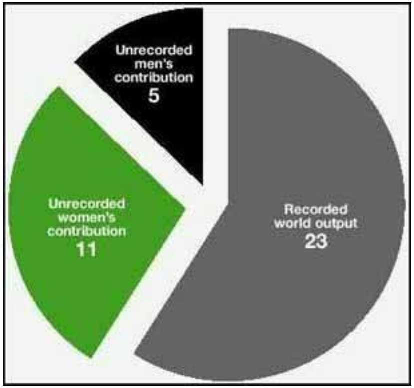

FIGURE 2.4. WOMEN'S SHARE OF WORLD OUTPUT, 1993 (TRILLIONS OF U.S. DOLLARS)

Source: De Almeida and de Oliveira, 1995.

The four factors discussed here - the energy resource base, the local economy, energy policy, and the position of women in families and communities - are closely connected. But the last of these factors is perhaps more fundamental than the others. It is a root cause, the reason it is necessary to study linkages not only between women and energy but also between women and a range of productive assets and social services. Women, by virtue of their position in society (or lack thereof), stand disadvantaged in decision-making processes in family, community, and country, as well as in accessing productive assets. Poor women in developing countries are doubly disadvantaged, while their sisters in rural areas are triply disenfranchised. Two aspects of this disenfranchisement that have particular bearing on the linkages between women and energy deserve closer attention: the value assigned to women's labour and the value placed on women's time.

- **Valuing women's labour. Across cultures and economic rankings, women's work has been under-valued, sometimes to the extent that it has been rendered invisible.**

This applies not only to women's reproductive work and household work but also to their immensely active participation in the so-called informal sector of the economy. This under-valuation, in terms of what is included in the UN System of National Accounts (SNA) and what is not, is similar in industrialised and developing countries.[12] In both cases only about one-third of women's work is taken into account. Two-thirds is left out.

Women's contribution to world output is also under-valued, and to a much greater extent (figure 2.4). According to published statistics, world output in 1993 totalled $23 trillion. But this reflects only recorded economic activity - and the unrecorded economic contributions of women are almost 45 percent of this amount (UNDP, 1995).

Furthermore, women are under-paid relative to men for the same tasks. Again, this applies both in industrialised and developing countries. Women also shoulder the burden of household survival activities (cooking, cleaning, collecting fuel and water, and caring for children, plus sometimes raising kitchen gardens), all of which are largely unacknowledged. The result is that across the globe, women work longer hours than men. One of the most tangible linkages between women and energy is that the growing scarcity and cost of cooking fuel have lengthened women's workdays and made them more arduous.

- **Valuing women's time. Rural women in developing countries have been forced to become experts at multitasking.[13] Faced with impossible workloads and only their own time and labour to fall back on, poor rural women have become very efficient at managing time. These skills are not assigned any value in the labour market. Even women often do not consider what they do as 'work'. Though the survival of the family - in literal as well as economic terms - may depend on the skill with which a woman manages her household, she has little or no economic decision-**

making power, and her time and her work have very low status. Not only are the cash-earning activities of the male members of the household given higher status, but even the leisure time of men may rank higher than the work time of women (Nathan, 1997).

To summarise, many of the world's women (roughly 400 million) rely on energy sources that are not part of the market economy in order to fulfil their survival activities and household responsibilities. They often depend on these sources for their economic activities as well. Women are more vulnerable than men to environmental degradation, because there is often a direct impact on their workload. They are also more likely to be directly affected by increases in fuel prices and by scarcity. Often the only asset that women can turn to in times of scarcity or high prices is their own bodies, their own labour. This results not only in longer workdays but also in declining health, nutrition, and a score of other ill effects. Apart from the overwhelming importance of biomass energy, the role of human energy and particularly of women's energy must be recognised (chapter 3).

Specific concerns and priority areas

Health and sanitation. Thus there is a very direct link between energy and women's health. Most of the burdens placed by energy scarcity are borne by women. Even where biomass energy is relatively easily available, women feel the health impacts of having to collect fuelwood. These impacts may range from cuts, falls, bites, and back injuries to sexual harassment (Government of India, 1988). Often these problems are compounded by having to haul water for the household as well.

Exposure to indoor air pollution is another well-documented health risk associated with the use of biomass fuels in traditional stoves that are little more than shielded fires in poorly ventilated kitchens (WHO, 1992). Rural women and children in developing

countries are most affected by this pollution. The rural-urban differential in pollutant concentrations and exposures is marked, as are differences between countries at different stages of human development (figure 2.5). The urban-rural differential is reversed in high-HDI countries, where exposures are higher due to the greater amount of time spent indoors and due to building characteristics and materials.

Fuel scarcity has wider implications. Women may be forced to move to foods that can be cooked more quickly or to eat more raw food. Such a shift can have health repercussions for the whole family, especially children (Batliwala, 1982; Ramakrishna, 1992).

An additional critical factor related to health is the lack of sanitation in many rural areas of developing countries, which is directly related to the difficulty of accessing clean water. There is an energy-sanitation link here because energy often has to be used to lift 'clean' sub-soil water or to boil water to reduce the health risk from contamination. The convenience of the water supply - for instance, the distance to the source and the number of sources - correlates with the amount of water used daily per capita. For most rural people in developing countries, the amount of clean water available per capita is well below the minimum required for maintaining sanitation. In addition, the supply of drinking water is highly inadequate. As water drawers and carriers and household managers, women feel the impact of water shortages most keenly. The availability, supply, and quality of water could be greatly improved by increasing the amount of energy available for these functions.

Environmental quality. Energy scarcity often relates directly to environmental quality for households and for communities in general. The implications of this relationship are particularly relevant for women. Deteriorating environmental quality places greater burdens on women's time and labour. In addition, as mentioned above, women's health and productivity may be significantly undermined. This is only partly due to the increased effort required to meet minimum household energy requirements.

Apart from the overwhelming importance of biomass energy, the role of human energy and particularly of women's energy must be recognised.

Energy, after all, is only one of the inputs that women must secure for survival. Water also becomes scarce with increasing environmental degradation. In cases of severe environmental decline, male migration often increases, as in Sub-Saharan Africa. In such circumstances women have to bear the additional responsibility of heading households. A key intervention to arrest or slow environmental degradation in many developing countries would be to increase the energy options for poor rural women. In particular, the potential of renewable energy sources has not been realised.

Economic activities. The linkages between women's economic activities and energy have two aspects. One is the strong correlation between the time women have for economic activities and the time they have for survival activities, including collecting and preparing cooking fuels. The other is securing energy inputs for economic activities. The main point is that women's choices are often very restricted, and they do not have much margin for error for the unforeseen. Given that most women, whether bakers, brewers, or food processors, are small-scale producers whose businesses are frequently biomass-energy intensive, both technology development and improved energy supply could greatly enhance their productivity.

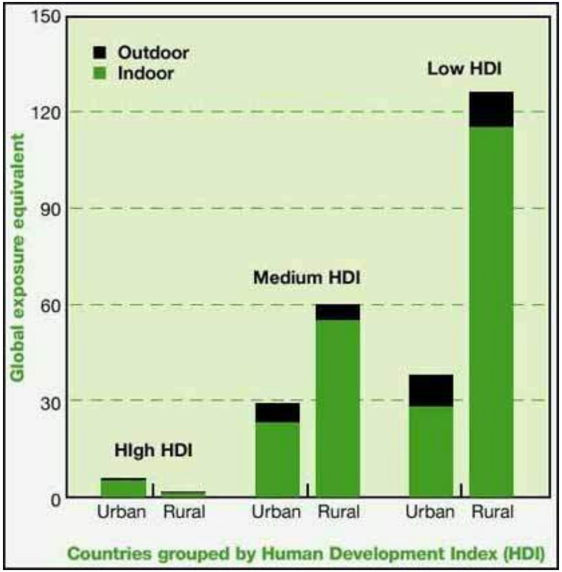

FIGURE 2.5. GLOBAL EXPOSURE EQUIVALENTS FOR PARTICULATES IN 12 MAJOR MICROENVIRONMENTS

The global exposure equivalent is defined as the equivalent (particulate) concentration that the entire world's population would have to breathe continuously to equal the population exposure in each micro-environment.

Note: Data are for various years from the late 1980s to early 1990s.

Source: Based on Smith, 1993.

Education. Despite momentous advances in the literacy of women, much remains to be

done. As long as the drudgery of survival activities continues to grow, given the division of labour in most households, getting girls into schools will be an uphill battle. Improved access to better-quality, affordable, reliable cooking fuels could make an enormous difference. As it is, girls are the first to be called on to shoulder survival activities that cannot be managed by the adult women of the household. Invariably, girls' education suffers as a result.

Human productivity. The gravest consequence of energy scarcity is probably that human productivity - especially women's productivity - is depressed. When survival of the family becomes the goal, there is no opportunity to develop human potentials and talents. This is a loss not only to the individual, but to society as well.

Energy for improving the position of women

Energy can be a vital entry point or 'lever' for improving the position of women in the household and society. As a bottleneck and burden, the lack of affordable energy has often constrained the options and opportunities available to women. But there are many strategic advantages in using energy as an entry point.

Energy scarcity condemns many women to spend all their days and a good part of their nights meeting basic survival needs. Enhancing their access to affordable, clean energy sources would go a long way towards reducing the drudgery they face, and allow them to use their time and energy for other purposes. This could lead to improved health, education, nutrition, and economic status, not only for women but for their families as well. The greatest benefit would accrue to the next generation; and in particular to girls, who would gain - as their workload at home decreases - better health and nutrition and opportunities to go to school.

Energy is also a key productive asset for strengthening the economic standing of women. In many cases it is also necessary for providing equal access to productive resources

(Batliwala and Reddy, 1996). Whether a woman is engaged in food processing or in farming, her economic return largely depends on a dependable supply of energy and on improvements in energy technology products relevant to her trade.

Energy is a good organising issue for women, because energy is a primary concern in their daily lives - especially poor women's. Energy resource scarcity, cost, quality, and reliability are their constant concerns. Whereas alone each woman may be able to do little to improve the situation, together their power could be fairly easily demonstrated. In some countries farmers (mainly men) have organised themselves to demand affordable and reliable energy supplies. Women can broaden these movements by adding their agenda.

Energy can be a vital entry point or 'lever' for improving the position of women in the household and society.

Finally, energy provides many opportunities for skill building among women. That these skills would be non-traditional ones, and would not restrict women to the kitchen and home (as do those perennial-favourite income-generation schemes tailoring and pickle-making) are added advantages. The exploitation of such opportunities, combined with improved access to credit for women, could result in considerable entrepreneurial activity.

This perspective can also be turned on its head with good effect. Involving women more integrally in the energy sector could be a boon for the sector as well. The energy sector has evolved as a capital-intensive, expert-dominated, centralised sector. But there is a role for decentralised energy in which women can play an important part. In fact, the 'engendering' of the energy sector could be its salvation in the long run, leading to

decentralisation, longer-term perspectives, and investment, and a better fit between energy source, energy quality, and end use - in other words, to a greater emphasis on renewable energy sources, in keeping with the underlying philosophy of sustainable development.

Energy and population

Many of today's global problems arise from the availability and use of natural resources, which depend on the size of the human population putting pressure on them. This pressure has been escalating in an alarming manner.

The world's population has increased explosively over the past 100 years. "It took the world population millions of years to reach the first billion, then 123 years to get to the second, 33 years to the third, 14 years to the fourth, 13 years to the fifth billion" (Sen, 1994). Additions to the population have been unprecedented: "Between 1980 and 1990, the number of people on earth grew by about 923 million, an increase nearly the size of the total world population in Malthus' time" (about 1800; Sen, 1994).

This explosive growth has led to talk of a runaway population inexorably bringing humanity to its doom and of a situation of 'standing room only' on this planet. But these predictions have generally assumed the persistence of the very high population growth rates of the 1950s, which corresponded to a doubling every 23 years or so.

Demographic transitions

The recent tremendous increase in world population is associated with what is known as a demographic transition. In such a transition, the population moves from a pre-industrial balance of high mortality and high fertility to a post-industrial balance of low mortality and low fertility.

Demographic transitions have occurred in the past - in Western Europe in the 19th century, and in Southern and Eastern Europe in the first quarter of the 20th century. They are now taking place all over the developing world. In some countries they are just starting. In others they are well under way. And in the remaining countries they are over or almost over.

The demographic transition currently under way in developing countries has been initiated by the rapid fall in mortality in these countries, brought about by improvements in public health and advances in medical technology. For example, an increase in life expectancy from 40 to 50 years was accomplished in developing countries in just 15 years, from 1950-65. In comparison, a similar increase of life expectancy required 70 years (from 1830-1900) in Western Europe and 25 years (from 1900-25) in southern and Eastern Europe.

If a large reduction in mortality were not accompanied by a fall in fertility, the population would increase indefinitely. But what happened in industrialised countries is that fertility also fell, and the low value of mortality was balanced by a new low value of fertility. Thus the growth rate of population is low both before and after the demographic transition during which the population grows rapidly:

> **The rate of world population growth is certainly declining, and even over the last two decades, its percentage growth rate has fallen from 2.2 percent per year between 1970 and 1980 to 1.7 percent between 1980 and 1992. This rate is expected to go down steadily until the size of the world's population becomes nearly stationary (Sen, 1994).**

The crucial question, therefore, is whether the reduction in mortality that took place in developing countries from 1950-65 has been followed by a fall in fertility. The evidence seems clear. Until the mid-1960s there was no sign of a fertility decline, but since then

fertility has begun to fall in almost all developing countries, except those in Sub-Saharan Africa. The average total fertility rate in developing countries fell from 5.9 to 4.7, that is, by about 20 percent, from 1965-70.[14]

It is important to note that the response of fertility is not as rapid as the decline in mortality - fertility is not in sync with mortality. The delay in fertility decline leads to a 'bulge' in the time variation of population. This bulge gives rise to the problems associated with population size. Thus it seems that a demographic transition is taking place and that the population of developing countries and of the world is likely to stabilise eventually. But the world is sure to have a growing population for quite some time because of 'population momentum (Sen, 1994).

Population momentum

Population momentum has important geographic, locational, and age dimensions. First, the geographic distribution of population growth is uneven - 90 percent of the growth is taking place in developing countries. These additions to population are primarily in populous countries with a low average income. In addition, the population explosion is worse in countries that already have a severe population problem. Second, the locational distribution of population growth is such that the urban share of growth has increased and will continue to go up.

Third, the age distribution of the population is changing in all countries, but the nature of the change varies among them. The population is becoming older in rich countries because life expectancy is increasing while infant mortality is relatively stable. In poor countries the age distribution depends on the phase of the demographic transition. In the initial phase the dependent non-working-age population grows faster because infant mortality is declining much more than the increase in life expectancy. In the middle phase the growth of the working-age population (with the potential of being economically active) is

relatively greater.[15] And in the final phase, the elderly population grows faster.[16]

It is important to estimate this future population. An average of the 1992 UN medium estimate and the World Bank estimate of the future population yields 9.79 billion in 2050,[17] 11.15 billion in 2100, and 11.45 billion in 2150. In 1998 the UN Population Division projected 8.9 billion people by 2050, thanks to the fertility rate decreasing around the world (New York Times, 21 October 1998, p. A8). The bulk of the population increase is expected to take place in developing countries, where the population is expected to triple to 9 billion by 2110.

The increase in global population before its expected stabilisation by about 2100 means that per capita resources will continuously decline in the near future. In fact, per capita estimates conceal the differential growth that is likely to take place in industrialised and developing countries, which will exacerbate the already serious disparities between these two worlds.

The energy-population nexus

Population levels influence the magnitude of energy demand in a straightforward way: The larger the population, the more total energy is required, with the magnitude of this total energy depending on per capita energy consumption. This is perhaps the basis of a view that population increases in developing countries represent the most serious threat to the global atmosphere through the phenomenon of global warming (Atiq, Robins, and Roncerel, 1998).

There is an another view, however. The patterns of energy consumption in rich industrialised and poor developing countries, and the rich and poor within developing countries, are such that industrialised countries, and the rich within developing countries, have - because of their energy-intensive consumption patterns - far greater per capita

impact on the global atmosphere. Hence the greater rates of population growth of poor developing countries, and the poor within developing countries, are far less relevant to global warming than the lower rates of population growth of industrialised countries, and the rich within developing countries. In fact, 49 percent of the growth in world energy demand from 1890-1990 was due to population growth, with the remaining 51 percent due to increasing energy use per capita.[18] This relationship will hold true for the future if per capita energy consumption does not change significantly.

Thus the conventional view of the energy-population nexus is that population is an external factor influencing energy consumption. This exogenous impact of population on energy is the well-known (and obvious) aspect of the population-energy connection, although many people seem not to realise the scale of its impact even today.

But there can be another connection, in which energy strategies may lessen the intensity of the population problem. If energy consumption and population growth are a dialectical pair - each transforming the other, and each being an effect when the other is the cause - then the pattern of energy consumption should also have an effect on population growth.

This is the other side of the coin - energy consumption patterns influencing the rate of population growth through their effect on the desired number of births in a family and the relative benefits and costs of fertility. These patterns can retard or accelerate the demographic transition (Goldemberg and others, 1988).

This dimension of the energy-population nexus - not yet elaborated sufficiently - will be sketched through the influence of energy consumption on population growth at two levels: the micro level of villages in developing countries and the macro level of the world. The implication is that energy can play a key role in accelerating the demographic transition, particularly by achieving dramatic reductions in fertility to stabilise global population as quickly as possible and at as low a level as possible.

Rural energy consumption and population implications

To proceed, several features of rural energy consumption in developing countries must be highlighted. Though these features vary with country and agroclimatic conditions, a few numbers typical of south Indian villages are presented to give a flavour of the features involved (ASTRA, 1982):

- **Commercial energy accounts for a very small percentage of the inanimate energy used in villages; the bulk of the energy comes from fuelwood.[19]**

- **Animate sources - human beings and draught animals such as bullocks - account for less than 10 percent of the total energy, but the real significance of this contribution is that these animate sources represent the bulk of the energy used in agriculture.**

- **Nearly all the energy consumption comes from traditional renewable sources. Thus agriculture is largely based on human beings and bullocks, and domestic cooking (which uses the bulk of the total inanimate energy) is based entirely on fuelwood.[20] But the environmental soundness of this pattern of dependence on renewable resources comes at an exorbitant price. Levels of agricultural productivity are very low, and large amounts of human energy are spent on fuelwood gathering (for example, about 2-6 hours and 4-8 kilometres a day per family to collect about 10 kilograms of fuelwood).**

- **Fetching water for domestic consumption also uses a great deal of human energy (an average of 1.5 hours and 1.6 kilometres a day per household) to achieve an extremely low per capita water consumption of 1.7 litres a day.**

- **Almost half of the human energy is spent on grazing livestock (5-8 hours a day**

per household), which is a crucial source of supplementary household income in these parts of the country.

- **Children contribute about one-third of the labour for gathering fuelwood, fetching water, and grazing livestock. Their labour contributions are vital to the survival of families. This point is usually ignored by population and education planners.**

- **The end uses of human energy in villages show that their inhabitants, particularly women and children, suffer burdens that have been largely eliminated in urban settings by the deployment of inanimate energy. For example, gathering fuelwood and fetching water can be eliminated by changing, respectively, the supply of cooking fuel and water. There are also serious gender and health implications of rural energy consumption patterns (Batliwala, 1982).**

Industrialised countries have - because of their energy-intensive consumption patterns - far greater per capita impact on the global atmosphere.

To understand the population implications of these features of energy consumption in villages, it is necessary to consider how these features influence the desired number of births in a family and the relative benefits and costs of fertility. A useful starting point is the general preconditions for a decline of fertility, as set forth by the demographer A. J. Coale (1973, 1983):

- **Fertility must be within the calculus of conscious choice. Potential parents must consider it an acceptable mode of thought and form of behaviour to balance advantages and disadvantages before deciding to have another child.**

- **Reduced fertility must be advantageous. Perceived social and economic circumstances must make reduced fertility seem an advantage to individual couples.**

- **Effective fertility reduction techniques must be available. Procedures that will prevent births must be known, and there must be sufficient communication between spouses and sufficient sustained will, in both, to use them successfully.**

The exercise of choice in matters of fertility is a culture-dependent issue, and awareness and availability of fertility-reduction techniques depend on specific technologies and the success with which they are spread. But the desired number of births, and therefore the relative benefits and costs of fertility, depend upon socioeconomic factors such as

- **Infant mortality and the probability of offspring surviving. The lower this probability, the larger the number of children aspired to and the greater the exposure of the mother to the possibility of additional pregnancies.**

- **The role of women in arduous, time-consuming household chores. The greater this role, the smaller the scope and emphasis on women's education and the lower the age of marriage.**

- **The use of children to perform essential household tasks. The greater the use of children for these tasks, the more they become essential for the survival of the household.**

- **Opportunities for children to earn wages. Wage-earning children become desirable as economic assets.**

Only a few of these factors enter into perceptions of advantages and disadvantages of fertility and family size. Nevertheless, the reduction of fertility, and therefore the

acceleration of the demographic transition, depends on crucial developmental tasks. These tasks include an increase in life expectancy, improvement of the immediate environment (including drinking water, sanitation, and housing), education of women, and diversion of children away from household support tasks and employment to schooling.

Further, almost every one of these socioeconomic preconditions for smaller family size and fertility decline depends on energy-using technologies. Infant mortality has much to do with inadequate, unsafe supplies of domestic water and with an unhealthy indoor environment resulting from polluting fuel-stove cooking systems. The conditions for women's education become favourable if the drudgery of their household chores is reduced with efficient energy sources and devices for cooking and with energy-using technologies to supply water for domestic uses. The deployment of energy for industries that generate employment and income for women can also help delay the marriage age, which is an important determinant of fertility. And if the use of energy results in child labour becoming unnecessary for crucial household tasks (cooking, gathering fuelwood, fetching drinking water, grazing livestock), an important rationale for large families is eliminated.

From this standpoint, it is obvious that prevailing patterns of energy consumption in villages do not emphasise energy inputs for the following tasks:

- **Providing safe and sufficient supplies of drinking water.**
- **Maintaining a clean and healthy environment.**
- **Reducing the drudgery of household chores traditionally performed by women.**
- **Relieving children of menial tasks.**
- **Establishing income-generating industries in rural areas.**

Thus current energy consumption patterns exclude the type of energy-using technologies needed to promote the socioeconomic preconditions for fertility decline. In fact, they

encourage an increase in the desired number of births in a family and an increase in the relative benefits of fertility (Batliwala and Reddy, 1996).

Traditional biomass-based cooking and demographic indicators

Traditional biomass-based cooking is predominant in most developing countries, particularly in rural areas. The negative health impacts of this are discussed in chapter 3. The low efficiencies of traditional biomass stoves derive from the incomplete combustion of the biomass, resulting in a number of health-damaging pollutants, particularly suspended particulates and carbon monoxide. These pollutants exceed acceptable levels inside poorly ventilated houses, especially those without chimneys. Thus one would expect to find a correlation between the percentage of biomass use in total energy use and a number of demographic indicators, especially those related to women and young children, who are thought to be most vulnerable.

Indeed, such a correlation has been revealed by recent work on a large number of developing countries (Bloom and Zaidi, 1999). Table 2.1 shows that, as the percentage of biomass increases, life expectancy decreases, infant (and child) mortality increases, and the annual population growth rate increases. Such trends do not prove causality but are consistent with the view that traditional biomass use impedes the demographic transition.

Energy-population nexus at the global level

One way of considering the energy-population nexus at the global level is through the 1 kilowatt per capita scenario (Goldemberg and others, 1985) described above. That scenario shows that, if the most energy-efficient technologies and energy carriers available today were implemented, a mere 10 percent increase in the magnitude of energy would be required for the populations of developing countries to enjoy a standard of living as high as that in Western Europe in the 1970s. In other words, under the conditions of this scenario, energy supplies need not become a constraint, and dramatic increases in

living standards can be attained in developing countries. It follows that, if energy-efficient technologies and modern energy carriers were implemented to enable the populations of developing countries to realise higher living standards, then these standards would likely result in low growth rates for developing country populations, similar to rates in Western European countries. Insofar as current energy strategies do not sufficiently emphasise energy-efficient technologies and modern energy carriers, they are not addressing directly the population problem.

TABLE 2.1 BIOMASS USE AND DEMOGRAPHIC INDICATORS

Indicator	Percentage of biomass in total fuel use				
	0-20	**20-40**	**40-60**	**60-80**	**Above 80**
Number of countries	70.00	12.00	14.00	10.00	16.00
Female life expectancy (years)	74.70	68.80	62.00	56.10	48.30
Life expectancy (years)	71.50	66.50	59.90	54.50	47.00
Male life expectancy (years)	68.50	64.00	57.80	53.00	45.80
Infant mortality (per 1,000 live births)	22.50	46.60	64.70	82.60	116.80
Under-five mortality (per 1,000 live births)	27.50	59.30	93.00	135.30	173.00
Total fertility rate	2.51	3.26	4.64	5.35	6.33
Crude birth rate	19.20	26.20	35.00	39.10	45.00
Crude death rate	8.60	7.60	10.90	12.80	18.10
Annual population growth rate (percent)	1.00	1.61	2.43	2.74	2.52
Female-male life expectancy gap (years)	6.20	4.50	4.20	3.10	2.60

Sources: UN, 1993a; World Bank, 1998.

Energy and urbanisation

A century ago, even visionaries could not imagine a city with more than 1 million inhabitants.[21] Yet by 2010 more than 500 such concentrations will dot the globe, 25 of them with more than 10 million people (so-called megacities). The availability of energy sources in combination with the phenomena of motorisation and industrialisation have substantially altered the manner in which people relate to their environment.

Urban dwellers will soon outnumber those in traditionally rural areas and constitute half the world's population. Of the 1.23 billion urban residents added to the world population since 1970, 84 percent have been in less developed regions. The global population is growing by 2.5 percent a year (3.5 percent a year in less developed regions, and 0.8 percent in more industrialised regions). The annual growth is 61 million people - roughly the equivalent of adding six cities with a population of 10 million to the urban population world-wide. By 2020-25 the global annual urban growth rate will have declined to less than 2 percent, but the urban population will increase by 93 million people a year - more than the current annual increase in the total world population.

The rate of urbanisation and its attendant impacts differ in regions across the globe. Thus strategies to capitalise on the positive factors of urbanisation and to mitigate the negative factors will also differ by region. Latin America is the most urbanised region in the developing world. Nearly three-quarters of Latin Americans live in urban areas. Although Africa is the least urbanised region, it is experiencing the highest urban growth rate, and already a third of its people live in cities. However Asia contains almost half the world's megacities and continues to urbanise rapidly. Given its current annual growth rate, Asia's urban population is expected to double in less than 20 years.

Increasingly, larger portions of the world's people live in the biggest cities. In addition, more live in intermediate-sized cities than ever before. In 1950 there were 83 cities or

urban areas with more than 1 million people. Today 280 such urban areas exist. The growth of large cities also affects smaller cities, particularly in less developed regions. Over the next 15 years the number of cities with 5-10 million residents will increase significantly. Further, the number of people in them will more than double, as will the population of cities in the 1-5 million and 0.5-1.0 million ranges. This means that while megacities are the most visible symbols of problems and challenges, smaller cities are no less significant.

Urbanisation reflects more than demographic change. It is both driven by and profoundly influences the context and processes of development. It exerts both direct and indirect advantages in the struggle towards global sustainability and human development. The origins of many global environmental problems related to air and water pollution are located in cities - this is the urbanisation-pollution linkage. Unsustainable consumption and production patterns are also a feature of cities. But it is also in cities that one can find potential solutions, because they have several positive features.

Birth rates are three to four times lower in urban areas than in rural areas, thereby reducing environmental pressures from population growth. Cities provide greater accessibility to education, services, and training. They increase the access of residents to information on environmental issues and facilitate their integration into the policy process according to identified needs and priorities. Because of their concentrated form and efficiencies of scale, cities offer major opportunities to reduce energy demand and minimise pressures on surrounding land and natural resources. Women are also the direct beneficiaries of urbanisation, because their interests and demands are more easily articulated and negotiated in their new, dynamic social environment.

Cities are the engines of economic growth and centres of employment and opportunity for expanding and diversified national economies. Eleven of the twelve urban agglomerations with 10 million or more people are located within one of the 25 largest economies. The

economic prosperity of nations will depend on the performance of their cities. With a focus on cities, appropriate energy policy can be targeted more effectively and resources leveraged far more efficiently to affect large numbers of individuals, communities, industries, and services. But a lack of competent and accountable urban governance can lead to the loss of much of the potential contribution of cities to sustainable economic and social development and, at worst, to a completely dysfunctional living environment. Concerned and innovative urban development planning, on the other hand, can enable growing urban populations to contribute towards sustainable human development by empowering individuals to convert their creative assets into global wealth.

Urbanisation and energy linkages

The 1996 United Nations Conference on Sustainable Human Settlements, known as Habitat II, reaffirmed that the vast majority of population growth in developing countries will occur in urban centres. The type and scale of urban development will largely affect future energy consumption. In turn, urbanisation also has a profound effect on the amount and type of energy consumed. Other factors - including economic development, industrialisation, and such social-cultural particularities as consumption patterns - also drive the global increase in energy demand. Although traditional rural societies rely heavily on human and animal energy and on wood for fuel, today's urban societies rely primarily on fossil fuels and electricity.

Per capita energy consumption remains low in the developing world. For many urban Africans and Asians, biomass fuels meet a large portion of energy needs. As these countries urbanise, energy demand increases, and traditional bulky fuels (such as wood and charcoal, which require energy-intensive forms of transportation), food, and other materials consumed in urban areas must be transported across greater distances. Urban manufacturing and industry also require more energy than traditional agriculture. In addition, the provision of infrastructure and services to new urban residents requires

energy that is not typically consumed in rural settlements.

Urbanisation imposes enormous demands on the ecosphere, because most urban activities at the industrial, community, and household levels are based on natural capital depletion. Housing construction, transportation, economic activities, and the generation of residential heat and electricity all put stress on the environment and compete for ecological space. Energy use is already high in industrialised countries and is increasing rapidly in developing countries as they industrialise. But energy can be an instrument for sustainable development with an emphasis on more efficient use of energy, and an increased use of renewable energy sources, among other measures.

Urbanisation and energy strategies

Although many countries prepared national plans of action for Habitat II, most did not formulate a national policy on the linkages between urbanisation and energy. Few governments have allocated significant resources to encouraging more effective use of non-renewable energy resources or to increasing the long-term supply of renewable energy resources. In light of current urbanisation trends and the opportunities presented by new energy-efficient technologies and processes, the moment is opportune for this discussion to take place.

Cities have the potential to be far more environmentally benign. The spatial concentration of humans and their activities can minimise pressures on surrounding land and natural resources. Well-designed cities can channel development far away from wetlands and other sensitive areas, and protect natural resources. By integrating land-use and transportation planning, cities can reduce both congestion and pollution.

Cities offer important opportunities for protecting the environment. With proper planning, dense settlement patterns can ease pressures on per capita energy consumption and provide opportunities to increase energy efficiency. For example, recycling becomes more

feasible due to the large quantities of materials and the number of industries that can benefit from it. In addition, land use, infrastructure, and services are better used, and the need for extensive transportation networks and residential heating is reduced. Low-density communities tend to have the opposite characteristics.

Transportation. Mobility and access remain among the greatest challenges for cities in the developing world, especially considering the growing proportion of lower-income people. A city that cannot be accessed by all its inhabitants is not sustainable. Because motor vehicle ownership remains relatively low in many of these cities, there is a window of opportunity to avoid the mistakes made in the industrialised world and design urban transportation systems that facilitate walking, bicycling, and public transportation. Such measures can improve the environmental health of cities and citizens as well as mitigate the threat of global warming.

The new millennium is ushering in a new urbanised era. For the first time ever, more people will reside in urban settlements than in rural.

Cities are centres of employment, residence, and leisure, and of the integration between them. Mobility and access are therefore complementary aspects of the same problem. Mobility implies movement: people going to work, people going to the market, people bringing vegetables to sell in the market. Access implies the ability to take advantage of urban functions: people developing 'backyard industries', people being able to find in their neighbourhoods the services they need, people being able to walk to work. A sensible balance between mobility and accessibility concerns should result in a more energy-efficient transport strategy based on demand management. In this regard, the systemic integration between land use and transport is much more important than an isolated

concern with vehicles, fuels, and emissions. These are also important complementary concerns.

To illustrate, given the opportunity to work legally at home (for example, inputting data or transcribing reports from remote places), the informal sector, a thriving and integral sector in developing economies, would be formalised and backyard industries would proliferate, reducing the need for urban residents to commute to places of employment. The integration of sustainable transport and employment-related strategies could reduce stress on the local environment, promote more creative employment options (especially for women), and lead to a general improvement in quality of life.

Patterns of energy consumption also depend on the means and availability of transport. Where extensive road networks, vehicles, and other transport infrastructure exist, there is a high risk of depending on a supply-driven vicious circle. As is well known, conventional traffic planning based on individual modes of transport can lead to potentially difficult situations, as has occurred, for example, in Bangkok (Thailand), Kuala Lumpur (Malaysia), Mexico City, and So Paulo (Brazil). The creation of appropriate land-use legislation for residential and commercial sites and access to public transportation services can mediate the demand for more energy-intensive transport use.

Considerable opportunity exists to design more efficient transportation systems and create more liveable cities. A critical step for industrialised and developing countries is to move towards managing urban travel demand rather than simply increasing the supply by reducing or averting over-reliance on the privately owned car through appropriate pricing, spatial settlement policies, and regulatory measures.

A number of strategies are available to governments to advance a sustainable transport sector (Rabinovitch, 1993; UN, 1996):

- **Exploration of surface (rather than above-ground or underground) solutions**

based on affordable technologies. Buses should be considered before a high-technology rail system.

- **Development of an integrated transport strategy that explores the full array of technical and management options and pays due attention to the needs of all population groups, especially those whose mobility is constrained because of disability, age, poverty, or other factors.**

- **Coordination of land-use and transport planning to encourage spatial settlement patterns that facilitate access to basic needs such as places of employment, schools, health centres, and recreation, thereby reducing the need to travel.**

- **Encouragement and promotion of public access to electronic information services and technology.**

- **Promotion, regulation, and enforcement of quiet, use-efficient, low-polluting technologies, including fuel-efficient engine and emission controls, fuel with a low level of polluting emissions, and other alternative forms of energy.**

- **Provision or promotion of effective, affordable, physically accessible, and environmentally sound public transport and communication systems that give priority to collective means of transport, with adequate carrying capacity and frequency to support basic needs and reduce traffic flows.**

- **Exploration of partnerships with private-sector providers. Ideally the public sector should provide monitoring and operational standards, and the private sector should invest in capacity and contribute managerial comparative advantages and entrepreneurship.**

Construction. Low-energy building materials such as timber, soil, sand, and stone require

little energy in their manufacture and processing. The durability of many of these materials can be improved without large energy expenditures. These materials are often used in the construction of housing in developing countries. It is often possible to improve the use of such materials through appropriate construction methods and design techniques that maximise their functionality and natural advantage.

One example is construction using earth, in which the mechanical energy required is ultimately much more efficient than that for ceramic building materials, which require large amounts of heat (usually applied inefficiently). The low costs of locally available renewable energy resources could potentially ensure a continuous supply of energy to meet the demand of domestic, agricultural, and small-scale industrial sectors. These materials also have the advantage of being familiar to local building operators and planners.

Energy to improve the urban environment

The new millennium is ushering in a new urbanised era. For the first time ever, more people will reside in urban settlements than in rural. Perhaps the forces of change - economic, social, technological, and political - render this process inevitable. If so, policy design and prescriptions should be targeted differently. Rather than attempting to arrest rural-urban migration, it is important to make rural life less difficult and arduous and more pleasant and attractive.

The rapid expansion of urbanised areas, especially in developing countries, creates a unique opportunity to implement 'leapfrogging' approaches.

Energy interventions can play a positive role in this task through electrification of homes for lighting, labour-saving appliances, and entertainment, as well as for the supply of safe piped water. Thus an improvement in the quality of rural life can decrease the negative aspects of urbanisation, making it wise to pursue balanced urban and rural development and to ensure synergies between the two. The focus of development efforts should be redirected towards achieving more sustainable urban and rural living environments in light of the inevitability of a mostly urban world.

Rapid urbanisation is associated with a rise in energy demand - which potentially threatens the sustainability of human settlements and the natural environment. The spatial concentration and diversification of human and economic activities hasten the demand for resources and compromise the carrying capacity of final disposal systems and infrastructure. In addition, the rise in disposable income of urban populations is likely to lead to a concomitant desire for more material goods and services.

Yet many of the negative effects of urbanisation can be mitigated through innovative energy policies. In developing countries rapid urbanisation and its attendant demands on material and financial resources have severely compromised the ability of governments to foster sustainable environment. Although the use of fossil fuels in industrial processes, heating, electricity, and motor vehicles tends to expand with economic growth, measures can be taken to promote renewable, clean technologies that lessen the burden of economic activity on human populations and ecosystems. In cities in industrialised countries, control of motor vehicle emissions has led to a dramatic reduction in ground-level ozone and carbon monoxide levels on or near major roads.

Urban areas offer enormous potential for easing the demand for energy-intensive materials and increasing the efficiency of resource use. The agglomeration of social networks fosters an environment that is more accessible to public awareness campaigns, creating a favourable learning environment for changing wasteful patterns of consumption

on a large scale. The application of new energy-efficient technology is more easily accelerated in an urban setting because business and industry may be more amenable to experimentation and thus bypass the environmentally deleterious path of excessive technological use that has often been followed in industrialised countries.

Most technologies used in cities in the industrialised world were invented about a century ago. The rapid expansion of urbanised areas, especially in developing countries, creates a unique opportunity to implement ‘leapfrogging’ approaches. Widespread urbanisation may provide the economies of scale needed to implement innovative affordable technologies.

The urban environment is also conducive to offering education opportunities and creating jobs. This facilitates capacity-building efforts to deal with the operation and maintenance of environmentally friendly energy infrastructure based on renewable sources. Opportunities for reducing the material inputs of production by recycling waste by-products are more feasible in urban areas. For urban services such as transportation, a reduction in cost and in the share of energy-intensive services provides an additional means by which energy strategies can take advantage of the positive aspects of urbanisation. A prime example is the promotion of surface bus modes of transportation rather than expensive solutions such as subways.

Energy and lifestyles

After the oil shocks of the 1970s, one of the issues that often arose in discussions of energy was the sustainability of a world with glaring and grave disparities in per capita energy consumption between industrialised and developing countries. A related issue was the need for convergence in per capita consumption through minimisation, if not removal, of these disparities.

These discussions were set aside because of optimists’ belief in the enormous potential of efficiency improvements. These improvements - it was believed - would enable

industrialised countries to sustain their energy services (and therefore living standards and lifestyles) with far less energy consumption. At the same time, the improvements would enable developing countries to achieve dramatic improvements in their standards of living with only marginal increases in their inputs of energy. Now, almost 30 years after the oil shocks, the time has come to revisit these fundamental issues by analysing the experiences of industrialised countries.

Energy use in the United States

Consider the United States.[22] Following the oil shocks and for almost 10 years, from 1973-83, the United States reduced its consumption even as its population and economy expanded. "Americans learned to do more with less" (Myerson, 1998). For instance, there was an emphasis on thicker insulation and tighter windows to cut space-heating bills. Compact, fuel-efficient cars became popular. There was investment in more efficient appliances, machines, and engines. As a result per capita residential energy consumption fell by a tenth. It looked as if energy patterns were following the hopes of the optimists.

But during the next 15 years, from 1983-98, the United States lost all the gains in energy conservation it achieved in 1973-83. Declining energy prices offset the conservation gains. In 1983-98 per capita residential energy consumption rose by 10 percent, offsetting its 10 percent reduction from 1973-83 and rising to within 2 percent of its 1973 peak. Americans returned to consuming nearly as much energy as before the oil shocks.

In 1999 Americans were expected to burn more fuel per capita than in 1973. U.S. dependence on oil imports has increased - in 1973 imports were 35 percent of consumption; in 1998, 50 percent. In 1973, 5 percent of oil imports came from the Gulf; in 1998, 10 percent. The reduction in the energy intensity of the U.S. economy has tapered off; from 1972-86 energy per unit of GDP fell 43 percent; but from 1987-97 the fall was only 8 percent. It appears as if, to one-third of Americans, "conservation means doing

less, worse or without, i.e., privation, discomfort and curtailment" (Myerson, 1998).

Houses. The number of people in the average U.S. household has shrunk by one-sixth, but the area of the average new home has grown by one-third. In 1973 the average new home was 1,600 square feet for the average family of 3.6 people; by 1998 the average size had increased to 2,100 square feet even though the average family had shrunk to 3.0 people. In addition, many energy-intensive changes have taken place inside the home. For example, the average ceiling height, which was 8 feet in 1973, had risen to 9 feet by 1998. Ceilings are often so high that ceiling fans are required in winter to blow back rising heat.

Appliances. The penetration of energy-intensive appliances has increased. For example, in 1973 fewer than 40 percent of homes had central air conditioning. But in 1998 more than 80 percent had it. Forty percent of homes had two or more television sets in 1970; by 1997, the percentage was 85 percent. And homes with dishwashers increased from 19 percent in 1970 to 57 percent in 1996. There has also been an invasion of new always-on, electricity-sucking 'vampires' such as computers, videocassette recorders, microwave ovens, and telecommunications equipment. The energy consumption of these gadgets is rising 5 percent a year, and they will soon consume more per household than a refrigerator.

Transport. Americans are driving automobiles more than ever, primarily because there are more wage earners per family and more urban sprawl. The number of women working or looking for work increased from 47 percent in 1975 to 72 percent in 1997. Households with three or more cars increased from 4 percent in 1969 to 20 percent in 1998. From 1983-95 average commuting distance increased by one-third, from 9.72 to 11.6 miles. And only 15 percent of commuters use public transit.

Fuel-intensive minivans, sport utility vehicles, and pickup trucks are growing in popularity. As a result the average horsepower of motor vehicles increased from 99 in

1982 to 156 in 1996. It took 14.4 seconds to accelerate from 0-60 miles per hour in 1982, but only 10.7 seconds in 1996.

Gasoline prices are a key factor in these developments. The 1973 per gallon price (adjusted for inflation) was $1.10, but the 1998 price was only $1.00. U.S. gasoline prices are only about a third of those in Europe and Japan. No wonder U.S. per capita consumption is much higher than that in Europe and Japan.

Industry and commerce. U.S. corporations have all but stopped making improvements solely to save energy. Industrial and commercial energy use fell 18 percent from 1973-83 but rose 37 percent from 1983-97.

Environment. Clearly, energy prices and environmental concerns point in opposite directions. At the 1992 Earth Summit, U.S. President George Bush pledged to reduce carbon emissions by 7 percent between 1990 and 2010. But the U.S. Energy Information Administration predicts that emissions will rise 33 percent. If fears of global warming are justified, it looks as if the pattern of U.S. energy consumption during the past 25 years has grave implications for the global environment - even though U.S. national and urban environments are much cleaner.

Energy and income. How have changes in lifestyle influenced the pattern of energy use in industrialised countries?[23] What are the determinants of energy consumption? What are the driving forces of energy consumption patterns?

The general relationship between per capita GDP and per capita energy use has been established in many studies (Nakicenovic and John, 1991). The relationship is non-linear - energy use typically grows slower than GDP. For instance, in 1985-95 per capita GDP in OECD countries grew 1.6 percent a year, whereas per capita energy use grew 0.8 percent (IEA, 1997).

It is instructive to look at energy use from the point of view of individual consumers or households. Households use energy directly (for example, electricity, natural gas, and gasoline) as well as indirectly, in the goods and services that they purchase. The sum of direct and indirect use represents the total energy requirements of a household. If it is assumed that, in the ultimate analysis, all products and services of society are produced for the service of households, then an overall picture of the energy requirements of society can be obtained.

The relationship between household income and energy requirements (using input-output analysis) has been known for a long time. In the early 1970s it was found that, if the income of households increases by 1 percent, their use of energy increases by 0.7-0.8 percent - that is, the income elasticity of energy requirements for any year lies between 0.7 and 0.8 (Roberts, 1975). More detailed research in the Netherlands using a combination of process analysis and input-output analysis came to similar findings; for 1990 the income elasticity of energy requirements was 0.63.

The most salient finding is that income is the main determinant of energy consumption. Other household characteristics, such as size, age of oldest member, life-cycle phase, degree of urbanisation, education level, and so on, turn out to be relatively unimportant (Vringer and Blok, 1995; Vringer, Gerlach, and Blok, 1997).

Income elasticity is smaller than unity because the growth of direct energy consumption is less than the growth of income. In contrast the indirect part of energy consumption grows in proportion to income. Thus a shift to less energy-intensive products does not take place as household income grows.

In the case of direct energy use, saturation effects occur. Lower-income households already use a large amount of natural gas (or other energy carriers for space heating). Gasoline consumption saturates at a much higher income level. Electricity consumption

did not saturate in the income categories considered.

While some saturation effects occur, lifestyles in industrialised countries still evolve towards higher levels of energy use.

A cross-sectional analysis for 1948-96 yielded similar results. Indirect energy use grew at a rate more or less proportional to income. Direct energy consumption shows a different behaviour; from 1976-96 it grew at less than average income levels (Vringer and Blok, 1995).

Thus the lifestyle issue becomes an income issue. Seen from the perspective of households, income is by far the main driver of energy requirements. There does not seem to be any tendency to adopt less energy-intensive consumption patterns with rising incomes.

Trends towards increased energy use

Increasing income levels tend to lead to a higher use of energy services by citizens of modern society. Some saturation effects occur, but they do not have a dominant effect on energy consumption. The effects of energy-efficiency improvements, especially in space heating and large appliances, may be more important. Nevertheless, lifestyles in industrialised countries still evolve towards higher levels of energy use.

Many of the driving forces described here cannot easily be altered to lead to lower energy use. But energy-efficiency improvement (including design that stimulates energy-efficient use of equipment) had a considerable impact in the early 1980s. Hence increasing the rate

of efficiency improvement seems to be the most straightforward approach to limiting the growth of energy consumption.

If it is necessary to go beyond the limits of efficiency improvements, it is not sufficient to identify income as the determinant. After all, one cannot look for income reduction strategies. But income is only a proxy for more fundamental determinants of energy use. Income is translated into consumption, which is the material expression (more appliances, bigger homes, heavier cars, more goods) of lifestyles. If one takes these material expressions as determinants, one can think of strategies directed towards altering the consumption patterns associated with the most energy-intensive categories of energy use without impairing quality of life. But a great deal of thought and action will be required to influence lifestyles in this way. They may require a fundamental change in current pricing and taxing policies - not to mention taking advantage of the Internet revolution to change trends.

Conclusion

This chapter has clarified the two-way linkages between energy, on the one hand, and poverty, women, population, urbanisation, and lifestyles, on the other. The relationship between energy and these major global issues is dialectical - the global issues determine energy consumption, and in turn, energy systems influence the issues. If attention is focussed on the global issues as the cause, then energy becomes the effect. But if the focus is on energy as the cause, then one can see the myriad ways in which energy shapes the global issues.

It has also been shown that current energy consumption patterns are aggravating various global problems, leading to further unsustainability. But energy can also contribute to the solution of problems; in particular, poverty, the situation of women, population growth, unplanned urbanisation, and excessively consumptive lifestyles. To realise energy's

enormous potential in these areas, it must be brought to centre stage and given the same importance as other major global concerns.

A goal is an objective to be achieved, a strategy is a broad plan to achieve the goal, and a policy is a specific course of action to implement a strategy. Policies are implemented through policy agents working with policy instruments.

The goal for energy systems is sustainable development. Energy strategies to advance this goal should be derived from the details of the linkages between energy and social issues. In particular strategies should emerge from the manner in which energy can contribute to the solution of social problems.

Thus poverty alleviation in developing countries should involve the energy strategy of universal access to adequate, affordable, reliable, high-quality, safe, and environmentally benign modern energy services, particularly for cooking, lighting, income generation, and transport. Poverty alleviation in industrialised countries requires the energy strategy of universal protection and maintenance of access to affordable energy services, particularly for space heating and lighting.

Improvement in the position of women requires energy strategies that minimise, if not eliminate, arduous physical labour at home and at work, replace traditional biomass-based fuel-stove cooking systems with modern (preferably gaseous) fuels and cooking devices, and use the intrinsic managerial and entrepreneurial capabilities of women in decentralised energy systems.

Control over population growth can benefit from energy strategies that increase life expectancy and reduce infant (and child) mortality in developing countries through modern fuels and cooking devices that render unnecessary the physical labour of children for household chores such as gathering fuelwood, cooking, fetching drinking water, and grazing livestock - and that improve the quality of life of women.

Accentuating the positive aspects of urbanisation and alleviating its negative aspects require energy strategies that exploit the advantages of high-density settlements, provide universal access to affordable multi-modal public transportation, and reduce the 'push' factor in rural-urban migration by improving energy services in rural settlements.

Finally, reducing energy consumption through lifestyle changes requires a strategy - using pricing and taxation - of discouraging the use of energy-intensive devices and encouraging the use of energy-conserving devices.

To be successful, the strategies outlined above must harness both appropriate supply and end-use technologies. The strategies must also be converted into policies wielded by policy agents through policy instruments. Complete hardware plus 'software' - policies, management, financing, training, institutions - solutions are essential for the deployment of energy as an instrument of sustainable development. These challenges will be discussed in the chapters that follow.

Notes

1. Self-reliance does not preclude imports and exports but requires that control over destiny be indigenous.

2. Energy use is taken as a proxy for useful energy, which means that the efficiency of energy use has been held constant.

3. The linkages between energy and security, between energy and economics, and between energy and environment are dealt with in later chapters.

4. This section is based on inputs from Anton Eberhard and Wendy Annecke of the Energy Research Development Centre, University of Cape Town, and from David Bloom, Harvard University.

5. Unfortunately, estimates of absolute poverty are quite sensitive to the methods used to make these adjustments. In addition, all such methods focus on the cost of a standardised bundle consumed by an average household, not on the typical bundle consumed by a poor household. Insofar as market baskets consumed by poor households tend to be filled with relatively high proportions of less costly non-tradable goods and services, absolute poverty will be overstated with all methods of estimation.

6. This number has been adjusted for differences in the purchasing power of different national currencies in 1985 using estimates contained in Penn World Table 5.6 (Center for International Comparisons at the University of Pennsylvania, 2000).

7. Because of irregularities in supply, price rises, and so on, households have, in addition to a preferred or dominant fuel, other fuels as back-ups. Thus when LPG, for instance, is in short supply, households may be forced to switch to electricity.

8. The thought experiment was not intended to recommend Western European living standards as the goal for developing countries or to establish activity level targets for these countries to be achieved by some particular date. The appropriate mix and levels of activities for the future in developing countries will have to be different to be consistent with their climate, culture, and development goals. Rather, the purpose of the thought experiment was to show that it is possible not only to meet basic human needs but also to provide improvements in living standards that go far beyond the satisfaction of basic needs, without significant increases in per capita energy use. Thus energy supply availability need not be a fundamental constraint on development.

9. The correspondence between the 1 kilowatt per capita increase (about 30 gigajoules per capita annually) and a vastly improved standard of living is not very different from the threshold of 1 tonne of oil equivalent per capita (about 40 gigajoules per capita annually), above which infant mortality, illiteracy, life expectancy, and fertility all show substantial

improvement and saturation (see figure 2.1).

10. This section is based on the paper prepared for this chapter by Jamuna Ramakrishna, Humanist Institute for Cooperation with Developing Countries (HIVOS), Bangalore, India.

11. The initial (early 1970s) belief that this degradation was the result of villagers' dependence on biomass for cooking has given way to a broader understanding that includes factors such as urban demand for biomass, industrial needs, logging, and clearing for agriculture. The fact remains that biomass cover (indicated, for instance, by remote sensing) is decreasing.

12. Under the criteria set forth in the 1993 revision of the SNA, the boundary between productive activities that are market-oriented and those that are not is drawn in such a way that the majority of household work and community voluntary work is excluded from the SNA. Education is also excluded. Although this leads to a gross under-estimation of women's economic contributions, the 1993 revision is actually an improvement over the previous version of the SNA, which excluded production of household goods for own consumption and activities such as carrying water (UNDP, 1995).

13. This section is based on the paper prepared for this chapter by Jamuna Ramakrishna, HIVOS, Bangalore, India.

14. Total fertility is a measure of the average number of children a woman will bear throughout her child-bearing years if at each age she has the average fertility corresponding to that age group.

15. Incidentally, the growth in the percentage of the working-age population capable of being economically active (relative to the total population) has been ascribed a key role in the East Asian economic miracle in conjunction with educational, health, and institutional measures to realise the economic potential of this boom in the labour force. Thus the

middle phase of the demographic transition has important implications for economic growth.

16. The importance of the percentage of working-age population was brought out by Bloom and Williamson (1998).

17. The 'demographic indicators for countries of the world, 1950-2050, medium variant' (UN, 1996) estimates 9.37 billion in 2050.

18. Data are from John Holdren, Harvard University.

19. In one of the villages studied, fuelwood consumption corresponded to about 217 tonnes of firewood per year; that is, about 0.6 tonnes per day for the village, or 0.6 tonnes per year per capita.

20. Unlike in some rural areas of India, dung cakes are not used as cooking fuel in the region studied. In situations where agro-wastes (such as coconut husks) are not abundant, it appears that, if firewood is available within some convenient range (determined by the capacity of head-load transportation), dung cakes are never burnt as fuel. Instead dung is used as manure.

21. This section is based on the paper prepared for this chapter by Jonas Rabinovitch, senior urban development adviser, UNDP, with the assistance of Raquel Wexler.

22. Apart from information provided by the U.S. Energy Information Administration, an excellent article is Myerson (1998).

23. This section is based on the input of Kornelis Blok, Utrecht University.

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Chapter 3. Energy, the Environment, and Health

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ABSTRACT

In this chapter, the principal environmental and health impacts of energy are discussed according to the *scale* at which they occur. About half of the world's *households* use solid fuels (biomass and coal) for cooking and heating in simple devices that produce large amounts of air pollution-pollution that is probably responsible for 4-5 percent of the global burden of disease. The chief ecosystem impacts relate to charcoal production and fuelwood harvesting.

At the *workplace* scale, solid-fuel fuel cycles create significant risks for workers and have the largest impacts on populations among energy systems. In *communities*, fuel use is the main cause of urban air pollution, though there is substantial variation among cities in the relative contributions of vehicles and stationary sources. Diesel-fuelled vehicles, which are more prominent in developing countries, pose a growing challenge for urban health. The chief ecosystem impacts result from large-scale hydropower projects in forests, although surface mining causes significant damage in some areas.

At the *regional* scale, fine particles and ozone are the most widespread health-damaging pollutants from energy use, and can extend hundreds of kilometres from their sources. Similarly, nitrogen and sulphur emissions lead to acid deposition far from their sources. Such deposition is associated with damage to forests, soils, and lakes in various parts of the world. At the *global* scale, energy systems account for two-thirds of human-generated greenhouse gas increases. Thus energy use is the human activity most closely linked to potential climate change. Climate change is feared to have significant direct impacts on human health and on ecosystems.

There are important opportunities for 'no regrets' strategies that achieve benefits at more than one scale. For example, if greenhouse gas controls are targeted to reduce solid fuel use in households and other energy systems with large health impacts (such as vehicle fleets), significant improvements can occur at the local, community, regional, and global scales.

The harvesting, processing, distribution, and use of fuels and other sources of energy have major environmental implications. Insults include major land-use changes due to fuel cycles such as coal, biomass, and hydropower, which have implications for the natural as well as human environment.[1] Perhaps the most important insult from energy systems is the routine and accidental release of pollutants. Human activities disperse a wide variety of biologically and climatologically active elements and compounds into the atmosphere,

surface waters, and soil at rates far beyond the natural flows of these substances. The results of these alterations include a 10-fold increasein the acidity of rain and snow over millions of square kilometres and significant changes in the global composition of the stratosphere (upper atmosphere) and troposphere (lower atmosphere).

The rough proportions of various pollutants released into the environment by human activities are shown in table 3.1. Note the importance of energy supply systems, both industrial and traditional, in the mobilisation of such toxic substances as sulphur oxides and particles as well as in the release of carbon dioxide, the principal greenhouse gas. Also shown is the human disruption index for each substance, which is the ratio of the amount released by human activities to natural releases. This indicates that together with other human activities, energy systems are significantly affecting the cycling of important chemical species at the global scale. Although by themselves these indexes do not demonstrate that these insults are translated into negative impacts, their magnitudes provide warning that such impacts could be considerable.

In the past hundred years most of these phenomena have grown from local perturbations to global disruptions. The environmental transition of the 20th century-driven by more than 20-fold growth in the use of fossil fuels and augmented by a tripling in the use of traditional energy forms such as biomass-has amounted to no less than the emergence of civilisation as a global ecological and geochemical force.

The impacts from energy systems, however, occur from the household to the global scale. Indeed, at every scale the environmental impacts of human energy production and use account for a significant portion of human impacts on the environment.

This chapter examines the insults and impacts of energy systems according to the scale at which the principal dynamics occur-meaning the scale at which it makes the most sense to monitor, evaluate, and control the insults that lead to environmental impacts. In addition,

some cross-scale problems are considered to illustrate the need to control insults occurring at one scale because of the impacts they have at other scales. Impacts are divided into two broad categories: those directly affecting human health (environmental health impacts) and those indirectly affecting human welfare through impacts on the natural environment (ecosystem impacts).

Because of their ubiquity and size, energy systems influence nearly every category of environmental insult and impact. Indeed, large multiple-volume treatises have been devoted to discussing the environmental problem of just part of the energy system in single countries (as with U.S. electric power production in ORNL and RFF, 1992-98). A detailed review of the environmental connections of energy systems world-wide is beyond the scope of this volume. Indeed, simply cataloguing the routes of insults and types of impacts of energy systems world-wide would take substantially more space than is available here, even if accompanied by little comment.

Because of their ubiquity and size, energy systems influence nearly every category of environmental insult and impact.

In addition, for three other reasons reproducing catalogues involving simple listings of insults and impacts for each of the many types of energy systems would not serve the interests of readers. First, many detailed studies in recent years have done this job much better than we could here. Thus we will cite a range of such material to enable interested readers to expand their understanding. In addition, there is a substantial amount of such information in other chapters, for example, on the environmental and health impacts of renewable energy systems in chapter 7 and of fossil and nuclear power systems in chapter 8. Chapter 8 also addresses the technological implications of reducing urban pollution

according to changes in local willingness to pay for health improvements. Chapter 1 discusses some of the relationships between environment and energy development, and chapter 9 has much discussion of the implications of various future energy scenarios for greenhouse gas emissions.

The second reason relates to our desire to help readers understand the relative importance of the problems. The significance of known environmental impacts from energy systems varies by orders of magnitude, from the measurable but minuscule to the planet-threatening. Just as the other chapters in this volume must focus on just a few of the most important energy system issues for the next half-century, we must do so for environmental impacts.

Finally, we feel that it is as important to give readers a framework for thinking about environmental impacts as it is to document current knowledge about individual problems. Thus we have devoted much of our effort to laying out the problems in a systematic manner using scale as the organising principle. Near the end of the chapter we also discuss two of the most common analytical frameworks for making aggregate comparisons involving a range of environmental impacts from energy systems: economic valuation and comparative risk assessment using fuel-cycle analysis.

Given space limitations and the reasons summarised above, we focus below on the two or three most important environmental insults and impacts at each scale. This approach brings what may seem to be a geographic bias as well-examples at each scale tend to be focused not only on the most important problems but also on the places in the world where the problems are most severe. We recognise that there are innumerable other impacts and places that could be mentioned as well, but we offer this set as candidates for those that ought to have the highest priority in the next few decades.

Indeed, if these environmental problems were brought under control, the world would

have moved most of the way towards a sustainable energy future from an environmental standpoint.

This chapter focuses almost entirely on the environmental insults and impacts associated with today's energy systems, in line with this report's goal of exploring the sustainability of current practices. In later chapters, as part of efforts to examine the feasibility of advanced energy conversion technologies, new sources of energy, and enhanced end-use efficiencies, the potential environmental impacts of future energy systems are explored.

TABLE 3.1. ENVIRONMENTAL INSULTS DUE TO HUMAN ACTIVITIES BY SECTOR, MID-1990S

Insult	Natural baseline (tonnes a year)	Human disruption index[a]	Share of human disruption caused by			
			Commercial energy supply	Traditional energy supply	Agriculture	Manufacturing, other
Lead emissions to atmosphere[b]	12,000	18	41% (fossil fuel burning, including additives)	Negligible	Negligible	59% (metal processing, manufacturing, refuse burning)
Oil added to oceans	200,000	10	44% (petroleum harvesting, processing, and transport)	Negligible	Negligible	56% (disposal of oil wastes, including motor oil changes)
Cadmium	1,400	5.4	13% (fossil	5%	12%	70% (metals

Cadmium emissions to atmosphere	1,400	5.4	13% (fossil fuel burning)	5% (traditional fuel burning)	12% (agricultural burning)	70% (metals processing, manufacturing, refuse burning)
Sulphur emissions to atmosphere	31 million (sulphur)	2.7	85% (fossil fuel burning)	0.5% (traditional fuel burning)	1% (agricultural burning)	13% (smelting, refuse burning)
Methane flow to atmosphere	160 million	2.3	18% (fossil fuel harvesting and processing)	5% (traditional fuel burning)	65% (rice paddies, domestic animals, land clearing)	12% (landfills)
Nitrogen fixation(as nitrogen oxide and ammonium)[c]	140 million (nitrogen)	1.5	30% (fossil fuel burning)	2% (traditional fuel burning)	67% (fertiliser, agricultural burning)	1% (refuse burning)
Mercury emissions to atmosphere	2,500	1.4	20% (fossil fuel burning)	1% (traditional fuel burning)	2% (agricultural burning)	77% (metals processing, manufacturing, refuse burning)
Nitrous oxide flows to atmosphere	33 million	0.5	12% (fossil fuel burning)	8% (traditional fuel burning)	80% (fertiliser, land clearing, aquifer disruption)	Negligible
Particulate	3,100	0.12	35% (fossil	10%	40%	15% (smelting,

emissions to atmosphere	million[d]		fuel burning)	(traditional fuel burning)	(agricultural burning)	non-agricultural land clearing, refuse)
Non-methane hydrocarbon emissions to atmosphere	1,000 million	0.12	35% (fossil fuel processing and burning)	5% (traditional fuel burning)	40% (agricultural burning)	20% (non-agricultural land clearing, refuse burning)
Carbon dioxide flows to atmosphere	150 billion (carbon)	0.05[e]	75% (fossil fuel burning)	3% (net deforestation for fuelwood)	15% (net deforestation for land clearing)	7% (net deforestation for lumber, cement manufacturing)

Note: The magnitude of the insult is only one factor determining the size of the actual environmental impact. a. The human disruption index is the ratio of human-generated flow to the natural (baseline) flow. b. The automotive portion of anthropogenic lead emissions in the mid-1990s is assumed to be 50 percent of global automotive emissions in the early 1990s. c. Calculated from total nitrogen fixation minus that from nitrous oxide. d. Dry mass. e. Although seemingly small, because of the long atmospheric lifetime and other characteristics of carbon dioxide, this slight imbalance in natural flows is causing a 0.4 percent annual increase in the global atmospheric concentration of carbon dioxide.

Source: Updated from Holdren, 1992 using Houghton and others, 1994; IPCC, 1996b; Johnson and Derwent, 1996; Lelieveld and others, 1997; Nriagu, 1989, 1990; Smithsonian Institution, 1996; Smith and Flegal, 1995; and WRI, 1998.

Household scale

The oldest human energy technology, the home cooking fire, persists as the most

prevalent fuel-using technology in the world. For much of the world's population, the home cooking fire accounts for most direct energy demand. Household fuel demand accounts for more than half of energy demand in most countries with per capita incomes under $1,000 (see figure 2.1).

The 'energy ladder' is a useful framework for examining trends and impacts of household fuel use (see figure 10.1). The ladder ranks household fuels along a spectrum running from simple biomass fuels (dung, crop residues, wood) through fossil fuels (kerosene and gas) to the most modern form (electricity). The fuel-stove combinations that represent rungs in the ladder tend to become cleaner, more efficient, more storable, and more controllable in moving up the ladder.[2] But capital costs and dependence on centralised fuel cycles also tend to increase in moving up the ladder (OTA, 1992).

Although there are local exceptions, history has generally shown that when alternatives are affordable and available, populations tend to move up the ladder to higher-quality fuel-stove combinations. Although all of humanity had its start a quarter of a million years ago at the top of the energy ladder in those times (wood), only about half has moved up to higher-quality rungs (figure 3.1). The remaining half is either still using wood or has been forced by local wood shortages down the ladder to crop residues, dung, or, in some severe situations, to the poorest-quality fuels such as shrubs and grass.

Throughout history in places where coal is easily available, local wood shortages have led some populations to move to coal for household use. This shift occurred about a thousand years ago in the United Kingdom, for example, although it is relatively uncommon there today (Brimblecome, 1987). In the past 150 years such transitions occurred in Eastern Europe and China, where coal use still persists in millions of households (see figure 3.1). In terms of the energy ladder, coal represents an upward movement in terms of efficiency and storability. Because of these characteristics and its higher energy densities, it is possible to ship coal economically over longer distances than wood and to efficiently

supply urban markets. In these senses, coal is like other household fossil fuels. Unlike kerosene and gas, however, coal is often a dirtier fuel than wood.

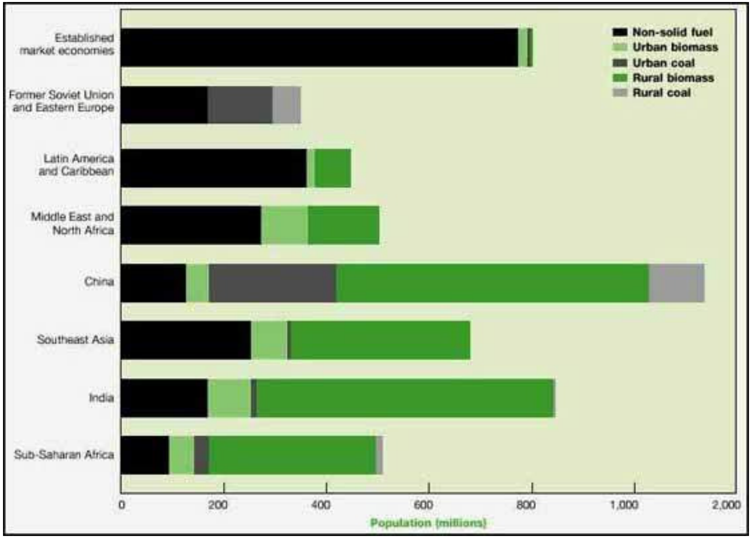


FIGURE 3.1. POPULATION AND HOUSEHOLD FUEL USE BY REGION, 1995

Source: Updated from Reddy, Williams, and Johansson, 1997.

Harvesting

The chief environmental impacts of household fuel cycles relate to harvesting and combustion. In the 1970s books and newspapers called attention to the ‘other’ energy crisis, referring to the growing and alarming shortage of woodfuel affecting a large fraction of the world population that depended on it. Since deforestation and

desertification were often also occurring in such places, it was perhaps a logical conclusion that fuel demand was to blame. It is still common today to read that deforestation is caused by fuel gathering in rural areas of developing countries. Detailed studies in many areas around the world, however, have rarely documented cases in which fuel demand is a significant cause of deforestation. The most important cause by far seems to be expansion of agricultural lands, followed by lumbering and road building. Indeed, the causation is more often the reverse-that is, the shortage of fuelwood is due to deforestation, rather than the other way around.

Part of the misunderstanding stems from the assumption that rural households gather woodfuel from forests. In many areas villagers gather significant amounts of fuelwood from what Gerald Leach has called 'invisible trees'-the trees around fields, next to houses, along roads, and so on that do not show up in most satellite remote sensing surveys or national forest statistics. Thus when estimates of local fuelwood demand appear to exceed growth rates in local forests, it does not necessarily imply that deforestation is taking place. Conversely, if deforestation is known to be occurring, it does not mean that fuel demand is necessarily the reason.

Similarly, desertification in the Sahel and elsewhere in Sub-Saharan Africa has links to fuel demand. But it has been difficult to separate out the influence of all the relevant factors, including climate change, intensification of grazing, land-use shifts, and fuel harvesting. Nevertheless, as with deforestation, there are some poor areas where harvesting of wood and brush plays an important role.

BOX 3.1. HEALTH-DAMAGING POLLUTANTS IN SOLID FUEL SMOKE FROM HOUSEHOLD STOVES IN INDIA

Biomass smoke

- Small particles, carbon monoxide, nitrogen dioxide.
- Formaldehyde, acrolein, benzene, 1,3-butadiene, toluene, styrene, and so on.
- Polyaromatic hydrocarbons such as benzo(a)pyrene.

Coal smoke

- All the above plus, depending on coal quality, sulphur oxides and such toxic elements as arsenic, lead, fluorine, and mercury.

Physical form and contaminant content are the two characteristics of fuels that most affect their pollutant emissions when burned.

Although the link between fuelwood harvesting and deforestation is far from universal, there are localised cases in which fuelwood demand seems to contribute significantly to forest depletion. Most prominent among these are places, mainly in Sub-Saharan Africa, where commercial charcoal production is practised. In these areas temporary kilns (legal or illegal) in forested areas are used until local wood resources are depleted, then moved or rebuilt elsewhere. Charcoal, being a relatively high-quality and high-density fuel, can be trucked economically across long distances to urban markets. Thus large charcoal-using cities can have 'wood sheds' extending hundreds of kilometres along roadways, though there is evidence that significant regrowth often occurs over long enough periods. In some arid and semiarid areas, harvesting by woodfuel traders to meet urban demand seems to contribute to forest depletion, although, again, regrowth is often occurring. The

quality of regrowth in terms of biodiversity and other ecosystem parameters is not well documented, however.

The harvesting of dung and crop residues as fuel does not have much direct environmental impact. But in some areas it may deprive local soils of needed nutrients and other conditioners. Indeed, in most rural areas the use of dung as fuel rather than fertiliser is probably a sign of poverty and lack of fuel alternatives. Crop residues, on the other hand, consist of a wide variety of materials, many of which do not have much value as fertiliser or soil conditioner. Indeed, in some cases disposal becomes a serious problem if these residues are not gathered for fuel. In these cases the usual practice is to burn the residues in place on the fields, with consequent pollution implications (although sometimes with benefits in terms of pest control). Consequently, regardless of development level, air pollution from post-harvest burning of farmland is a significant seasonal source of air pollution in many agricultural areas around the world (see chapter 10). Harvesting and preparation of household biomass fuels also have occupational health impacts on women and children, due, for example, to heavy loads and burns (see the section on workplace scale, below).

Combustion

It is generally difficult to pre-mix solid fuels sufficiently with air to assure good combustion in simple small-scale devices such as household stoves. Consequently, even though most biomass fuels contain few noxious contaminants, they are usually burned incompletely in household stoves and so produce a wide range of health-damaging pollutants (box 3.1). Wood and other biomass fuels would produce little other than non-toxic products, carbon dioxide, and water when combusted completely. But in practice sometimes as much as one-fifth of the fuel carbon is diverted to products of incomplete combustion, many of which are important health-damaging pollutants.

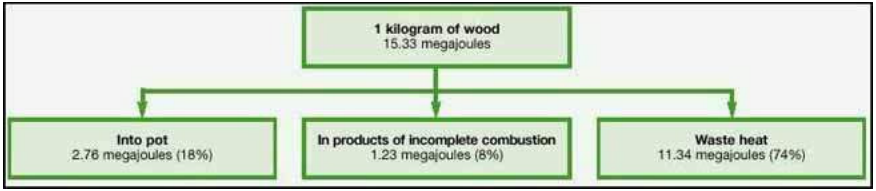


FIGURE 3.2A. ENERGY FLOWS IN A TYPICAL WOOD-FIRED COOKING STOVE

Source: Smith and others, 2000 a.

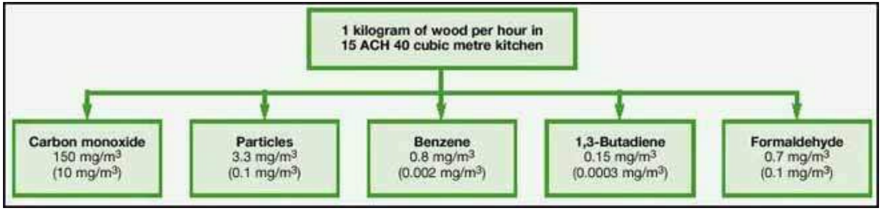


FIGURE 3.2B. INDOOR CONCENTRATIONS OF HEALTH-DAMAGING POLLUTANTS FROM A TYPICAL WOOD-FIRED COOKING STOVE

Note: Dozens of other health-damaging pollutants are known to be in woodsmoke. Mg/m^3 stands for milligrams per cubic metre. Numbers in parentheses are typical standards set to protect health.

Source: Smith and others, 2000 a.

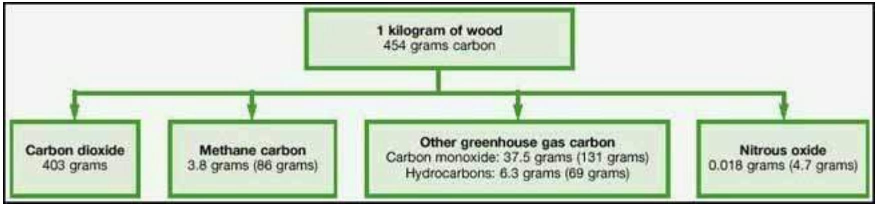


FIGURE 3.2C. GREENHOUSE GAS EMISSIONS FROM A TYPICAL BIOMASS COOKSTOVE

Note: Numbers in parentheses are carbon dioxide equivalents of non-carbon dioxide gases.

Source: Smith and others, 2000 a.

Coal, on the other hand, is not only difficult to burn completely because it is solid, but also often contains significant intrinsic contaminants that add to its emissions of health-damaging pollutants. Most prominent among such emissions are sulphur oxides (see box 3.1). But in many areas coal also contains arsenic, fluorine, and other toxic elements that can lead to serious health-damaging pollutants. Tens of millions of people in China, for example, are exposed to such pollutants from household coal use.

Petroleum-based liquid and gaseous fuels, such as kerosene and liquefied petroleum gas, can also contain sulphur and other contaminants, though in much smaller amounts than in many coals. In addition, their physical forms allow much better pre-mixing with air in simple devices, assuring much higher combustion efficiencies and lower emissions of health-damaging pollutants in the form of products of incomplete combustion. Furthermore, stoves for petroleum-based liquid and gaseous fuels are much more energy efficient than those for coal. As a result emissions of health-damaging pollutants per meal from these fuels are at least an order of magnitude less than those from solid fuels (Smith and others, 2000a).

Not only do solid-fuel stoves produce substantial emissions of health-damaging pollutants per meal, but a large fraction do not have chimneys for removing the emissions from the home. Consequently, indoor concentrations of health-damaging pollutants can reach very high levels. Figure 3.2a shows the energy flows of a typical wood-fired cooking stove, in which a large fraction of the fuel energy is lost because of low combustion efficiency or low transfer of the heat to the pot. Figure 3.2b shows the excessive pollutant levels commonly reached in these circumstances, well beyond World Health Organization guidelines. Even in households with chimneys, however, heavily polluting solid-fuel stoves can produce significant local outdoor pollution. This is particularly true in dense urban slums, where such 'neighbourhood' pollution can be much higher than average urban pollution levels.

To estimate the health damage from pollution, it is necessary to take into account the amount of pollution released. Equally important, however, is the behaviour of the population at risk. Even a large amount of pollution will not have much health impact if little of it reaches people. But a relatively small amount of pollution can have a big health impact if it is released at the times and places where people are present, such that a large fraction is breathed in. Thus it is necessary to look not only at where the pollution is but also at where the people are.

Unfortunately, pollution from household stoves is released right at the times and places where people are present-that is, in every household every day. This is the formula for high pollution exposures: significant amounts of pollution often released in poorly ventilated spaces at just the times when people are present. Moreover, because of their nearly universal responsibility for cooking, women and their youngest children are generally the most exposed.

Thus, although the total amount of health-damaging pollution released from stoves world-wide is not high relative to that from large-scale use of fossil fuels, human exposures to a

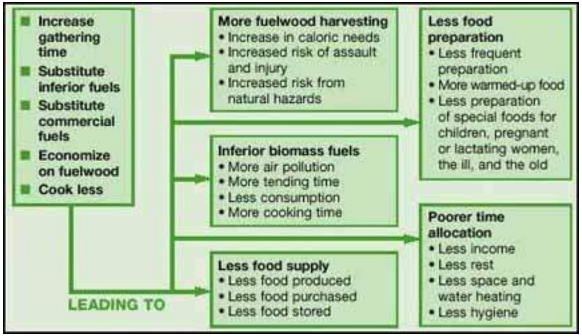
number of important pollutants are much larger than those created by outdoor pollution. As a result the health effects can be expected to be higher as well.

In many ways the harvesting impacts and air pollution from use of biomass fuels are the result of fuel shortages, particularly where inferior forms (dung and crop residues) are in use. Thus these can be considered part of the health effects of too little energy, along with lower nutrition and chilling (box 3.2).

BOX 3.2. HEALTH EFFECTS OF TOO LITTLE WOODFUEL

Lack of sufficient fuel for heating and cooking has several negative health impacts. First, in many places women and children must walk further and work harder to gather fuel, using more energy and time and placing themselves at increased risk of assault and natural hazards such as leeches and snakes. In addition, nutrition can be negatively affected if families have to walk long distances to gather cooking fuel. When seasonal changes result in longer fuel collection times, families are unable to compensate by reducing the time spent on agricultural activities. Instead the time is subtracted from resting and food preparation.

Inferior fuels, such as twigs and grass, that are used as substitutes in times of shortage require more attention from women during cooking, keeping them from other tasks. These fuels also produce more health-damaging smoke and are inadequate for processing more nutritious foods such as cereals and beans (since they have long cooking times). The figure at right outlines some coping strategies adopted by households to deal with fuel shortages and their health consequences.



Household coping strategies for fuelwood shortages

Source: Agarwal, 1985; Brouwer, 1994.

BOX 3.3. NATIONAL BURDEN OF DISEASE FROM HOUSEHOLD SOLID FUEL USE IN INDIA

National surveys, including the 1991 national census, show that nearly 80% of Indian households use biomass as their primary cooking fuel. As a result, a large portion of the Indian population is potentially exposed to indoor and outdoor levels of pollution produced by cooking stoves. Based on risks derived solely from studies of the health effects of individual diseases occurring in biomass-using households in developing countries, many in India itself, it is possible to estimate the total national burden of disease in India from use of these fuels:

Acute respiratory infection. More than a dozen studies around the world have found that household use of solid fuels is associated with acute respiratory infection in young children (although, as with all the diseases discussed here, there are other important risk factors, including malnutrition and crowding). Acute respiratory infection is the leading cause of death of the world’s children and the largest category of ill health in the world in terms of disease burden. Almost 9 percent of the global burden of ill health and 12 percent of India's is due to acute respiratory infection. Acute respiratory infection linked to solid fuel use is estimated to cause 290,000-440,000 premature deaths a year in Indian children under 5.

Tuberculosis has been associated with household solid fuel use in a national survey in India involving nearly 90,000 households as well as in smaller studies. Although this relationship is not yet established with complete certainty, it would be highly significant because tuberculosis is on the rise in many developing countries due to HIV infection and the increase in drug-resistant strains. In India 50,000-130,000 cases of tuberculosis in women under 15 are associated with solid fuel use.

Chronic respiratory disease, such as chronic bronchitis, is almost entirely due to smoking in the industrialised world. But studies in Asia and Latin America have found the chronic respiratory disease develops in women after long years of cooking with solid fuels. In India 19,000-34,000 women under 45 suffer from chronic respiratory disease linked to solid fuel use.

Lung cancer, which is also dominated by smoking in industrialised countries, has been found to result from long-term exposure to cooking with coal in more than 20 studies in China. No such effect has been shown for biomass fuels, however. In India 400-800 women under 45 suffer from lung cancer linked to solid fuel use; the number is small because households rarely use coal.

Cardiovascular (heart) disease. Although there are apparently no studies in biomass-using households, studies of urban air pollution suggest that in India 50,000-190,000 women under 30 suffer from pollution-related heart disease.

Adverse pregnancy outcomes. Stillbirth and low birthweight have been associated with solid fuel use by pregnant women in Latin America and India. Low birthweight is a big problem in developing countries because it is a risk factor for a range of health problems. In India, however, there are too few studies to calculate the impacts of solid fuel use on adverse pregnancy outcomes.

Total. Because there is more uncertainty in the estimates for tuberculosis and heart disease, only the low ends of the estimated ranges are used. In India 410,000-570,000 premature deaths a year in women and children, of 5.8 million total, seem to be due to biomass fuel use. Given the age distribution of these deaths and the associated days of illness involved, 5-6 percent of the national burden of disease in women and young children can be attributed to biomass fuel use in households. For comparison, about 10 percent of the Indian national burden of disease is attributed to lack of clean water and sanitation.

Source: Smith, 2000; Smith and others, 2000; Murray and Lopez, 1996.

Estimated health effects

Considering the sizes of the relevant populations and the exposures to health-damaging pollutants, there has been relatively little scientific investigation of the health effects of indoor air pollution in developing countries relative to studies of outdoor air pollution in cities. Nevertheless, enough has been done to enable rough estimates of the total impact of air pollution, at least for women and young children (who suffer the highest exposures).

Four main types of health effects are thought to occur, based on studies in households that use solid fuels and corroborated by studies of active and passive smoking and outdoor air pollution (Smith, 1998):

- **Infectious respiratory diseases such as acute respiratory infections and tuberculosis.**

- **Chronic respiratory diseases such as chronic bronchitis and lung cancer.**

- **Adverse pregnancy outcomes such as stillbirth and low birth-weight in babies born to women exposed during pregnancy.**

- **Blindness, asthma, and heart disease (less evidence to date).**

The best estimates of such effects for developing countries have been done for India (box 3.3). These indicate that household solid fuel use causes about 500,000 premature deaths a year in women and children under 5. This is 5-6 percent of the national burden of ill health, or 6-9 percent of the burden for these two population groups.[3] This is comparable to, though somewhat less than, the estimated national health impacts of poor water and sanitation at the household level-and more than the national burdens of such major health hazards as malaria, tuberculosis, tobacco, AIDS, heart disease, or cancer (Murray and Lopez, 1996).

Given that India contains about one-quarter of the world's solid-fuel cooking stoves, the global impact could be expected to be about four times larger, or about 2 million deaths a year in women and children. This is roughly compatible with World Health Organization estimates of about 2.5 million, estimates that were generated by extrapolating studies from industrialised country cities to developing country conditions (WHO, 1997). The global burden of disease from major risk factors, including indoor air pollution, is shown in figure 3.3.

Greenhouse gases

The same incomplete combustion processes that produce emissions of health-damaging pollutants from household solid-fuel stoves also produce greenhouse gas emissions. (Greenhouse gas emissions and their global impacts are described below, in the section on the global scale.) A large amount of fuel carbon is typically diverted to gaseous products of incomplete combustion, all of which cause greater global warming per carbon atom than would be the case if complete combustion occurred and all the carbon was released as carbon dioxide (see figure 3.2c). The most powerful of these is methane, which over a 20-year period causes more than 20 times the global warming from the same amount of

carbon as carbon dioxide (equivalent to a discount rate of about 4 percent).

Greenhouse gas emissions from several of the most important household fuels in developing countries (as measured in India) are shown in figure 3.4. Because of significant emissions of non-carbon dioxide greenhouse gases, solid biomass fuels, even though renewable, can have a larger greenhouse gas commitment per meal than fossil fuels, kerosene, and liquefied petroleum gas. These relationships have several important policy implications:

- **Even if renewably harvested, many biomass fuel cycles are not greenhouse gas neutral because of their substantial production of products of incomplete combustion.**

- **In some situations, therefore, substitution of fossil fuels for renewable biomass might be recommended to reduce greenhouse gas emissions.**

- **To be greenhouse gas neutral, biomass fuel cycles must be based on renewable harvesting and must have close to 100 percent combustion efficiency (which most do not in their current configurations).**

- **Improved biomass stoves should be designed to increase overall efficiency and to reduce combustion inefficiency, which is the cause of greenhouse gas and health-damaging pollutants.**

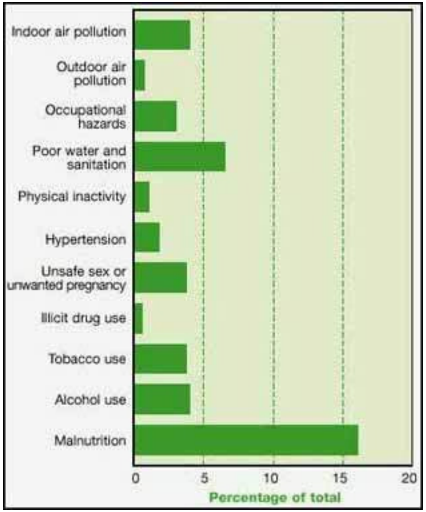


FIGURE 3.3. GLOBAL BURDEN OF DISEASE FROM SELECTED MAJOR RISK FACTORS, 1995

Note: Burden of indoor air pollution extrapolated from data for India.

Source: Smith, 2000; Murray and Lopez, 1996.

Stoves using biogas, which is made in household or village anaerobic digesters from dung (see chapter 10), have by far the least greenhouse gas emissions per meal-only about 10 percent of those for liquefied petroleum gas and a factor of 80 less than the average stove burning dung directly (see figure 3.4). A complete comparison of these fuel-stove combinations would require evaluating greenhouse gas emissions over the entire fuel cycle in each case, for example, including methane leaking from biogas digesters and releases from oil refineries making kerosene. Nevertheless, the extremely low greenhouse gas emissions from biogas stoves illustrate the potentially great advantage for greenhouse

gas emissions of processed biomass fuels such as biogas. Such fuels can be both renewably harvested as well as burned as liquids or gases with high combustion efficiency. (The section on cross-scale impacts, below, discusses some of the potential opportunities for reducing impacts at the household and global scales through improvements in household cooking.)

Reducing the human health and global warming impacts of household stoves will require better stoves with higher efficiency, lower emissions, and cleaner fuels. These issues are discussed in chapter 10. Of course, the largest greenhouse gas emissions are from energy systems used in industrialised countries, as discussed in later sections.

Workplace scale

The extraction, transport, use, and waste management of energy sources involve important health hazards related to the work and workplaces involved in these activities. Many of the jobs involved, such as forestry and mining for solid fuels, are particularly dangerous. Many workers are engaged in these jobs, particularly in countries that are rapidly developing their industries and the energy sources that the industries require. In addition, much of the work needed for household energy supply in developing countries is carried out as a household task that does not figure in national statistics as an 'occupational issue'.

This section analyses these health issues based on the type of energy source and give examples of how the effects have been documented in different countries. The fourth edition of the International Labour Organisation's *Encyclopaedia of Occupational Safety and Health* (Stellman, 1998) provides additional detail about energy jobs and their health hazards.

Biomass

As noted, wood, crop residues, dung, and the like are common energy sources for poor households in developing countries. Wood is also still widely used in industrialised countries, in some cases promoted in the interest of reducing greenhouse gas emissions. Wood and agricultural waste are often collected by women and children (Sims, 1994). Such collection is part of daily survival activities, which also include water hauling, food processing, and cooking (see chapters 2 and 10). An analysis in four developing countries found that women spend 9-12 hours a week on these activities, while men spend 5-8 hours (Reddy, Williams, and Johansson, 1997). Women's role in firewood collection is most prominent in Nepal (2.4 hours a day for women and 0.8 hours for men).

Firewood collection may be combined with harvesting of wood for local use in construction and small-scale cottage industry manufacturing. This subsistence work is often seasonal, unpaid, and not recorded in national economic accounts. Globally about 16 million people are involved in forestry (Poschen, 1998), more than 14 million of them in developing countries and 12.8 million in subsistence forestry.

A number of health hazards are associated with the basic conditions of the forest. Forest workers have a high risk of insect bites, stings from poisonous plants, leech infestation, cuts, falls, and drowning. In tropical countries the heat and humidity put great strain on the body, while in temperate countries the effects of cold are a potential hazard. The work is outside, and in sunny countries ultraviolet radiation can be another health hazard, increasing the risk of skin cancer and eye cataracts (WHO, 1994). All forestry work is hard physical labour, with a risk of ergonomic damage such as painful backs and joints as well as fatigue, which increases the risk of injuries. Heavy loads of firewood contribute to ergonomic damage (Poschen, 1998). Women carrying heavy loads of firewood are a common sight in areas with subsistence forestry (Sims, 1994). Falling trees, sharp tools, dangerous machinery, and falls from heights are the main causes of injuries. In addition, the living conditions of forestry workers are often poor, and workers may be spending long periods in simple huts in the forest with limited protection against the weather and

poor sanitary facilities.

Urbanisation leads to the development of a commercial market for firewood and larger-scale production of firewood from logs or from smaller waste material left over after logs have been harvested. Energy forestry then becomes more mechanised, exposing workers to additional hazards (Poschen, 1998). Motorised hand tools (such as chain saws) become more common, resulting in high risks of injuries, noise-induced hearing losses, and 'white finger disease' caused by vibration of the hands. In addition, fertilisers and pesticides become part of the production system, with the potential for poisoning those who spray pesticides. As forestry develops further, more logging becomes mechanised, with very large machinery reducing the direct contact between workers and materials. Workers in highly mechanised forestry have only 15 percent of the injury risk of highly skilled forestry workers using chain saws (Poschen, 1998). Still, firewood production remains an operation that requires manual handling of the product at some stage and so tends to remain hazardous.

Another health aspect of wood-based energy is the risk of burning wood that has been treated against insect damage with copper-arsenic compounds or that has been painted with lead paint. Such wood may be harder to sell and so may be used to a greater extent by firewood production workers in stoves and open fires. When burned, poisonous arsenic and lead compounds will be emitted with the smoke. These compounds are health hazards when inhaled.

Coal

Coal is a major global energy source, accounting for 23 percent of total energy consumption. It was the primary energy source from 1900 until 1960, when it was overtaken by oil (WHO, 1997). Coal can be produced through surface (open cast) mining or underground mining. Like mining in general, both operations are inherently dangerous

to the health of the workers. About 1 percent of the global workforce is engaged in mining, but these workers account for 8 percent of the 15,000 fatal occupational accidents each year. Armstrong and Menon (1998) offer a detailed review of occupational health and safety issues in coal mining and other mining.

Pollution from household stoves is released right at the times and places where people are present - that is, in every household every day.

Underground coal miners are exposed to the hazards of excavating and transporting materials underground. These hazards include injuries from falling rocks and falls into mine shafts, as well as injuries from machinery used in the mine. There are no reliable data on injuries of this type from developing countries (Jennings, 1998), but in industrialised countries miners have some of the highest rates of compensation for injuries - and the situation is likely to be worse in developing countries. In addition, much of the excavation involves drilling into silica-based rock, creating high levels of silica dust inside the mine. Pneumoconiosis silicosis is therefore a common health effect in coal miners (Jennings, 1998).

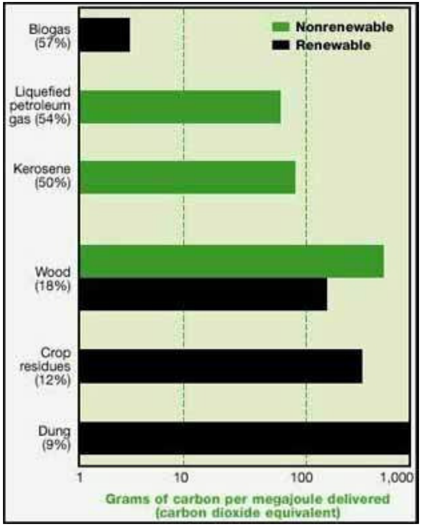


FIGURE 3.4. GREENHOUSE GAS EMISSIONS FROM HOUSEHOLD FUELS

Note: Includes warming from all greenhouse gases emitted: carbon dioxide, methane, carbon monoxide, non-methane hydrocarbons, and nitrous oxide. Weighted by stove distribution in India. Numbers in parentheses are average stove energy efficiency.

Source: Smith and others, 2000 b.

Other health hazards specific to underground coal mining include coal dust, which can cause 'coal worker's pneumoconiosis' or anthracosis, often combined with silicosis. Coal dust is explosive, and explosions in underground coal mines are a constant danger for coal miners. Coal inherently burns, and fires in coal mines are notuncommon. Once such a fire has started, it may be almost impossible to extinguish. Apart from the danger of burns, the

production of smoke and toxic fumes create great health risks for the miners.

Even without fires, the coal material produces toxic gases when it is disturbed: carbon monoxide, carbon dioxide, and methane (Weeks, 1998). Carbon monoxide is extremely toxic because it binds to haemoglobin in the blood, blocking oxygen transport and creating chemical suffocation (Bascom and others, 1996). Carbon monoxide is a colourless and odourless gas and so gives no warning before the symptoms of drowsiness, dizziness, headache, and unconsciousness occur. Carbon dioxide, also colourless and odourless, displaces oxygen in underground air and can also cause suffocation. Another health hazard in mining is exhaust from the diesel engines used in underground machinery and transport vehicles. This exhaust contains very fine particles, nitrogen oxides, and carbon monoxide, all of which pose serious health hazards (Bascom and others, 1996). Exposure to fine particles in diesel exhaust increases the risk of lung cancer (Holgate and others, 1999).

Surface coal mining avoids some of the hazards of working underground. Still, it involves the risk of injuries from machinery, falls, and falling rocks. In addition, coal mining is energy-intensive work, and heat, humidity, and other weather factors can affect workers' health. The machinery used is also noisy, and hearing loss is a common among miners. Another health hazard is the often squalid conditions under which many coal workers and their families in developing countries live, creating particular risk for the diseases of poverty. In addition, such workers are likely to receive part of their compensation in the form of coal for use as household fuel, with consequent indoor and neighbourhood pollution.

After extraction, coal needs to be processed and transported to residential areas, power stations, and industries. This creates other types of occupational hazards (Armstrong and Menon, 1998). For instance, coal for residential use is often ground and formed into briquettes. This work involves high levels of coal dust as well as noise hazards. Loading, transportation, and off-loading of large amounts of coal involves ergonomic, noise, and

injury hazards.

The large-scale use of coal in power stations and industry creates yet more hazards. One is the conversion of coal to coke in steel production. This process distils a large number of volatile polycyclic aromatic hydrocarbons in coal, the so-called coal tar pitch volatiles (Moffit, 1998). Exposure to these hydrocarbons puts coke oven workers at twice the lung cancer risk of the general population (IARC, 1984). (This process is not entirely associated with energy supply, as an important aim is to provide carbon to reduce iron oxides to elemental iron.) Additional health hazards are created for workers when the large amounts of ash produced by power stations and industry need to be transported and deposited. Crane (1998) reviews the health hazards faced by power generation workers.

Solid biomass fuels, even though renewable, can have a larger greenhouse gas commitment per meal than fossil fuels, kerosene, and liquefied petroleum gas.

Oil and gas

Oil and gas exploration, drilling, extraction, processing, and transport involve a number of the same hazards as mining: heavy workload, ergonomic hazards, injury risk noise, vibration, and chemical exposures (Kraus, 1998). This work is often carried out in isolated areas with inclement weather conditions. Long-distance commuting may also be involved, causing fatigue, stress, and traffic accident risks.

The ergonomic hazards lead to risks of back pain and joint pain. Injury hazards include burns and explosions. Skin damage from exposure to oil and to chemicals used in drilling creates a need for well-designed protective clothing. In addition, many oil and gas

installations have used asbestos to insulate pipes and equipment. Inhalation of asbestos dust in the installation and repair of such equipment creates a risk of lung cancer, asbestosis, and mesothelioma (WHO, 1998a).

A lot of exploration and drilling for oil and gas occur offshore. This involves underwater diving, which is dangerous. In addition, weather-related exposures can be extreme, particularly since the work often requires round-the-clock operations (Kraus, 1998).

Hydropower and other renewables

Major hazards occur when a hydroelectric power station is built, because this usually requires constructing a large dam, excavating underground water channels, and building large structures to house the generator. McManus (1998) lists 28 occupational hazards potentially involved in the construction and operation of hydroelectric power stations. These include asbestos exposure, diesel and welding fumes, work in confined spaces or awkward positions, drowning, electrocution, noise, heat, electromagnetic fields, vibration, weather-related problems, and chemical exposures from paints, oils, and PCBs (polychlorinated biphenyls). As in any industry, however, proper attention to health and safety can keep the risks to acceptable levels.

The manufacture of wind and solar power equipment involves the typical hazards in manufacturing: injuries, noise, chemical exposures, and so on. In addition, the technologies for solar electricity generation involve new chemical compounds, some based on rare metals with poorly known toxic properties (Crane, 1998).

Nuclear danger

Nuclear power generation has its own hazards due to the radiation danger involved in mining, processing, and transporting uranium, as well as the radiation in nuclear power stations. In addition, occupational hazards will develop as countries start to deal with the

backlog of radioactive waste. Due to the major potential risk to the general public from a malfunctioning nuclear power station, the safety of stations is always paramount. This has contributed to a low average occupational health risk for workers in the stations (Morison, 1998).

The mining of uranium has been an important occupational health hazard in nuclear power generation, as underground mining for uranium often entails high exposure to radon, a radioactive gas emitted from uranium. Radon exposure leads to an increased risk of lung cancer. In addition, the same occupational hazards in mining noted above occur, although the relatively high energy content of uranium ore means that there are fewer health effects per unit of electricity produced.

Until the Chernobyl accident, relatively few nuclear power station workers had been affected by radiation exposure. In that accident, however, 40 workers lost their lives in the fire or due to acute radiation exposure. The long-term impact on workers exposed during the accident in the form of cancer and other radiation-related effects is not yet known, however. The clean-up after the accident may eventually create substantially more effects. As many as 900,000 army, police, and other workers were called on to take part. Many workers were needed because they were only allowed to work for a short time, until they had reached the maximum allowable radiation dose. In some cases this dose was reached in a few minutes. Studies are now being undertaken to establish the exposure of each clean-up worker and the long-term health impacts (WHO, 1996).

Number of workers and quantitative health effects estimates

It is difficult to estimate the number of workers involved in meeting the energy requirements of communities. As noted, in poor communities much of this work is carried out by family members, particularly women, who are not formally employed. In addition, much of this work is carried out by small industries that are not always recorded in

national employment statistics.

As noted, an estimated 16 million people are involved in forestry, most of them in developing countries. In industrialised countries with reliable statistics, the occupational mortality rate for agricultural workers is 5-10 times the average for all workers (Kjellstrom, 1994). Because of the additional risks in forestry, mortality rates for these workers are possibly twice as high again, or 32,000-160,000 at a global level. Not all of this activity is directly related to fuel demand, however.

As noted, miners are a large occupational group in international statistics (UN Demographic Yearbooks). They represent up to 2 percent of the economically active population in certain developing countries. Mining is an extremely dangerous occupation. Recent data show that occupational mortality rates for miners are up to 20 times the average for all occupations (ILO, 1998). The range of mortality rates may be as wide as that for forestry (2-10 per 1,000 workers per year). In most countries the economically active population is 40-60 percent of the population over 15. Thus miners may account for 1 percent of the population over 15, or about 30 million people world-wide. If half of these miners are coal miners, the number of miners killed each year in accidents would be about the same as for forestry workers (30,000-150,000). Another approach to this calculation is through total coal production. If applied to the world's coal production today, about 70 percent of which is in developing countries, the mean death rate in U.S. mines from 1890-1939 of 3.1 deaths per million tons produced would predict 16,000 coal mining deaths a year world-wide (ORNL and RFF, 1994a). This may be low, however, because China alone has about 6,500 coal mining deaths a year according to official statistics, which tend to be incomplete (Horii, 1999). The estimate of 6,500 of 16,000 deaths, on the other hand, is roughly consistent with China's 30 percent share of global production (BP, 1998).

For energy production and distribution as a whole, occupational mortality may sum to 70,000-350,000 a year. These numbers are likely to exclude many cases of occupational

disease (such as cancers caused by asbestos or radiation) and deaths among the many workers in informal workplaces. The upper limit of the numbers, however, may also be inflated by the crude estimates of mortality rates and number of workers. Occupational mortality rates in energy jobs in industrialised countries are generally 10-30 times lower than in developing countries (Kjellstrom, 1994; ILO, 1998), indicating that more effective prevention programs could eliminate more than 90 percent of the deaths referred to above. Still, energy-related jobs have inherent health risks that need to be considered when assessing the full impact of energy production and distribution.

Although too often ignored in discussions of environmental health risks, the burden of occupational disease and injury is substantial on a global scale. It is conservatively estimated that with well over 1 million deaths a year, nearly 3 percent of the global burden of ill health is directly attributable to occupational conditions (Leigh and others, 1996). This is substantial, accounting for more than motor vehicles, malaria, or HIV and about equal to tuberculosis or stroke. Although the fraction due directly to supplying energy is unclear, energy systems employ many millions of people worldwide in jobs substantially riskier than average-particularly in jobs producing solid fuels.

Community scale

Energy systems are associated with a vast array of insults and impacts (see table 3.1). Many of these are expressed at the community scale, including problems associated with coal and uranium mining, petroleum and gas extraction, water use and contamination by power plants, thermal pollution, and noise from wind farms. Here we can only focus on the largest of these impacts world-wide.

Urban air pollution is the chief environmental impact of energy systems at the community level. Although there are industrial and other sources of some pollutants, the vast bulk-whether measured by mass or by hazard-is generated by fuel combustion or, as in the

case of photochemical smog, is created in the urban atmosphere by precursor chemicals largely released in the course of fuel use. From the 1930s to the 1950s a number of urban air pollution episodes in the industri-alised world brought air pollution to the attention of the public. The first major improvements came by banning the burning of refuse and coal within city limits. By the early 1970s the infamous London smogs (and their parallels in other cities), caused by coal combustion, were memories. Two other community-level impacts are also discussed in this section: those due to large hydroelectric dams and to nuclear power.

Fuel-derived air pollution in cities of industrialised countries

During the past 25 years the cities of the industrialised world have generally brought energy-derived urban air pollutants under even greater control. In the United States, for example, emissions per unit of useful energy from power plants and automobiles-the two largest urban energy polluters-have fallen 65 percent and 50 percent in health hazard (weighted by the relative standards for each pollutant).[4] Japan and Western Europe have achieved similar results.

In the power sector these achievements have mostly come about by relying more on nuclear power and natural gas and by requiring smokestack controls for particles and nitrogen and sulphur oxides at coal-fired power plants. In addition, thermal power plants have become more efficient, and more improvements are expected, particularly for those using gas (see chapter 8). For vehicles, the reductions have come from a mix of improvements in engine combustion, increases in fuel efficiency (in North America), and the nearly universal requirement of catalytic converters (devices to help control pollutant emissions). Thus, despite significant increases in power production and vehicle use since 1975, overall emissions of most pollutants are now lower.

As a result of these emission reductions, urban air quality has generally improved

throughout the industrialised world. Although fuel combustion produces a number of health-damaging pollutants, as explained above, small particles are probably the best single indicator. Suspended small particles are a mix of primary combustion particles-carbonaceous materials and associated trace elements-and secondary conversion products such as sulphate and nitrate aerosols. In many parts of the world, windblown and urban dust can also be significant contributors to suspended particles.

Small particles are deposited deep in the lungs, where their clearance is slow and their ability to cause damage is enhanced. Small particles also carry adsorbed trace metals and carcinogenic hydrocarbons into the lungs, intensifying the potential for health damage. Assessments of the human health effects of air pollutants increasingly focus on these small particles. Still, there are few measurements of these particles in most cities, although more cities are measuring PM_{10} (particles less than 10 micrograms), which is considered a better indicator than simple total particulate levels (National Research Council, 1998).5 In the late 1990s the mean annual cocentration of PM_{10} in North American, Western European, and Japanese cities ranged from 30-45 micrograms per cubic metre (figure 3.5). (The U.S. standard is 50 micrograms per cubic metre.) In the 1960s particulate levels were probably two to four times higher. (Small particles were not measured routinely until the mid-1980s, so previous levels have to be inferred from measurements of total particles.)

About 1 percent of the global workforce is engaged in mining, but these workers account for 8 percent of the 15,000 fatal occupational accidents each year.

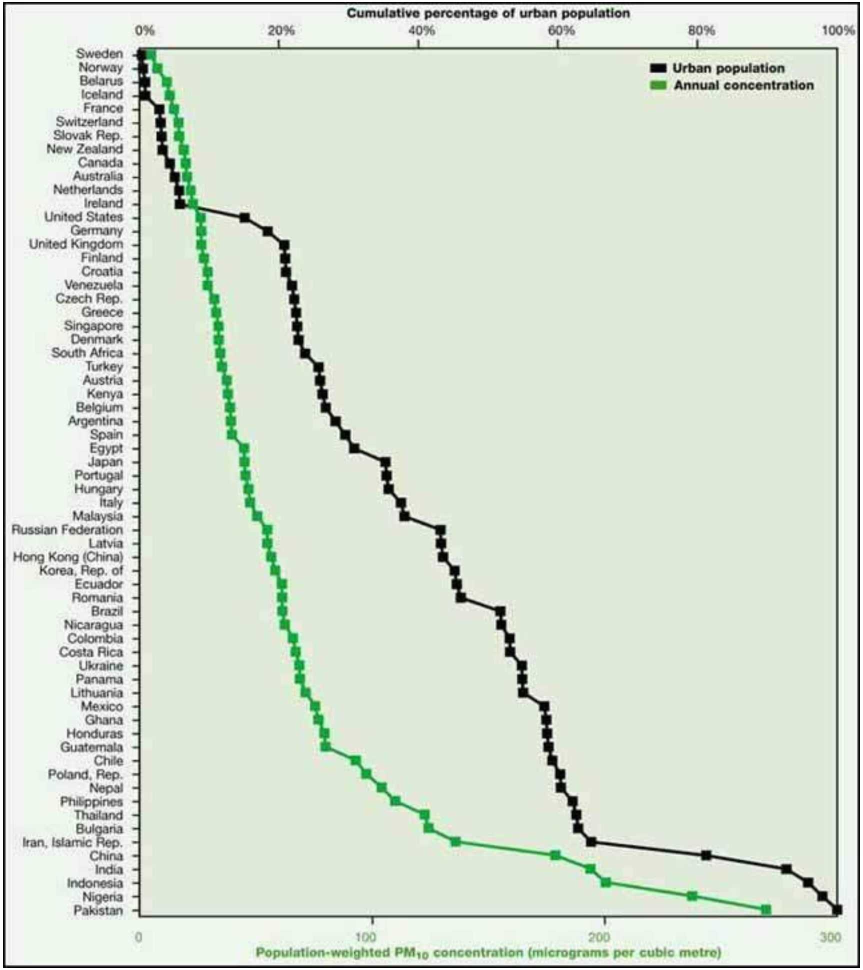
Still, industrialised countries face a number of energy-related air pollution challenges. Nitrogen dioxide and ozone levels exceed standards in many cities, particularly in sunny cities with large auto fleets such as Los Angeles (California) and Athens (Greece). The recent evidence suggesting that small particles (less than 2.5 micrograms) may be even better indicators of ill health than PM_{10} has led the United States to propose new regulations aimed at $PM_{2.5}$, potentially putting a number of cities out of compliance. European countries are also considering such regulations. Since long-term data are not widely available, it is not clear how much $PM_{2.5}$ levels have decreased in recent decades, partly because such particles are transported over much larger areas than larger particles.

This focus on even smaller particles has brought diesel exhaust particles under more scrutiny. Unlike gasoline, diesel produces a significant amount of emissions of particles that are not only smaller but may have chemical properties that make them more dangerous. This feature raises questions about the future of diesel-fuelled vehicles, even though such vehicles can be slightly more fuel-efficient and cost-effective than gasoline-fuelled vehicles. The tendency for many countries to keep diesel prices low relative to gasoline-as a means of assisting farming, fishing, and other industries-can artificially promote diesel passenger vehicles. (See the section on cross-scale impacts, below, for a discussion of the economic implications of diesel particle health effects.)

Since the 1980s studies have seemed to indicate that there is no threshold for the health effects of particle pollution. In other words, there no longer seems to be an identifiable level that can be termed safe. All that can be said is that the effect is lower at lower levels, but does not seem to disappear even at the lowest (background) concentrations. Indeed, in the late 1990s European and global offices of the World Health Organization revised their particle guidelines to reflect the absence of thresholds (figure 3.6).

Because it is rarely (if ever) practical to set a standard of zero for pollutants with significant natural sources, standard setting is much harder for pollutants with no

threshold for significant effects. Policy-makers must determine that the benefits of fuel combustion outweigh the extra mortality produced by the resulting pollution-for example, that the 5 percent increase in mortality 'allowed' by a PM_{10} standard of 50 micrograms per cubic metre above background (see figure 3.6) is acceptable given the societal advantages of fuel use. This is a difficult determination, and much more politically difficult than endorsing a standard that has some scientific validity of being below a 'no effects' level, which is how most standards are set. The likely result will be continuous pressure to tighten particle standards, with stronger incentives for lower particle emissions from vehicles, power plants, and other fuel-using sources. Indeed, as discussed in later chapters, emission reductions are the driving forces for new power and transport technologies.



Cumulative percentage of urban population
0%
20%
40%
60%
80%
100%
Urban population
Annual concentration
Sweden
Norway
Belarus
Iceland
France
Switzerland
Slovak Rep.
New Zealand
Canada
Australia
Netherlands
Ireland
United States
Germany
United Kingdom
Finland
Croatia
Venezuela
Czech Rep.
Greece
Singapore
Denmark
South Africa
Turkey
Austria
Kenya
Belgium
Argentina
Spain
Egypt
Japan
Portugal
Hungary
Italy
Malaysia
Russian Federation
Latvia
Hong Kong (China)
Korea, Rep. of
Ecuador
Romania
Brazil
Nicaragua
Colombia
Costa Rica
Ukraine
Panama
Lithuania
Mexico
Ghana
Honduras
Guatemala
Chile
Poland, Rep.
Nepal
Philippines
Thailand
Bulgaria
Iran, Islamic Rep.
China
India
Indonesia
Nigeria
Pakistan
0
100
200
300
Population-weighted PM_{10} concentration (micrograms per cubic metre)

FIGURE 3.5. GLOBAL DISTRIBUTION OF URBAN PM_{10} CONCENTRATIONS

Note: In many cases, PM_{10} levels have been entirely estimated from measurements of total particles.

Source: WRI, 1998; WHO, 1998b.

FIGURE 3.6. PROVISIONAL GLOBAL AIR QUALITY GUIDELINES FOR PARTICLES

Source: WHO, 1999.

As recently as the early 1990s, the main source of lead emissions throughout the world was tetra-ethyl-lead used as an additive to raise octane in gasoline. But nearly every country now has a plan to remove lead from gasoline (box 3.4). Still, significant numbers of children in many industrialised and developing countries have blood lead levels above those thought to affect cognitive development (intelligence). These levels will decline as lead is removed from the rest of the world's gasoline, although industrial and other sources must be controlled as well.

Fuel-derived air pollution in cities of developing countries

Developing country cities have much higher mean pollutant concentrations than industrialised country cities (see figure 3.5). In cities in China and India, averages seem to be nearly 200 micrograms per cubic metre of PM_{10}, though there is much variation by season and city. Such concentrations must be causing significant premature deaths-perhaps 15 percent or more above background levels. Indeed, estimates for premature mortality from urban air pollution range from 170,000-290,000 a year in China (World Bank, 1997; Florig, 1997) and 90,000-200,000 in India (Murray and Lopez, 1996; Saksena and Dayal, 1997).

BOX 3.4. GETTING THE LEAD OUT: A SLOW SUCCESS STORY

“The current consensus is that no amount of Pb [lead] in the environment can be considered safe” (Schwela and Zali, 1999). Although this was not the first reason to remove lead from gasoline, it soon became the driving force. The introduction of catalytic converters spawned the need for unleaded gasoline to protect the devices. Shortly after, concerns about the health effects of lead emissions led to an increase in sales of unleaded gas and a reduction in the lead content of leaded fuel. Since leaded gasoline has been responsible for about 90 percent of lead emissions, it was the most logical target for reduction (Lovei, 1998).

Many nations have taken action to phase out lead from fuel. Canada, Japan, and the United States have completely phased out leaded gasoline (Lovei, 1998; Schwela and Zali, 1999). Los Angeles (California) saw a 98 percent reduction in the lead exposure of commuters between 1979 and 1989. In Western Europe leaded gasoline has a very low lead content, and unleaded fuel has a large market share in most countries. In addition, a few developing nations have lowered or even banned lead in gasoline (Lovei, 1998).

Over the past 20 years Singapore has taken significant steps to phase out lead in fuel. Between

1980 and 1987 the lead content of leaded gasoline fell to a low 0.15 grams a litre. In 1991 unleaded petrol was introduced and taxes were changed to make it cheaper than leaded fuel. By the end of 1997 unleaded fuel accounted for about 75 percent of gasoline sales. In addition, more stringent exhaust emission standards were implemented for gasoline-fuelled vehicles, promoting an unleaded fuel market. Finally, oil companies agreed to phase out leaded gasoline by July 1998.

Mexico has also taken steps to reduce the lead content of fuel, though it still has far to go. Since 1994 the lead content of leaded fuel has been cut to 0.15 grams a litre. But it appears that the Mexican National Petroleum Co. has recently raised lead levels. No government agency has the authority to ensure fuel quality, making enforcement of low lead levels a challenge. Unleaded gasoline accounts for 46 percent of sales in Mexico City and 84 percent in Monterrey (which is wealthier and closer to the U.S. border). Leaded fuel is still cheaper, however. Mexico is implementing new standards requiring catalytic converters and so unleaded gas.

But large problems remain in many developing countries. The biggest lead problems are in Africa and in petroleum-exporting nations. These countries, including Venezuela and those in the Middle East, are dominated by powerful oil companies and state-owned refineries.

Although in 1994 two-thirds of global gasoline sales were unleaded, additional efforts are needed. Several mechanisms can encourage the reduction of lead in gasoline. The most promising is to set fuel taxes so that unleaded gasoline is cheaper than leaded fuel. Fuel filler inlets should be required in automobiles to allow only the narrower nozzles of unleaded fuel pumps to be used. Requiring catalytic converters in vehicles would further decrease the use of leaded fuel. Emphasising other benefits of using unleaded gasoline, such as lower exhaust emissions of hydrocarbons, also promotes the reduction of lead in gasoline (Schwela and Zali, 1999). Finally, as shown in Brazil, it is possible to substitute 5-10 percent ethanol for lead as an octane booster, thereby promoting renewable fuels.

An enduring urban myth exists that some older cars need lead to operate well. As long as the fuel has the correct octane level, no engine needs lead. Indeed, in many cases the removal of lead will have direct benefits in the form of less engine maintenance. The persistence of this myth slows the introduction of low-lead fuels despite technical evidence to the contrary.

The causes of air pollution in developing country cities are much more varied than in industrialised countries. Although automobile ownership rates are much lower, there tend to be many other types of vehicles as well, including two- and three-wheelers using highly polluting two-stoke engines. There also tend to be larger portions of light-duty and heavy-duty vehicles using diesel rather than gasoline. In addition to power plants and large industries with limited pollution controls, developing country cities tend to have large numbers of small boilers, engines, and open fires in the commercial and light-industry sectors, as well as in informal sectors such as street food. These enterprises tend to rely on the most inexpensive and thus dirty fuels in inefficient applications without pollution controls-and so have high emissions per unit of useful energy.

Furthermore, such cities often do not have adequate refuse and garbage collection, leading to street-side trash burning, a highly polluting activity. Even when collected, trash often burns uncontrollably in landfills in or near cities, wasting potential energy and producing clouds of noxious emissions. Another major non-energy source of particle pollution in many cities is dust from construction sites and unmanaged empty land. Finally, unlike in industrialised countries, a large fraction of urban households in developing countries still use solid fuels for cooking and space heating in inefficient stoves with no pollution controls (see figure 3.1). Although individually small, their large number means that these stoves can contribute significantly to urban pollution.

In addition to dealing with trash, dust, and other non-energy issues, the most pressing need for pollution control in developing country cities is to reduce and eventually eliminate small- and medium-scale combustion of dirty fuels. For stationary sources, this means shifting away from solid fuels (coal and biomass) and high-sulphur fuels of any

kind. For mobile sources, it means dealing soon with, in order of priority, two-stroke engines, poorly operating diesel engines, and gasoline-fuelled vehicles without catalytic converters. In addition, as is happening in Bangkok (Thailand) and New Delhi (India), there is great advantage in shifting vehicle fleets (taxis, buses, government vehicles) to clean-burning gaseous fuels such as compressed natural gas or liquefied petroleum gas (Mage and Zali, 1992).

Urban pollution control in the longer run

Because the best commercial technology in terms of energy efficiency and emissions has not been deployed completely in industrialised countries and has been used little in developing countries, much improvement is possible in the next 20 years without switching to advanced technologies. In the longer term, however, if air pollution levels are to be brought down to and kept at low levels given the projected increase in population, urbanisation, economic activity, and energy use, it will be necessary to develop and deploy new, even cleaner and more efficient energy-using technologies. A number of advanced power plant technologies potentially offer such performance (see chapter 8).

Dams affect Earth at scales rivalling other major human activities, such as urbanisation and road building.

In addition, some near-commercial vehicle technologies may allow vehicle densities in developing country cities to grow for several decades and still meet air quality goals (box 3.5). Strong pollution controls will be needed to bring these technologies into wide use, however.

In addition to technical changes in vehicles of all types (not just private cars), a range of other improvements will be needed if the world's cities are to accommodate the greater demand for transport that increases in population and income will bring. These include improvements that result in significant and sustained enhancement in the attractiveness of public transport, land-use planning to reduce the need for intraurban trips, and implementation of policy tools such as time-of-day, congestion, and central-zone pricing. In addition, significant switches to public transport might occur through such means as including the cost of vehicle insurance in the price of fuel and taxing employer-provided parking as income (see chapter 11).

Hydroelectric dams6

Dams, large and small, have brought tremendous benefits to many regions, including important contributions to development in industrialised countries. It is important not to deny these benefits to developing countries. But such dams need to be designed and constructed with care. Although dams frequently serve many purposes-including flood control, irrigation, navigation, and recreation-major dams (those over 150 metres high, with 25 cubic kilometres of storage, or 1,000 megawatts of electricity) tend to have hydropower as one of the their main objectives. Such dams often have big impacts on the environment. There are more than 300 major dams world-wide, and nearly all have hydropower as a major component of their function. The environmental impact per unit of electricity production, however, can often be smaller for large than for small dams. The type rather than the size can be the most important factor (Gleick, 1992).

With a total capacity of about 640,000 megawatts of electricity, hydropower provides about one-fifth of the world's electricity (Gleick, 1992). In Central and South America hydropower provides about 60 percent of electricity; in Asia this figure is about 15 percent. Itaipu, on the border of Brazil and Paraguay, is the most powerful hydropower dam built to date, with a capacity of 12,600 megawatts of electricity. It cost $20 billion to

build. When finished, China's Three Gorges Dam will produce about 18,200 megawatts of electricity and may cost as much as $75 billion (*The Economist,* 1999). Thus hydroelectric dams are the most expensive energy projects in the world.

No major river in the world is without existing or planned hydroelectric dams. Nearly four-fifths of the discharge of the largest rivers in Canada, Europe, the former Soviet Union, and the United States are strongly or moderately affected by flow regulation, diversions, and the fragmentation of river channels by dams (Dynesius and Nilsson, 1994). More than 500,000 square kilometres-the area of Spain-have been inundated by dam reservoirs world-wide, though not all for hydropower (Collier, Webb, and Schmidt, 1996). (Indeed, many hydropower plants have no reservoirs.) Globally, about 200 cubic kilometres of water a year-about 7 percent of the freshwater consumed by human activities-are evaporated from the surface of reservoirs due to their increased exposed surface area (Shiklomanov, 1998). Thus dams affect Earth at scales rivalling other major human activities, such as urbanisation and road building.

Direct human impacts. During the 20th century 30-60 million people were flooded off their lands by dams (Dunn, 1998). The World Bank, using Chinese government figures, estimates that 10.2 million people were displaced by reservoirs in China between 1950 and 1989 (World Bank, 1993). Given that a number of major dams are under construction or planned in developing countries, there will be no slackening in the pace of population displacement. China's Three Gorges Dam, for example, is expected to displace more than 1 million people, and the proposed Pa Mong Dam between Lao PDR and Thailand is expected to displace more than 500,000 (Gleick, 1998).

Large population resettlements can have a number of direct social and health impacts. The social and cultural stress, loss of income, disruption of traditional support services, and other problems facing displaced populations often lead to lowered health status. Even when efforts are made to resettle people in new areas, it is difficult to locate land of

similar productivity because other groups are likely to already occupy the best areas. Some 13,500 people have been swept to their deaths by the 200 or so dams (outside China) that have collapsed or been overtopped in the 20th century. In 1975 in Henan, China, about 230,000 people died from a series of dam bursts (Gleick, 1998).

BOX 3.5. ALTERNATIVE VEHICLES

With growing energy and environmental concerns surrounding today's conventional vehicles, a great deal of research is going into alternative vehicles. Four main types of alternative vehicles have the potential to reduce the environmental and efficiency deficits of conventional vehicles and to become commercially available in the near future. Electric vehicles are powered by rechargeable batteries and have no internal combustion engines. The battery, which can be made of lead-acid, nickel-metal hydride, and lithium-polymer, can be recharged at home or, in the future, at recharging stations.

Electric vehicles have several environmental benefits relative to conventional vehicles, including no tailpipe emissions and lower hydrocarbon, carbon monoxide, and nitrogen oxide emissions (including emissions from the production of electricity). Other advantages include lower maintenance costs and the elimination of the need for complicated tailpipe emission controls.

But electric vehicles also have several disadvantages, such as the environmental concerns of an increase in electricity use, increasing emissions of sulphur oxides, and possible contamination from the disposal and recycling of batteries. There are also disadvantages in terms of convenience and cost, such as lengthy recharging and lack of infrastructure for recharging stations, short driving ranges (though electric vehicles are good for local trips and commuting for two-car households), an inability to maintain high speeds, and high battery costs. Today electric vehicles cost about $30,000, which is too expensive for most markets.

Hybrid electric vehicles combine the battery and electric motor of an electric vehicle with the internal combustion engine and fuel tank of a conventional vehicle, to obtain the benefits from both technologies. The engine, which is much smaller than that in a conventional vehicle, operates at a constant power load and so is more efficient, and less polluting, and generates only the power required for most operations. Hybrid electric vehicles have several advantages over conventional vehicles and fewer disavantages than electric vehicles. Hybrid electric vehicles have higher fuel economy and lower emissions than vehicles with internal combustion engines, and better range and more rapid refuelling than electric vehicles. Hybrid electric vehicles also reduce petroleum consumption and increase energy diversity by using alternative engines, which can use a range of fuels. But hybrid electric vehicles are still expensive and not yet fully developed. Programs are in place to develop and improve hybrid electric vehicles, and several automobile manufacturers are or will soon be marketing models.

Compressed natural gas vehicles are powered by an abundant, inexpensive fuel composed largely of methane. Natural gas is a clean-burning fuel with lower carbon dioxide, carbon monoxide, hydrocarbon, and nitrous oxide emissions than gasoline. This is partly due to the lower carbon content per unit of energy in natural gas relative to other fossil fuels. In addition to its environmental benefits, natural gas vehicles are cheaper to maintain, requiring service less frequently than conventional vehicles as well as having a lower cost of refuelling. Converting vehicle fleets such as taxis, three-wheelers, and buses to natural gas is an important interim way to improve air quality in developing country cities. Conversion costs are relatively small, although baggage space is reduced because of the need to add pressurised tanks. It is hard to use compressed natural gas for private vehicles because of the need to create many fuelling stations. Urban vehicle fleets, on the other hand, can operate with relatively few centralised fuelling stations.

Fuel-cell vehicles operate by combining hydrogen and oxygen gases into an electrochemical device, a cell, that converts them into water and electricity without using combustion. The hydrogen gas can come from a number of sources, including multiple forms of pure hydrogen and a variety of hydrocarbon fuels. Fuel-cell vehicles have many advantages over conventional vehicles. Fuel cells have a much greater engine efficiency and fuel economy, drastically reduce pollution emissions (including greenhouse gas emissions), and can use a wide variety of fuels, promoting energy diversity.

In addition, they are quieter and smoother in operation, have tested at high performance levels, have long driving ranges, and have about the same operating costs as conventional automobiles. Still, there are several drawbacks to fuel-cell vehicles, including the lack of infrastructure to distribute hydrogen or another fuel (unless gasoline is used), difficult storage of pure hydrogen, and possible safety concerns. Major automobile companies are planning to have commercially available fuel-cell vehicles by 2004 and are currently demonstrating prototypes and improving on them. Large cost reductions need to occur, however, and fuel infrastructure issues must be resolved before fuel-cell vehicles are ready for the marketplace.

Of these four alternatives to conventional vehicles, electric vehicles have the fewest barriers to market entry. But they probably have the least consumer appeal in terms of environmental improvements and convenience. Fuel-cell vehicles will probably be found to be the most environmentally friendly, but they are the furthest from commercial development. Hybrid electric vehicles also offer a good option in the near future, with convenience and environmental benefits. All these cars will likely begin to enter the market in the next 5-10 years, and infrastructure will have to be built to accommodate all of them as well as today’s automobiles.

Source: American Honda Motor Company, 1999; California Energy Commission, 1998; California Environmental Protection Agency, 1999; Ford Motor Company, 1998, 2000; General Motors Corporation, 1999; Global Toyota, 1999; Gould and Golob, 1997; Hanisch, 1999; Krebs, 1999; Kremer, 2000; Mark, Ohi, and Hudson, 1994; Matsumoto, Inaba, and Yanagisawa, 1997; Mendler, 1997; National Fuel Cell Research Center, 1999; Natural Gas Vehicle Coalition. 2000a, b; Neil, 1999; Steinbugler and Williams, 1998; USDOE, 1995; USEPA, 1994, 1998b

TABLE 3.2. ECOLOGICAL INSULTS AND IMPACTS OF LARGE DAMS

Insult caused by dam	Impacts seen	Severity of impact	Example of impact
Changes in the chemical properties of release water	Deterioration of downstream ecosystem cased by inability to process the increased dissolved minerals	Depends on the sensitivity of the affected ecosystem(tropical ecosystems are especially sensitive)	Enhanced algae growth in the reservoir consumes the oxygen in the epilimnion and, as it decays, the mass sinks to the already oxygen-deficient hypolimnion, where decay processes reduce the oxygen concentration even further, resulting in acid conditions at lower levels and the dissolution of minerals from the reservoir bed.
Changes in the thermal properties of release water	Thermal pollution often results in species diversity reduction, species extinction, and productivity changes in the reservoir	Diversity, biomass, distribution, and density of fish stocks can be affected, disrupting breeding cycles	Productivity levels in the surface waters of new reservoirs often increase before long-term declines occur (Horne, 1994). China's Three Gorges Dam may be the final critical factor for driving to extinction the Yangtze River dolphin.
Changes in the flow rate and timing of release water	Erosion increases downstream of dam. Settling of sediments in the reservoir causes high sediment loads to be picked up in	Erosion of natural riverbeds can disturb the nurseries and spawning of many aquatic organisms,	Changes in the downstream river morphology and ecosystem productivity.

	the area immediately below the dam	disturbing their breeding cycles	
Changes in the sediment load of the river	High trap efficiencies of dams prevent the natural processes of sediments and associated nutrients refreshing downstream soils	Effects often noticed most severely in high-productivity areas downstream from the dam that no longer receive annual fertilisation	Before the Aswan High Dam was constructed, the Nile carried about 124 million tonnes of sediment to the sea each year, depositing nearly 10 million tonnes on the floodplain and the delta. Today 98 percent of the sediment remains behind the dam, resulting in a drop in soil productivity and depth, among other serious changes to Egypt's floodplain agriculture (Pottinger, 1997).
Changes in the dynamics of downstream riverbeds	Increased likelihood of lower water tables, which can create problems in areas near the dam where groundwater is a major source	Reduced access to potable water is a huge problem in many developing countries	Within nine years of the closure opening of the Hoover Dam, 110 million cubic metres of material had been washed away from the first 145 kilometres of riverbed below the dam (McCully, 1996).
Changes in the coastal area morphology	The loss of sediment in the rivers flowing through deltas and into the sea often results in a gradual process of delta and coastal degradation	Financially expensive for many areas where there is a large population living near the coastal zone.	Over the past 80 years dams have reduced by four-fifths the sediment reaching the coasts of southern California. This has reduced the beach cover at the base of cliffs along these shorelines, causing cliffs to collapse (Jenkins and others, 1988).

Disease can spread from vectors that thrive in secondary dam systems, such as irrigation canals and even dam reservoirs. Mosquitoes carrying malaria, for example, have thrived in conditions created by dams. The parasitic disease schistosomiasis has also become more prevalent through the creation of habitats for snails that act as the disease vector. Nearby populations, for example, suffered nearly universal infection after several large African dams were filled, including Aswan (Egypt), Akosombo (Ghana), and Sennar (Sudan) (Nash, 1993).

Ecosystem impacts. An internal survey of World Bank hydroelectric dam projects found that 58 percent were planned and built without any consideration of downstream impacts-even when these impacts could be predicted to cause coastal erosion, pollution, and other problems (Dixon, 1989). The main ecological insults and impacts of large dams (not just those producing hydropower) are summarised in table 3.2.

Dams and greenhouse gases. The work assessing the impacts of dams on greenhouse gas emissions is incomplete, but some estimates have been made. The most immediate changes are in the carbon flow between the flooded vegetation and the atmosphere. The decomposition of plants and soils causes the gradual release of their stored carbon (Rudd and others, 1993).

From a greenhouse gas standpoint, it might be thought that vegetation decaying in a reservoir would be no worse than the same amount of deforestation. Because of the low-oxygen conditions near and in the bottoms of many reservoirs, however, relative to deforestation a larger fraction of the biomass carbon is likely to be released as methane rather than as carbon dioxide. Since methane is a much more powerful greenhouse gas than carbon dioxide, the global warming impacts are greater than the same amount of carbon released as carbon dioxide.

The peak greenhouse gas emissions, however, are unlikely to rival those of a similarly

sized fossil power plant, emissions from which would not decrease with age like those from a reservoir. In addition, it is difficult to determine the baseline in tropical forests-that is, how much methane and other non-carbon dioxide greenhouse gases are released in natural conditions. In colder climates reservoirs apparently emit greenhouse gases at much lower rates (Gagnon, 1998).

Nuclear power

There are two main environmental concerns about nuclear power, both mostly with regard to its potential impacts on human health. One involves the highly radioactive products produced by nuclear fission inside power reactors. Such products require careful management at the reactor and during and after disposal. The other concern revolves around the weapons-grade plutonium or uranium that might be clandestinely derived from the nuclear power fuel cycle to make bombs or other weapons of mass destruction by nations or subnational groups (see chapter 8).

The routine (non-accidental) emissions of pollutants from the harvesting, processing, and conversion of nuclear fuels are not negligible. And more than many technologies, they are vulnerable to being enhanced by mismanagement. Still, the impacts of these emissions are generally substantially less than those involved with producing power with current coal technologies, the chief competitor in many areas. Although involving different pollutants, routine emissions from nuclear power systems are probably no more dangerous than those from new natural gas power systems-with the important exception of carbon dioxide, which is not produced by nuclear power. If public concerns about reactor safety, proliferation, and waste disposal can be satisfied, nuclear power may be able to play a significant role in de-carbonising the world energy system in the next 50 years (see chapter 8).

Regional scale

Nested between local-scale issues-such as the health effects of urban pollution-and global-scale issues-such as climate change-are a number of regional-scale problems that affect human health and ecosystems over areas the size of countries and continents. The most important regional-scale issues are acid deposition, tropospheric ozone, and suspended fine particles.

Matched with the regional spatial scale is a temporal scale that requires air pollutants to remain aloft for periods ranging from days to weeks and thereby be transported by prevailing winds and transformed by chemical reactions. Gases and fine particles meet this criterion; larger particles (greater than 1 micron or so in diameter) tend to settle out quickly and are considered contributors to local, rather than regional, impacts. Fine particles may be solid (such as elemental 'black' carbon) or liquid (such as aerosol droplets).

Contributing to regional pollution are a number of precursor species, most of which are generated by the use of fossil fuels and biofuels. Prominent among them are sulphur dioxide (SO_2) and nitrogen oxides (NO_x). Sulphur dioxide is released during the combustion of the sulphur found naturally in fossil fuels, while nitrogen oxides originate either as fuel nitrogen or as atmospheric nitrogen oxidised during combustion. Other species of importance are particulate matter (PM), carbon monoxide (CO), methane (CH_4), and non-methane volatile organic compounds (NMVOC), released during incomplete combustion and other activities. Ammonia (NH_3) is a significant regional pollutant, but fuel combustion is not its primary source.

TABLE 3.3. ANTHROPOGENIC EMISSIONS OF IMPORTANT SPECIES BY REGION, 1990 (MILLIONS OF TONNES)

Region	Sulphur dioxide as sulphur)	Nitrogen oxides as nitrogen)	Carbon monoxide	Non-methane volatile organic	Methane

							compounds			
	Energy-related	**Non-energy-related**	**Energy-related**	**Non-energy-related**	**Energy-related**	**Non-energy-related**	**Energy-related**	**Non-energy-related**	**Energy-**	**Non-**
Western Europe	8.8	2.5	3.6	0.4	45	23	10.1	7.6	5.5	18.0
Eastern Europe and former Soviet Union	13.5	3.4	3.5	0.6	47	36	13.9	6.2	37.6	20.3
North America	11.6	0.7	7.6	0.3	82	24	13.2	8.7	23.9	21.5
Asia	17.9	3.0	5.6	1.9	165	132	30.7	24.2	25.7	98.6
Rest of world	8.8	4.1	3.2	4.4	105	316	31.7	31.2	15.5	54.0
Total	60.6	13.6	23.5	7.6	444	531	99.6	77.9	108.2	212.3
		74.2		**31.1**		**975**		**177.5**		**320.4**

Note: These numbers are slightly different from those in table 3.1 because of different assumptions and methods. Energy-related sources include the combustion, extraction, processing, and distribution of fossil fuels and biofuels. Non-energy-related sources include industrial processes, deforestation, savannah burning, agricultural waste burning, and uncontrolled waste burning.

Source: Olivier and others, 1996.

When emissions of these primary species are released into the atmosphere, they form a complex, reactive 'soup,' the chemical and physical behaviour of which is determined by such factors as temperature, humidity, and sunlight. The primary species are transported and deposited, influencing the health of humans and of natural ecosystems. But these primary species are also transformed into secondary species-such as sulphate, nitrate, acids, ozone, and miscellaneous organic compounds-that can have effects even more damaging than their precursors and in areas far removed from the primary sources. This can lead to transboundary problems, where a country or regionhas little control over the emissions that damage its environment.

Emissions and energy

A snapshot of global and regional anthropogenic (human-caused) emissions in 1990 is provided in table 3.3. The emissions are partitioned into those derived from energy-related activities (including combustion, extraction, processing, and distribution of fossil fuels and biofuels) and those derived from non-energy activities (which have a wide variety of sources, including industrial processes, deforestation, savannah burning, agricultural waste burning, and uncontrolled waste burning). Non-anthropogenic sources (volcanoes, soils) are not included.

Energy activities account for 82 percent of anthropogenic emissions of sulphur dioxide and 76 percent for nitrogen oxides. Energy activities play a less dominant role for the three other species-56 percent for non-methane volatile organic compounds, 46 percent for carbon monoxide, and 34 percent for methane. The smaller role of energy in emissions of these three species reflects the important contributions of deforestation, savannah burning, and agricultural waste burning in the generation of products of incomplete combustion, coupled with rice cultivation and enteric fermentation in the case of methane. Nevertheless, table 3.3 demonstrates the critical contribution of energy to emissions of regional-scale pollutants. It also highlights the importance of the developing world in

current patterns of regional emissions.

Sulphur dioxide and nitrogen oxides play a role in the formation of acid deposition, because they can be transformed to acids in the atmosphere. The transformation products are fine particles, solid or aerosol, in the form of sulphates and nitrates. In addition, nitrogen oxides are a major precursor to the formation of regional tropospheric ozone. Finally, sulphates and nitrates have the ability to scatter and absorb radiation and so contribute to global and regional climate change, probably with a net cooling effect.

Carbon monoxide is an important regional atmospheric pollutant from several perspectives. It acts as an indirect greenhouse gas with a potential for global warming (see above, in the section on greenhouse gases) on a 20-year time horizon of about 4.5 due to its influence on the atmospheric lifetime of methane (IPCC, 1990). In addition, carbon monoxide is toxic to humans and is a critical component of many photo-chemical reactions in the atmosphere. It is a scavenger of hydroxyl radicals and so influences the production of ozone. There are many relatively easy ways to reduce carbon monoxide emissions-catalytic converters for automobiles, improved household stoves, and reuse of carbon monoxide gas in industry.

Energy activities account for 82 percent of anthropogenic emissions of sulphur dioxide and 76 percent for nitrogen oxides

Non-methane volatile organic compounds consist of a variety of chemical species. In China, for example, the mix of organic compounds is 46 percent paraffins, 32 percent olefins, 21 percent aromatics, and 1 percent aldehydes (Piccot, Watson, and Jones, 1992). These compounds are important in the chemistry of the atmosphere because of their

influence on the formation and destruction of ozone and methane. Non-methane volatile organic compounds are a product of the incomplete combustion of fossil fuels, biofuels, and other carbonaceous materials. They are also emitted during the extraction, processing, and handling of gaseous and liquid fossil fuels. And they are released through the evaporation of miscellaneous organic products in industry and households.

Ammonia is a significant component of regional emissions. Being an alkaline substance, it neutralises acids in the atmosphere. But once it is deposited on land, it can be converted to acid through biochemical processes in the soil. Ammonia emissions are largely derived from animal waste, fertiliser application, and fuel combustion. In 1990 energy-related activities accounted for just 5 percent of global ammonia emissions-2.7 of 52.0 teragrams (Olivier and others, 1998). Most ammonia emissions are from Asia and other developing countries, due to the rural nature of these countries, the intensive use of fertiliser for food production, and the heavy use of fossil fuels. In 1990 ammonia emissions in Asia were 22.5 teragrams, compared with 3.5 teragrams in Western Europe and 4.1 teragrams in North America.

Future emissions

Sulphur dioxide. The latest energy projections indicate that global sulphur dioxide emissions will likely stay roughly constant between 1990 and 2020, at about 59 teragrams of sulphur (Nakicenovic, Grbler, and McDonald, 1998). This 'middle-course' scenario incorporates modest economic growth, continued reliance on fossil fuels, and the elimination of trade barriers. At the regional level, however, a distinctive pattern emerges for all the important species. Emissions will decline in the industrialised regions of the Northern hemisphere-Europe, the former Soviet Union, North America-and increase sharply the developing regions of the Southern hemisphere and the Far East-Latin America, Africa, Asia (figure 3.7).

In Western Europe strong national environmental policies, changes in national energy policies, and implementation of the 1985 Helsinki Protocol and 1994 Oslo Protocol (under the 1979 Convention on Long-range Transboundary Air Pollution) have driven down sulphur dioxide emissions. As a result the region could see a 60 percent drop in sulphur dioxide emissions between 1990 and 2020. Similarly, in North America the adoption by the United States of the 1990 amendments to the Clean Air Act has reduced sulphur dioxide emissions. North America's sulphur dioxide emissions in 2020 are expected to be about 35 percent below 1990 levels. In Central and Eastern Europe and the former Soviet Union, a 50 percent reduction is anticipated.

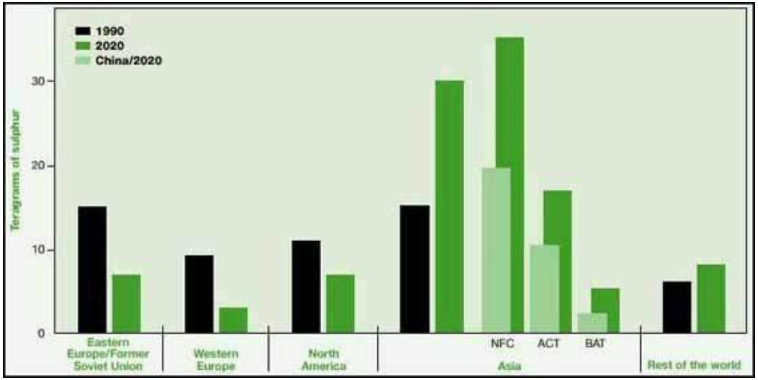


FIGURE 3.7. SULPHUR DIOXIDE EMISSIONS BY REGION, 1990 AND 2020 (PROJECTED)

Source: Nakicenovic, Grbler, and McDonald, 1998; Foell and others, 1995.

The problem of sulphur dioxide emissions has shifted to the developing world, with emissions in Latin America, Africa, and the Middle East expected to increase by about 30 percent between 1990 and 2020. The main problem region is Asia, where emissions are already high-with 17 teragrams of sulphur emissions in 1990-and could double by 2020. If

that happens, Asia will account for 58 percent of global emissions, much of them from China.

Three emission scenarios from the RAINS-ASIA model are also shown in figure 3.7 (Foell and others, 1995; Arndt and others, 1997; Streets and others, 1999). Driven by a similar energy forecast, the model projects that Asia's sulphur dioxide emissions in 2020 will be bounded by an upper value of 40 teragrams of sulphur (under the assumption of no further control policies beyond those in place in 1990-the NFC scenario) and a lower value of 6 teragrams of sulphur (with the assumption of very tight controls, similar to those in Western Europe). A mid-range estimate is 20 teragrams of sulphur, to be achieved if all large, new facilities are fitted with flue-gas desulphurisation units and other fossil-fuel users switch to low-sulphur fuels.

China continues to be the largest contributor to Asia's sulphur dioxide emissions, emitting about half of the continental total. But the establishment in 1997 of China's Two Control Zone policy for sulphur dioxide emissions has generated optimism that emissions will not grow as fast as once thought. Emissions of 11.9 teragrams of sulphur in 1995 are used as a baseline, and the plan is to limit national emissions to 12.3 teragrams of sulphur in 2000 by capping emissions in certain provinces at their 1995 levels. While implementation and enforcement questions linger, there is a commitment at the highest level in China to holding down sulphur dioxide emissions. The official (but undocumented) estimate for China's emissions in 2020 is 19.5 teragrams of sulphur.

The message from figure 3.7 is one of opportunity. With rapid growth in Asia, many of the coal-fired plants projected to be needed after 2000 have yet to be built. Thus the opportunity exists to fit these plants with emission controls or lower-emission technology at the time of construction. The incremental cost of emission reduction is then the only hurdle to be overcome-though it is a high hurdle ($25 billion a year for the ACT scenario, rising to $65 billion a year for the BAT scenario). Substitution of natural gas for coal is an

attractive interim measure, and any possibilities for increasing the efficiency of energy use and moving towards renewable energy would reduce emissions of sulphur, nitrogen, and other species. The ecologically driven scenario (chapter 9), for example, would lower global 2020 emissions from 59 teragrams of sulphur to 34 teragrams.

Nitrogen oxides. The situation for nitrogen oxides emissions is even more challenging, because of the added emissions from transportation. Though nitrogen emissions were not estimated by Nakicenovic, Grbler, and McDonald (1998), other analyses suggest a regional pattern similar to that of sulphur dioxide. An earlier study, *Energy for Tomorrow's World* (WEC, 1993), which was more optimistic about economic growth, forecast a 13 percent increase in global emissions of nitrogen oxide between 1990 and 2020 (from 24 teragrams of nitrogen to 27 teragrams) under case B assumptions. The increase in Asia was 70 percent (from 6.8 teragrams of nitrogen to 11.5 teragrams). Use of the RAINS-ASIA model, with its daunting view of the growth of fossil-fuel-based energy systems in Asia, yields an estimated increase of more than 300 percent in this period (van Aardenne and others, 1999).

Carbon monoxide and non-methane volatile organic compounds. Though there are no published projections for emissions of carbon monoxide and non-methane volatile organic compounds, carbon monoxide emissions are unlikely to increase in Asia, because inefficient combustion of biofuels will fall and inefficient vehicles will be replaced. On the other hand, emissions of non-methane volatile organic compounds may grow rapidly as expanding industrial production calls for greatly increased solvent use, increased vehicle use generates more hydrocarbons, and rising living standards increase the demand for domestic and commercial paints and solvents. Together, the expected rise in emissions of nitrogen oxides non-methane volatile organic compounds bodes ill for the formation of regional ozone in the developing world.

Acid deposition

Acid deposition-or acid precipitation in its 'wet' form-is perhaps the most important regional-scale manifestation of energy generation through fuel combustion. Acid deposition occurs when sulphur dioxide and nitrogen oxides are oxidised in the atmosphere to - sulphuric acid (H_2SO_4) and nitric acid (HNO_3), respectively, and dissolved in rainwater. Clean rainwater is naturally acidic, with a pH of about 5.6. In the industrialised regions of Europe, North America, and Asia, rainfall pH values of 4.0-6.0 are common-and values as low as 3.0 have been measured in isolated events.

Acid deposition is a problem because it causes damage to natural and human-made surfaces with which it comes into contact. If soils contain insufficient alkali to neutralise the acid, damage can be caused to vegetation, particularly sensitive tree species and agricultural crops. Lakes can become acidified, leading to the demise of fish populations. Over time the entire natural structure and function of ecosystems can change. Manufactured materials can be attacked: metal surfaces rust, and alkaline materials like concrete, limestone, and marble are eroded (box 3.6).

In Europe forest damage has long been attributed to acid deposition. Despite emission reductions, the health of European forests still seems to be deteriorating (UNECE, 1996). In a 1995 survey of 117,000 trees in 30 countries, more than 25 percent showed signs of significant defoliation, and more than 10 percent showed significant leaf discoloration. Both direct and indirect effects of air pollution, of which acid deposition is but one part, are considered the cause. Surveys of forest soils show that, while sulphur deposition has dropped drastically since the 1970s, nitrogen deposition is still high, impairing soil chemistry and nutrient status. For acidification of surface waters, there appears to be an overall improvement (with higher pH, for example), probably as a result of reductions in acid deposition (UNECE, 1997). With projected reductions in sulphur and nitrogen emissions through 2020, continued progress is expected towards healthier ecosystems in Europe.

BOX 3.6. ENVIRONMENTAL IMPACTS OF ACID DEPOSITION

In general, the exposure-response relationships between acid deposition and impacts on ecosystems, materials, visibility, and human health are complex. Some are reasonably well understood, but others involve poorly known relationships involving climate, geography, other chemicals, and time. Much research has been devoted to studies in North America and Western Europe, while relatively little has been done in Asia-where most of the growth in acid-depositing emissions is expected over the next few decades.

Acid deposition has harmful effects on many lakes and rivers, hurting aquatic life. In affected regions such as eastern Canada, lakes have acid levels that are unsafe for fish and other aquatic life. While species of fish vary in their sensitivities to acidification, those with low tolerance decline in population, at times to the point of extinction. This not only affects the species directly harmed, but loss of species diversity damages the ecosystem as a whole due to the interdependence among species (Curren and Nixon, 1992).

Although the impacts of acid rain on terrestrial systems are known with less certainty, several aspects are likely outcomes of acid deposition. Effects on soil include reducing the availability of nutrients and enhancing the solubility of metals. But nitrogen deposition into the soil can enhance its nutrient content, and some soils are fairly resistant to damage. Acid deposition can cause damage to foliage of trees and crops, however (Curren and Nixon, 1992). Forests, especially those at high elevations, are also affected by acid deposition directly through increased susceptibility to natural stresses and indirectly through a loss of nutrients obtained from soil (USEPA, 1999). Considerable uncertainty relates to long-term impacts that may not yet have been observed (NAPAP, 1998).

Several human health problems are linked to acid deposition. For example, many respiratory diseases, including bronchitis and emphysema, are likely caused or aggravated by sulphur particulates and nitrogen oxides. Respiratory problems are particularly noted in sensitive populations, such as children and asthmatics, as in Hong Kong, China (Hong Kong Municipal

Government, 1999). Another potential human health problem comes from increased levels of toxic metals leached from soil, especially aluminium, into drinking water in rural areas (Environment Canada, 1999).

Acid precipitation is also known to have negative non-ecological consequences. It causes the erosion of materials and structures, leading to aesthetic and functional damage as well as increased maintenance costs. This damage to structures includes those that have a great deal of historical significance and are considered highly valuable. Another impact of acid deposition is haze, or a lesseningof visibility, largely an aesthetic problem (USEPA, 1999).

The largest documented economic disruptions have been to fishery, forestry, and agricultural industries. The damage occurring to their products is causing a loss of productivity and jobs (Environment Canada, 1999). Furthermore, recreational use of aquatic regions and forests has diminished, causing a loss in revenue (NAPAP, 1998).

North America has seen significant reductions in the sulphate concentration and pH of precipitation as a result of the 1990 amendments to the Clean Air Act. Reductions in nitrate concentration have not been observed, however, because requirements for lower nitrogen oxide emissions did not go into effect until 1996 (NAPAP, 1998). On the whole, it is too early to tell if there has been significant improvement in the health of ecosystems. There is evidence of recovery in some New England lakes, but the U.S. Environmental Protection Agency has reported that additional reductions in sulphur and nitrogen deposition will be needed to fully restore the health of sensitive Adirondack lakes (USEPA, 1999). High-elevation spruce fir forests in the eastern United States continue to show signs of damage. But, as in Europe, there is reason to hope for improvement.

Asia is the region of greatest concern. Acid deposition is being reported throughout Asia (Wang and Wang, 1995), with many areas receiving levels that exceed the carrying capacity of their soils. Long-range transport is receiving scientific and political attention

as countries receive increasing pollution from neighbouring and even distant countries (Huang and others, 1995; Ichikawa and Fujita, 1995; Streets and others, 1999). By far the worst episodes of acid deposition occur in southwestern China (Zhao and Xiong, 1988). Average rainwater pH values of 4.0-5.0 are observed in the Sichuan Basin, and values below 3.0 have been recorded in individual episodes. Atmospheric conditions in Sichuan and Guizhou provinces, with weak winds and frequent temperature inversions, are conducive to high pollutant concentrations. Emissions are also high there because of the widespread burning of high-sulphur coal in small stoves and medium-size industrial boilers.

Southwestern China has seen damage from acid deposition. Sulphur deposition levels are more than 10 grams of sulphur per square metre per year, making the situation comparable to the worst parts of the former Czechoslovakia in the 1960s and 1970s. Zhao and Xiong (1988) report the following effects in the vicinity of Chongqing and the provinces of Sichuan and Guizhou:

- **A 50 percent dieback of pine forests on Nanshan Mountain, about 20 kilometres from Chongqing, attributed to acid deposition and air pollution.**

- **A more than 50 percent reduction in biomass production in commercial spruce forests in areas experiencing rain with a pH of less than 4.5.**

- **A yellowing of rice in large areas near Chongqing after rainfalls with a pH of less than 4.5.**

Seip and others (1995) sampled soil water and stream water in a 7-hectare catchment near Guiyang in Guizhou Province, about 350 kilometres south of Chongqing. Sulphate concentrations were very high, pH values were as low as 4.3, and aluminium concentrations were elevated. Despite these factors, no apparent damage to vegetation was observed. It appears that neutralisation of acid inputs by deep soils and underlying

bedrock may be averting ecosystem damage. Because of the heterogeneity of Chinese soils, however, local acidification and damage may be occurring in sensitive areas that have not been studied. A more recent survey of acidification in China by the Norwegian Institute for Water Research (Lydersen and others, 1997) reported severe effects of acid deposition on soils, water bodies with high loadings showing typical signs of acidification, and observed effects on surface water organisms.

Zhao and Xiong (1988, p. 342) describe some of the severe materials damage observed in Chongqing: "Metal structures are scraped of rust and painted once every 1-3 years. Shells of buses are generally replaced every 1-2 years. Structural components made of stainless steel become rusty after a few years. Some concrete works built in the 1950s have corroded in such a manner that the gravel is exposed. It is estimated that the corrosion depth reaches 0.5 cm in less than 30 years".

In northern China, by contrast, rainwater pH values are typically 6.0-7.0. Although emissions are high in many parts of northern China, meteorological conditions are more conducive to pollutant dispersion, and windblown dust from central Asian deserts tends to neutralise the acidity. The line delineating acid precipitation in China (pH of 5.6) extends just west of Beijing and along the eastern edge of the Greater Khingan mountain range. Since 1982 the area receiving acid deposition may have expanded by 600,000-700,000 square kilometres (Wang and Wang, 1995).

Acidification is responsible for much of the air pollution-related damage in China, though the relative roles of acid rain, dry deposition of sulphur dioxide, nitrates, particulates, ozone, and other factors have not been determined. Areas with lower rain acidity see much less damage than Chongqing and neighbouring cities of southwestern China. Acid rain damage to crops, forests, materials, and human health in China in 1995 is estimated to total more than $13 billion (*China Daily,* 9 March 1998).

In Asia there is also considerable concern about the fate of cultural materials as pollution levels rise. Concerns about the deterioration of the Taj Mahal were raised as far back as 1981 (Lal, Gauri, and Holdren, 1981). Throughout Asia, cultural buildings and monuments made of alkaline-based materials are vulnerable to attack. Glass, paper, textiles, and archives are also subject to accelerated deterioration in the warm, moist, polluted atmospheres of Asia. These problems are greatly under-appreciated and should be given high priority in future research before rich areas of cultural heritage are destroyed.

Finally, although not yet major emitters, Sub-Saharan Africa and Latin American have the potential for significant sulphur emissions as fossil fuel use increases.

Tropospheric ozone

Ozone is an important air pollutant that can cause damage to crops, trees, and human health. It is a major component of the harmful smog that forms in urban areas during periods of high temperature, intense solar radiation, low wind speed, and an absence of precipitation. In the polluted air mass, ozone is produced by a complex set of chemical reactions involving nitrogen oxides and non-methane volatile organic compounds. North America and Europe are developing coordinated strategies to reduce emissions of ozone precursors and thereby reduce some of the health and ecosystem damage attributed to it. Although there is still progress to be made in these regions, it is again in Asia that concern is greatest.

Episodes of high ozone concentrations are now common in the megacities (cities containing more than 10 million people) of southern Asia that have industrial emissions (producing volatile organic compounds), transportation (producing nitrogen oxides), and conducive climates-Bangkok (Thailand), Hong Kong (China), Mumbai (India), and Shanghai (China), to name a few. In addition, the formation and transport of regional ozone have been observed in measurement campaigns such as PEM-West (Akimoto and

others, 1996; Jaffe and others, 1996). Ozone concentrations were observed to be regionally enhanced by photochemical activity in continental air masses passing through areas with high nitrogen oxides emissions.

The potential effects of elevated ozone concentrations on human health and crop production in Asia are just beginning to be explored (Chameides and others, 1994). Studies in the West have established that crop yields are depressed by repeated exposures to ozone levels above 50-70 parts per billion; these concentrations are exceeded in fall and winter throughout large areas of southern China. There is concern that damage to winter wheat and other crops in the Yangtze Delta may endanger China's ability to meet increasing food demands. These analyses are still in their infancy, however, and much more work is needed on meteorological analysis, the gathering of monitoring data, field studies on crop responses to elevated concentrations, and regional assessments of economic impact. Until more of this work is done in Asia, a definitive statement cannot be made about the relationship between regional emissions of non-methane volatile organic compounds and nitrogen oxides and impacts on human health and vegetation.

Suspended fine particles

Particulate emissions are relatively well controlled in the industrialised world. Control systems on stationary and mobile sources are effective in limiting the release of primary particles, and secondary fine particles (such as aerosols) are being checked by reductions in emissions of their precursors. In the outdoor environments of many Asian cities, however, concentrations of fine particles are very high, exacerbated by domestic solid-fuel combustion, small-scale industrial activities, and inefficient transportation systems (see above). In many parts of the world the build-up of secondary fine particles over large regional areas during hot, dry spells leads to regional haze, impaired visibility, inhalation health effects, and related ecosystem problems.

Acid deposition is being

Acid deposition is being reported throughout Asia, with many areas receiving levels that exceed the carrying capacity of their soils

Alkaline dust is also important in Asia because of its ability to neutralise the acidity of precipitation and deposition. In the spring (March, April, May) large dust storms build in the Taklamakan and Gobi deserts and the loess plateau areas of China and Mongolia. These storms are associated with strong cold fronts and prevailing westerly winds. Dust particles are lifted as high as 6 kilometres into the atmosphere and transported over long distances to eastern China, the Republic of Korea, Japan, the Pacific Ocean, and even North America. The dust contains high concentrations of calcium, which neutralises part of the acidity in rainfall. Thus, while sulphate levels in northeast Asian deposition are high and similar to those in North America and Europe, pH values are less acid (typically 5.3-7.0+).

Although large amounts of carbonaceous particles are emitted from the burning of coal, most of the larger particles fall to ground quickly and are not part of the regional emissions picture. Similarly, a large portion of particles is collected, for even in the most polluted regions some form of particulate collection is usually employed. Nevertheless, a certain portion of fine particles from fuel combustion is carried aloft and transported over long distances. These particles are usually less than 1 micron in diameter and consist of carbonaceous solids-so-called black carbon-and organic compounds in aerosol form. These particles can participate in chemical reactions, contribute to reduced visibility, and lead to soiling of surfaces. They scatter and absorb solar radiation and hence play a role in global warming. They also affect cloud albedo (ability to reflect sunlight), because their hydrophilic qualities increase the number of cloud condensation nuclei. On balance, black carbon is thought to contribute a net warming of about 0.5 degrees Celsius (C) globally (Penner, Ghan, and Walton, 1991).

The combustion of biofuels and coal in rural households and diesel fuel in vehicles is a prime contributor to these fine particles. There is an urgent need to better characterise the anthropogenic emissions of primary particles from Asian sources, both by size and chemical and physical characteristics. Diesel vehicles that are poorly designed, operated, and maintained emit large quantities of fine particles in much of the developing world.

Forest fires are a large source of particle emissions in all size ranges. Some of these fires are of natural origin (caused by lightning strikes), while others are caused by human activities such as forest clearing. The fires in Indonesia in the summer of 1997 caused a months-long regional air pollution episode in Indonesia, Malaysia, Singapore, and parts of Thailand and the Philippines. The health of tens of millions of people was affected. Increases in acute respiratory infections, asthma, and conjunctivitis were noted in Kuala Lumpur (Malaysia), Sarawak (Malaysia), and Singapore. Tests on school children in Malaysia noted significant decreases in lung function, the chronic effects of which will not be known for a long time (Brauer and Hisham-Hashim, 1998). Fine particles from such fires can be transported thousands of kilometres if atmospheric conditions are conducive.

Regional climate change

In the early 1990s it was recognised that sulphate aerosols can influence the global climate by scattering and absorbing incoming solar radiation (Charlson and others, 1992) and hence exerting a cooling effect. The role of sulphate aerosols has now been clarified (IPCC, 1996a). Indeed, sulphate aerosols contribute negative radiative forcing (of about -0.4 watts per square metre) that offsets the positive forcing of carbon dioxide and other greenhouse gases. Hence a reduction in sulphur dioxide or nitrogen oxide emissions would be expected to reduce sulphate aerosol concentrations and increase the potential for global warming. The radiative forcing is spatially inhomogeneous, with values as large as -11 watts per square metre over heavily polluted areas such as Central Europe and eastern China.

Lal and others (1995) have suggested that sulphate aerosols can also interfere with local climates. The cooling effect of the aerosol haze reduces the difference between land and sea temperatures and weakens the monsoon. In addition, the cooler land surface reduces evaporation and lowers the amount of water vapour in the atmosphere. The authors estimate that sulphate aerosols in the Asian atmosphere will reduce monsoon rainfall over India and parts of China by the middle of this century. The calculated reduction of 7-14 percent over the fertile north and central Indian plains would be a serious threat to agricultural production. It also appears that large-scale forest fires can reduce rainfall regionally.

Global scale: climate change from greenhouse gases

The two most important human-caused problems associated with environmental processes operating at the global scale are:

- **The disruption of climate as the result of energy-related emissions of heat-trapping (greenhouse) gases with long atmospheric residence times.**

- **The depletion of stratospheric ozone as a result of emissions of chlorofluorocarbons and related compounds from air-conditioning and refrigeration equipment (among other sources).**

The character and origins of the first of these are discussed in this section. Stratospheric ozone is not addressed here because it is not primarily an energy issue, although it has connections to energy end-use technologies.[7]

It has been known since the work of Swedish scientist Gustav Arrhenius at the end of the 19th century that certain gases present in Earth's atmosphere in trace quantities exert a thermal blanketing effect that keeps the planet's surface much warmer than it would

otherwise be. These are called 'greenhouse gases' because they work in a way analogous to one of the functions of the glass in a greenhouse, letting sunlight in but trapping outgoing heat by absorbing it and re-radiating some of it back to the ground.

The most important greenhouse gas naturally present in Earth's atmosphere is water vapour. Next in importance is carbon dioxide (CO_2), followed by methane (CH_4) and nitrous oxide (N_2O). The concentrations of these gases in the atmosphere before the start of the industrial revolution kept the mean global surface air temperature about 33 degrees Celsius warmer than it would have been in absence of an atmosphere with such natural levels of greenhouse gases. (This natural 'greenhouse effect' is highly beneficial to life on Earth, since without it the average temperature would be far below freezing.[8])

Although water vapour contributes the largest part of the natural greenhouse effect, its concentration in the atmosphere globally-on which the size of the water-vapour contribution to the greenhouse effect depends-is not significantly affected by emissions of water vapour from human activities. The most important anthropogenic greenhouse gas emissions are those of carbon dioxide (CO_2), which arise mainly from combustion of fossil and biomass fuels and from deforestation (see below).[9, 10] An important indirect effect of human activities on the atmospheric concentration of water vapour results from increased evaporation of water from the surface of Earth because of the warming caused by increasing concentrations of anthropogenic greenhouse gases in the atmosphere. The resulting increase in atmospheric water-vapour content further warms Earth's surface-a significant 'positive feedback' in the anthropogenic greenhouse effect.[11]

Concerns developed many decades ago that human-caused increases in the carbon dioxide content of the atmosphere might accentuate the natural greenhouse effect enough to disturb the global climatic patterns to which human habitation, agriculture, forestry, and fisheries had become accustomed. As a result, in 1958 scientists began to take direct

measurements of the atmospheric concentration of carbon dioxide at locations far from its main human sources.[12] The continuous record of such measurements, at various remote locations on land and from ships and aircraft, has revealed a steady increase in the global atmospheric inventory of carbon dioxide, reaching 14 percent above the 1958 level by 1995.

Reconstruction of the earlier history of atmospheric carbon dioxide content (by analysis of air bubbles trapped in layered cores taken from polar ice sheets) has established that the increase from pre-industrial times to 1958 was about 13 percent. Thus the ratio of the 1995 concentration to the pre-industrial one is 1.14 x 1.13 = 1.29, representing an increase of 29 percent (figure 3.8). The rise in the atmosphere's inventory of carbon dioxide closely tracks the rise in global fossil-fuel burning over the past 150 years. Moreover, studies based on relatively abundant carbon isotopes confirm the role of fossil-fuel-derived carbon in the observed increase. There is reason to believe that the slower increase in the 100 years before that was due mainly to widespread deforestation for timber, fuelwood, and charcoal.

Not all of the carbon added to the atmosphere by human activities stays there. A substantial part is absorbed by dissolution into the surface layer of the world's oceans (from which oceanic mixing processes gradually transport the dissolved carbon dioxide into the much larger volume of water in the deep oceans). And part is absorbed into forests and soils in areas where the forest 'standing crop' or soil carbon inventory is growing.[13] Estimates for the balance of sources, sinks, and atmospheric accumulation of anthropogenic carbon during the 1980s are summarised in table 3.4. The mean residence time in the atmosphere of carbon dioxide contributed by human activities, relative to the processes that remove it, is more than 100 years.

FIGURE 3.8. ATMOSPHERIC CONCENTRATIONS OF CARBON DIOXIDE, 1850-1995

Source: OSTP, 2000.

Measurements and analyses over the past 20 years have revealed that the atmospheric concentrations of two other naturally occurring greenhouse gases-methane (CH_4) and nitrous oxide (N_2O)- have increased by 145 percent and 14 percent since pre-industrial times. Apparently these increases are at least partly due to direct inputs from human activities as well as to alteration of ecological conditions. The wholly anthropogenic chlorofluorocarbons (CFCs) implicated in the depletion of stratospheric ozone are potent greenhouse gases as well. The warming effect of ozone, itself a greenhouse gas, has been increased in the troposphere (as a result of anthropogenic emissions of hydrocarbons and nitrogen oxides) by more than CFCs have decreased it in the stratosphere.

Changes in the atmospheric concentrations of methane, nitrous oxide,

chlorofluorocarbons, and ozone since pre-industrial times are thought to have increased by about 75 percent the warming potential that would be expected from the observed increases in carbon dioxide concentrations alone. Increases over this same period in the atmospheric concentrations of particulate matter produced by combustion of fossil fuels and biomass have offset part of the warming effect of the greenhouse gas increases.[14] This offset, for which the best estimate is about half of the overall warming effect that would otherwise have occurred through 1995, is likely to diminish as emissions of particulates and their precursors are more tightly regulated.[15] Estimated effects of the various anthropogenic greenhouse gases on Earth's energy balance are shown in table 3.5, together with estimates of other changing influences on this balance.

TABLE 3.4. SOURCES AND FATES OF ANTHROPOGENIC CARBON EMISSIONS, 1980S

Source	**Billions of tonnes of contained carbon**
Emissions from fossil fuel combustion and cement production	5.5 ± 0.5
Emissions from tropical deforestation	1.6 ± 1.0
Total anthropogenic emissions	7.1 ± 1.1
Fate	
Storage in the atmosphere	3.3 ± 0.2
Uptake by the oceans	2.0 ± 0.8
Uptake by terrestrial ecosystems	1.8 ± 1.6

Source: IPCC, 1996.

TABLE 3.5. CHANGES IN EARTH'S ENERGY BALANCE, PRE-INDUSTRIAL TIMES-1992

Effect	**Global average watts per square metre**
Direct effect of increasing carbon dioxide	1.6 ± 0.2
Direct effect of increasing methane	0.5 ± 0.1
Direct effect of increasing halocarbons	0.25 ± 0.04
Direct effect of increasing tropospheric ozone	0.4 ± 0.2
Direct effect of decreasing stratospheric ozone	0.1 ± 0.02
Direct effect of tropospheric aerosols	-0.5 ± 0.3
Indirect effect of tropospheric aerosols	-0.8 ± 0.8
Direct effect of natural changes in solar output (since 1850)	0.3 ± 0.1

Source: IPCC, 1996b.

Are the changes in climate being observed in the forms and magnitudes that theory predicts for the measured increases in greenhouse gases? Although natural fluctuations in climatic variables would tend to mask human-caused disruption in its early stages, a variety of evidence indicates that the 'signal' of anthropogenic change is becoming visible despite the 'noise' of these fluctuations. Specifically:

- **Near-surface air temperatures around the globe have increased by 0.3-0.6 degrees Celsius since the late 19th century.[16] The 11 hottest years since 1860 have all occurred since 1983 (notwithstanding the multiyear cooling effect of particulate matter injected into the stratosphere by a major volcanic eruption in 1991).**

- **Directly measured ocean surface-water temperatures have also increased by 0.3-0.6 degrees Celsius on a global average over the past century. In the same period the global sea level, as determined from tidal-range measurements, rose 10-25**

centimetres (4-10 inches). Mountain glaciers have generally been in retreat all over the world, and mid- to high-latitude cloudiness and precipitation have generally been increasing.

These observed changes in climatic variables are consistent, in overall magnitudes and in the general pattern of their geographic distribution, with the predictions of basic theory for the effects of the changes in greenhouse gas and particulate matter concentrations known to have occurred over this period.

The observed climatic changes are also similar to the predictions of the most sophisticated computer models of global climate, when these models include the observed build-up of greenhouse gases (corrected for the effect of atmospheric particulate matter).[17] This agreement among theory, observation, and computer modelling extends, moreover, to a variety of subtler trends for which reliable measurements have become available only for the past 15-25 years, such as cooling in the lower stratosphere, reduction of day-night temperature differences, and maximum surface warming in northern high latitudes in winter. Taken together, these phenomena are 'fingerprints' of greenhouse gas-induced climate change-consistent with the hypothesis that increases in those gases explain the observed changes, and inconsistent with alternative hypotheses.

Based on the evidence and arguments summarised here, the Intergovernmental Panel on Climate Change (IPCC) concluded in its Second Assessment that "the balance of evidence suggests a discernible human influence on climate" (IPCC, 1996b, p. 4). In that report the IPCC also extended its earlier analyses of how the human influence on climate would be expected to grow under a business-as-usual trajectory of future greenhouse gas emissions and under higher and lower trajectories. The panel found that, under the range of trajectories considered (and taking into account the uncertainty in the global temperature response to a given increase in greenhouse gas concentrations), the global average surface air temperature would be 1.0-3.5 degrees Celsius higher in 2100 than in 1990.[18]

In all these cases, according to the IPCC (1996b, p. 5), the average rate of warming in the 21st century "would probably be greater than any seen in the last 10,000 years". In the IPCC's 'business-as-usual' emissions scenario, the average global temperature increase between 1990 and 2100 is 2.0 degrees Celsius-about 2.5 degrees Celsius above the temperature a century ago-which would make the world warmer than it has been at any time in the last 125,000 years. In this scenario the sea level would rise 50 centimetres between 1990 and 2100, then "continue to rise at a similar rate in future centuries beyond 2100, even if concentrations of greenhouse gases were stabilized by that time, and would continue to do so even beyond the time of stabilization of global mean temperature" (IPCC, 1996b, p. 5).

The IPCC assessment gives due consideration to the range of possible outcomes and to the size of the uncertainties attached to the group's best estimates. Still, the range of expected ecological and social impacts of climate changes in the next century leaves little room for complacency even at the lower end of the range. And the uncertainties include the possibility of unpleasant surprises that would extend the upper end:

> **Further unexpected, large and rapid climate system changes (as have occurred in the past) are, by their nature, difficult to predict. This implies that future climate changes may also involve "surprises". In particular these arise from the non-linear nature of the climate system. When rapidly forced, non-linear systems are especially subject to unexpected behavior. Progress can be made by investigating non-linear processes and subcomponents of the climate system. Examples of such non-linear behavior include rapid circulation changes in the North Atlantic and feedbacks associated with terrestrial ecosystem changes (IPCC, 1996b, p. 6).[19]**

Since the IPCC's Second Assessment, scientific evidence has continued to accumulate concerning human influences on the global climate system.[20] In particular, the data and analyses show more compellingly than ever that Earth's average surface temperature is

increasing and that this increase can largely be attributed to the accumulation of greenhouse gases in the atmosphere caused by human activities. Among the recent findings:

- ***1998 appears to have been the warmest year in a millennium,* and the 1990s were the warmest decade in 1,000 years for the Northern hemisphere. Scientists have reconstructed the millennial temperature record in the Northern hemisphere using proxy data for temperatures, such as ice cores, lake sediments, corals, and tree rings (Mann, Bradley, and Hughes, 1999).**

- ***Greenhouse gases from human activities are the driver of these temperature increases.* While solar variability, volcanic eruptions, and El Nio cycles also contribute to these global temperature patterns, the 20th century record cannot be explained solely by invoking these phenomena (Mann, Bradley, and Hughes, 1998).**

- ***Regional patterns of temperature change across Earth's surface and vertical patterns of temperature change in the atmosphere provide further evidence of human-induced global warming.* These patterns are consistent with what is expected under anthropogenic climate change-and are inconsistent with hypotheses that suggest that solar variability or the urban-heat island effect can be used to explain the instrumental temperature record (see Wigley, Smith, and Santer, 1998; Wentz and Schabel, 1998; and Peterson and others, 1999).**

Consequences of greenhouse gas-induced climate change

There is a natural tendency to suppose that an average global warming of 2.5 degrees Celsius-around the mid-range projection for the year 2100 relative to 1900-would not be such a bad thing. Raising Earth's average surface temperature from 15.0 to 17.5 degrees Celsius (from 59.0 to 63.5 degrees Fahrenheit) does not, at first glance, seem to be especially problematic. Some regions would have longer growing seasons, and some

would have shorter seasons of freezing weather. What would be so bad about that?

Such complacency is unwarranted for several reasons. Most important, small changes in the average global surface temperature will cause many changes in other climatic variables-latitudinal temperature differences, frequency of extreme temperatures, atmospheric circulation patterns, precipitation patterns, humidity, soil moisture, ocean currents, and more-that affect human wellbeing in myriad ways. Climatic conditions are the 'envelope' in which all other environmental conditions and processes exist and operate. Thus climate exerts powerful influences over, for example, the productivity of farms, forests, and fisheries, the geography of human disease, and the abundance and distribution of the plants, animals, and microorganisms constituting biodiversity, as well as determining the availability of water, the productivity of farms, forests, and fisheries, the geography of human disease, and the abundance and distribution of the plants, animals, and microorganisms constituting biodiversity, as well as determining the availability of water, the productivity of farms, forests, and fisheries, the geography of human disease, and the abundance and distribution of the plants, animals, and microorganisms constituting biodiversity, as well as determining the availability of water, the frequency and intensity of damage from storms and floods, the combination of heat and humidity that determines liveability (and requirements for air conditioning) in warm regions in summer, and the potential property loss from rising sea level.

Mountain glaciers have generally been in retreat all over the world

The average global surface temperature, then, is not a number that by itself reveals the features of climate that matter most-the spatial and temporal patterns of hot and cold, wet and dry, wind and calm, frost and thaw that constitute the climate locally and regionally,

where people live. Rather, it is a single, highly aggregated index of the global climatic state that is correlated in complicated ways with those crucial local and regional climatic features. When the average global temperature increases, the regional increases will be greater on land than on the ocean surface, greater inland than near the coasts, and greater at high latitudes than near the equator. In mid-latitude, mid-continent regions-the midwestern United States, for example-the increase in average temperature is expected to be 1.3-2.0 times the average global increase (hence as much as a 5 degree Celsius increase when the global average has gone up by 2.5 degrees; Wigley, 1999 and IPCC, 1996b). At higher latitudes-central Canada, northern Russia-the increase could be three times the global average, or more.

Evaporation and, hence, precipitation are expected to increase about 3 percent for each 1 degree Celsius increase in the average global temperature. (Thus a 2.5 degree Celsius increase in the average global temperature would produce a 7.5 percent increase in precipitation.) In addition, a larger fraction of the precipitation is expected to occur during extreme precipitation events, leading to an increase in flooding.[21] Notwithstanding the increase in precipitation, the increase in evaporation will likely reduce summer soil moisture over large regions, increasing the frequency and severity of droughts in some. At the same time, humid regions will likely become more so. Climate simulations conducted at the Geophysical Fluid Dynamics Laboratory of the U.S. National Oceanographic and Atmospheric Administration show that the average heat index (a discomfort indicator combining temperature and humidity) for the southeastern United States in July will increase from about 30 degrees Celsius (86 degrees Fahrenheit) today to about 35 degrees Celsius (95 degrees Fahrenheit) by the time the average global surface temperature has increased 2.5 degrees Celsius (GFDL, 1997).

As the average temperature and average heat index go up, the frequency of days with extremely high temperature and humidity increases disproportionately. An average warming of 1 degree Celsius might increase the number of days over a particular threshold

by 10 percent, while a 2 degree Celsius increase would increase the number of days over that threshold by substantially more than 20 percent (Wigley, 1999; IPCC, 1996b). This result portends not only much higher summer discomfort in a greenhouse gas-warmed climate but also a possibility of substantial increases in death rates from heat stress in areas that are already hot and humid in summer. A decrease in cold-related deaths in winter would partly offset this effect, but for a variety of reasons seems unlikely to offset it entirely (IPCC, 1996a).

An increase in sea level at the mid-range value of 50 centimetres between 1990 and 2100 would be devastating to low-lying islands and seriously damaging to coastal wetlands and many coastal communities. As with temperature, the damage will come not just from the increase in the average but from the increase in extremes. In the case of sea level, this refers to the damage done by storm surges and storm waves starting from a higher baseline (IPCC, 1996a).

As for the frequency and intensity of damaging storms themselves-hurricanes and typhoons in particular-some lines of argument and evidence suggest increases in a greenhouse gas-warmed world, but the origins and dynamics of such storms are complicated. The higher sea surface temperatures and higher atmospheric moisture contents associated with a warmer world tend to produce more powerful storms, all else being equal, but other relevant factors that could be affected by climate change might offset this tendency. There is evidence of an increase in the frequency of Atlantic hurricanes based on a correlation with sea surface temperatures, and there are simulation results indicating higher wind speeds and lower pressures in tropical storms world-wide under global temperature increases in the range expected for the 21st century (see Wigley, 1999 and Knutson, Tuleya, and Kurihara, 1998).

Also subject to considerable uncertainty are the effects of global warming on the large-scale patterns of atmospheric and oceanic circulation that are so crucial in determining

regional climates. One thinks particularly of the El Nio/Southern Oscillation phenomenon that affects climates across the central Pacific and the Americas and all the way to Africa, the monsoons that are so critical across Africa and South Asia, and the North Atlantic thermohaline circulation that drives the Gulf Stream and greatly moderates the winter climate in Western and Northern Europe. Although there is every reason to expect that global warming would influence these phenomena, neither historical correlations nor the ocean-atmosphere models used to simulate global climate have proven adequate for predicting with confidence what the exact effects will be.

There are, however, some suggestive preliminary findings. Some modelling results, for example, indicate a substantial weakening of the North Atlantic thermohaline circulation from greenhouse gas-induced warming, setting in well before the pre-industrial carbon dioxide concentration has doubled (Broecker, 1997; GFDL, 1997). Such a weakening would, somewhat paradoxically, make Europe much colder in winter in a world that was warmer overall.

And even bigger changes, such as some that might ensue from ocean-atmosphere-ice interactions, cannot be ruled out. One such scenario involves the complete melting of the Arctic sea ice (with no effect on sea level, since floating ice displaces its weight in water, but with large potential effects on oceanic and atmospheric circulations). Another involves the collapse of the largely land-borne but ocean-anchored West Antarctic Ice Sheet, the slow slide of which into the ocean if the anchor points melted away could raise sea level by 5 metres in 500 years (Oppenheimer, 1998).

In a range of cases considered by the IPCC, the average rate of warming in the 21st century "would probably be greater than any seen in the last 10,000 years."

If the ways in which global warming will affect regional climates are uncertain, the ecological consequences of those regional changes are even more so. Certainly both the averages and extremes of temperature, humidity, and precipitation are critical in governing the distribution and abundance of terrestrial animals, plants, and microorganisms, just as the averages and extremes of ocean temperatures, salinities, and current patterns are critical to marine life. The organisms in question include, of course, the plants that are the foundation of all terrestrial and oceanic food chains-including all those that support the human population-and they include the pests and pathogens that can destroy crops, fell farm animals, ravage forests, and bring debilitating diseases to humans. Even without the capacity to predict specific effects in detail (which is lacking because of inadequacies in ecological as well as climatological understanding), it is worth noting that:

- **The conditions governing what grows where on land are generally the result of co-evolution of soils, vegetation, and climate. Adjusting to climate change is therefore not just a matter of allowing cropping patterns and forest characteristics to rapidly migrate to a rearranged set of climatic zones; reaching a new equilibrium could take centuries. And where drastic changes in agricultural practices are required to deal with climate change, the capital- and infrastructure-poor developing world will be differentially disadvantaged.**

- **Winter is the best pesticide (which is why crop pests and many disease vectors and pathogens are more problematic in the tropics than in temperate zones). This means that warmer winters outside the tropics will be problematic for food production and for human disease.**

- **The warmer, wetter conditions that global warming will bring to many of the world's temperate zones will expand the ranges of a variety of diseases (including, quite probably, malaria, cholera, and dengue fever). Industrialised countries'**

technological and biomedical defences against these diseases may prove less robust than optimists predict, not least because of the continuing emergence of drug-resistant strains.

The conclusions of the IPCC Second Assessment about the consequences of the greenhouse gas-induced warming expected over the 21st century include the following (IPCC, 1996a):

- **Agricultural productivity "is projected to increase in some areas and decrease in others, especially the tropics and subtropics".[22] "Low-income populations depending on isolated agricultural systems, particularly dryland systems in semi-arid and arid regions, are particularly vulnerable to hunger and severe hardship" (p. 6).**

- **"As a consequence of possible changes in temperature and water availability under doubled equivalent of CO_2 equilibrium conditions, a substantial fraction (a global average of one-third, varying by region from one-seventh to two-thirds) of the existing forested area of the world will undergo major changes in broad vegetation types-with the greatest changes occurring in high latitudes and the least in the tropics" (pp. 5-6).**

- **"Climate change is likely to have wide-ranging and mostly adverse impacts on human health, with significant loss of life...Net climate-change-related increases in the geographic distribution (altitude and latitude) of the vector organisms of infectious diseases (e.g., malarial mosquitoes, schistosome-spreading snails) and changes in the life-cycle dynamics of both vector and infective parasites would, in aggregate, increase the potential transmission of many vector-borne diseases...Increases in non-vector-borne infectious diseases such as cholera, salmonellosis, and other food- and water-related infections also could occur,**

particularly in tropical and subtropical regions, because of climatic impacts on water distribution, temperature, and microorganism proliferation... [H]otter temperatures in urban environments would enhance both the formation of secondary pollutants (e.g., ozone) and the health impact of certain air pollutants. There would be increases in the frequency of allergic disorders and of cardiorespiratory disorders and deaths caused by various air pollutants".

- **"Climate change and the resulting sea-level rise can have a number of negative impacts on energy, industry, and transportation infrastructure; human settlements; the property insurance industry; tourism; and cultural systems and values".**

Nearly all attempts to predict the consequences of greenhouse gas-induced climate change, including those of the IPCC, have confined themselves to addressing the changes associated with roughly a doubling of pre-industrial carbon dioxide concentrations. This has been done so that the results of studies by different investigators would be readily comparable, inasmuch as they were all looking at a similar degree of climate change-not because there is any particular reason to believe that no more than a doubling of pre-industrial carbon dioxide will occur. Indeed, as the next section indicates, the world could end up with carbon dioxide levels three or even four times the pre-industrial value. But the prevalence of studies that look only at the effects of a doubling seems to have led many people to suppose that these are the most that could occur.

In reality, as the few studies of higher levels of warming make plain, the uncertainties and controversies surrounding whether a doubling of atmospheric carbon dioxide would have overwhelmingly negative consequences are of much less importance when one contemplates a quadrupling. A study of quadrupling by one of the main U.S. climate study centres concluded, for example, that the average temperature increases in Northern hemisphere mid-continent regions would be 8-12 degrees Celsius (15-22 degrees Fahrenheit); that mid-continent soil moisture in summer would fall about 50 percent from

1990s levels; that the sea level rise from thermal expansion alone (not allowing for the melting of any of the Greenland or Antarctic ice sheets) would approach 2 metres; that the North Atlantic thermohaline circulation would shut down completely; and that the July heat index for the southeastern United States would reach 44 degrees Celsius (110 degrees Fahrenheit). The ecological consequences of such changes-and their influence on humans-would be immense.

Greenhouse gas-induced climate change could also affect energy systems, potentially influencing their cost and reliability. The attractiveness of hydropower, windpower, and biomass energy systems, for example, depends on favourable and stable, or at least predictable, climate conditions at their sites over decades. Energy demand is also a function of climate, and changes in temperature, precipitation, wind, and the like will affect it. Thus it is conceivable that climate-change-related reductions in the attractiveness of renewables combined with increases in energy demand could act as positive feedback mechanisms-increasing greenhouse gas emissions faster than they would otherwise because of greater use of fossil fuels.

Alternative energy futures and greenhouse gas emissions

According to the IPCC, in 1990 global emissions of carbon dioxide from fossil fuel burning totalled about 5.9 billion tonnes of contained carbon. (It is customary to keep track of carbon dioxide emissions in terms of their carbon content rather than their total mass, to facilitate comparisons with other stocks and flows in the global carbon cycle, in which carbon may be in a variety of chemical compounds.) Carbon dioxide emissions from tropical deforestation totalled about 1.5 billion tonnes, with an uncertainty of plus or minus 1.0 billion tonnes. The IPCC assumes that rates of tropical deforestation will decline in the 21st century, becoming even smaller relative to fossil fuel carbon dioxide emissions. In 1997 fossil fuel combustion produced about 6.3 billion tonnes of carbon emissions (table 3.6).

The geographic distribution of industrial emissions of carbon- that is, emissions from fossil fuel combustion (including flaring of natural gas) and cement manufacturing-is shown in figure 3.9 for 1995 and projects for 2035 under a business-as-usual energy future. In 1995 nearly three-quarters of these emissions came from industrialised countries. Under the business-as-usual scenario, the developing country share will equal that of industrialised countries by 2035. (The cumulative contribution of developing countries to the atmospheric burden of anthropogenic carbon dioxide will remain smaller than that of industrialised countries for some time thereafter, however, and per capita emissions from developing countries will remain smaller than those from industrialised ones for longer still.)

TABLE 3.6 SOURCES OF INDUSTRIAL CARBON EMISSIONS, 1997 (BILLIONS OF TONNES)

Combustion of petroleum products	2.70
Combustion of coal	2.40
Combustion of natural gas for energy use	1.20
Cement manufacturing	0.20
Flaring of natural gas	0.05
Total	**6.60**

Source: Authors' calculations based on energy data from BP, 1998; USEIA, 2000.

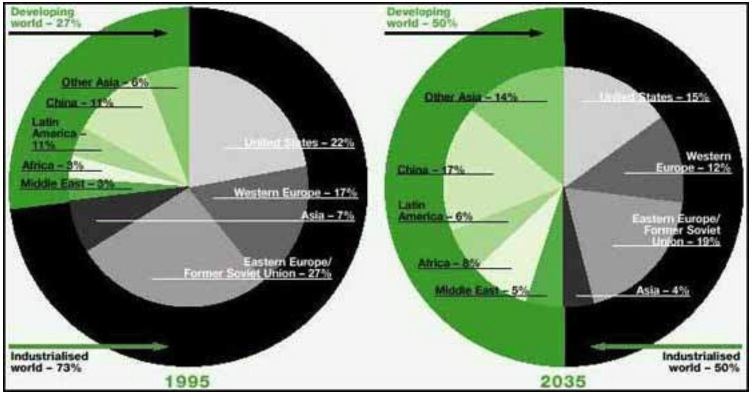


FIGURE 3.9. SOURCES OF INDUSTRIAL CARBON DIOXIDE EMISSIONS, 1995 AND 2035

Source: OSTP, 2000.

The IPCC analysis and its scenarios for future emissions also take into account the other anthropogenic greenhouse gases-methane, tropospheric ozone, nitrous oxide, and halocarbons-and anthropogenic particulate matter in the atmosphere that partly offsets the heat-trapping effect of the greenhouse gases by screening out incoming sunlight. As noted, the IPCC found that, as of the mid-1990s, the non-carbon dioxide greenhouse gases had added about 75 percent to the heat-trapping effect that would have resulted from the build-up of carbon dioxide alone. But the IPCC's best estimate of the effect of increasing particle concentrations was that these had approximately cancelled out the effect of the increases in non-carbon dioxide greenhouse gases. In one of the six scenarios developed by the IPCC in 1992, the 'central' scenario, designated IS92a, increases in the effects of atmospheric particles over the next 100 years continue to roughly counterbalance the effects of increases in the non-carbon dioxide greenhouse gases. Thus the net increase in the heat-trapping effect over this period is about what would be expected from the carbon

dioxide build-up alone.

The IS92a scenario is very similar to the 'unsustainable' IIASA-WEC (International Institute for Applied Systems Analysis - World Energy Council) A2 scenario presented in chapter 9. Both are based on World Bank 'medium' population projections; the IS92a scenario uses an older median projection in which the world population reaches 11.3 billion by 2100 and the IIASA-WEC uses a newer projection of 10.7 billion by 2100. The IS92a scenario assumes that real economic growth world-wide averages 2.9 percent a year from 1990 to 2025 and 2.0 percent a year from 2025 to 2100, resulting in overall growth of 2.3 percent a year from 1990-2100 compared with 2.5 percent a year in the A2 scenario. Both scenarios assume that the energy intensity of economic activity (energy per unit of real GDP) declines by 1.0 percent a year from 1990-2100 and that the carbon intensity of energy supply (kilograms of carbon emitted in carbon dioxide per unit of energy supplied) decreases by 0.2 percent a year over this period. The result is that global carbon emissions increase in both scenarios from 7.4 billion tonnes a year in 1990 to 20.0 billion tonnes a year in 2100, and cumulative carbon emissions between 1990 and 2100 total 1,500 billion tonnes.

The carbon content of the atmosphere in 2100 under the IS92a and A2 scenarios would be some 1,500 billion tonnes, or about 715 parts per million of carbon dioxide by volume, 2.5 times the preindustrial level, and still rising steeply. (Only about half of the 1,500 billion tonnes of carbon added between 1990 and 2100 would have remained in the atmosphere, the rest having been taken up by oceans and by vegetation according to the IPCC's carbon cycle model.) This is the scenario for which the IPCC obtained the surface temperature and sea level estimates mentioned above. Because of the thermal lag time of the oceans and the continuing melting of polar ice under warmer conditions, both temperature and sea level would continue to rise after 2100 even if the growth of atmospheric carbon dioxide were halted at that point.

The challenge of stabilising the carbon dioxide content of the atmosphere is illustrated in the IPCC's Second Assessment with emission trajectories that would be able to achieve stabilisation at concentrations ranging from 450-1,000 parts per million by volume (ppmv). (The pre-industrial concentration was about 280 ppmv; today's is 365 ppmv.) These trajectories can be characterised by the cumulative and average emissions they entail between 1990 and 2100 (although what happens after that also matters). The results are summarised in table 3.7.

The IPCC's IS92a scenario and the IIASA-WEC A2 scenario, with cumulative emissions of 1,500 billion tonnes of carbon between 1990 and 2100 and annual emissions of 20 billion tonnes of carbon in 2100, are both above even the highest of these stabilisation trajectories. Such emissions would nearly triple pre-industrial atmospheric carbon content by 2100 and create a situation in which an eventual quadrupling or more could not be avoided no matter what measures were taken thereafter. (These levels are so high as to render irrelevant the current controversies over exactly how severe the climatic consequences of a doubling of atmospheric carbon might be; a quadrupling would transform Earth's climate beyond recognition; see GFDL, 1997.)

To illustrate the challenge associated with reducing emissions to the levels being debated in the context of the United Nations Framework Convention on Climate Change (UNFCCC), consider what the numbers above imply for the stabilisation target for atmospheric carbon dioxide of 550 ppmv, about twice the preindustrial level. (While there can be no confidence that this level would avoid climate change seriously disruptive of human wellbeing throughout much of the world, a doubled carbon dioxide target is widely discussed because it is, at least arguably, near the upper limit of what is tolerable and near the lower limit of what seems achievable.) This would require that cumulative emissions between 1990 and 2100 be less than two-thirds those in the IS92a scenario. It would also require that emissions begin to decline after peaking at about 11 billion tonnes of carbon a year around 2030.

This more sustainable development path and the challenge of achieving the transition towards such a path are illustrated by the IIASA-WEC C scenario presented in chapter 9. That scenario leads to the stabilisation of atmospheric carbon concentrations at about 430 ppmv and cumulative emissions of some 540 billion tonnes of carbon from 1990-2100. Perhaps more important, the development path that leads to atmospheric stabilisation of carbon at a relatively benign level also leads to the fulfilment of most of the other criteria for sustainable development discussed in this report.

The difficulty of achieving this goal becomes particularly apparent when one views it in terms of the roles of industrialised and developing countries. In 1990 industrialised countries emitted about 4.5 billion tonnes of carbon from fossil fuel burning (three-quarters of the world total, or 3.6 tonnes per inhabitant of these countries). Developing countries emitted 1.5 billion tonnes (about 0.37 tonnes per capita). In 1992, as part of the UNFCC, industrialised countries agreed to try to limit their carbon emissions in 2000 to 1990 levels (see below). But few are on a track towards achieving this. For example, in 1997 U.S. carbon emissions were about 9 percent higher than in 1990.

Considerably more effort is required. For example, assume that industrialised countries were willing and able to return to their 1990 carbon emissions by 2010-a decade after the initial UNFCCC target (and a performance considerably weaker than called for in the 1997 Kyoto Protocol; see below)-and were also willing and able to reduce these levels by 10 percent a decade thereafter. Even then, stabilising atmospheric carbon dioxide concentrations at 550 ppmv would still require that per capita emissions in developing countries not exceed 1 tonne of carbon in the global peak-emissions year of 2030. (This assumes that emissions from deforestation have been eliminated by 2030 and that the population of developing countries is about 7.5 billion at that time, consistent with the 'medium' World Bank projection.) As shown in later chapters, with vigorous promotion of renewables and energy-efficient technologies, such a per capita level could produce much higher living standards.

TABLE 3.7. IPCC SCENARIOS FOR STABILISING CARBON DIOXIDE LEVELS, 2075-2375

To stabilise concentrations at (parts per million by volume)	450	550	650	750	1,000
By about the year	2075	2125	2175	2200	2375
Cumulative emissions in 1990-2100 would need to be in the range of (billions of tonnes of carbon)	550-750	750-1,100	970-1,270	1,090-1,430	1,220-1,610
Average emissions in 1990-2100 would be in the range of (billions of tonnes of carbon per year)	5.7-5.9	7.9-9.0	10.2-10.8	10.0-11.8	12.7
And peak emissions (billions of tonnes of carbon per year)	9.5	11	12.5	13.5	15
In the year	2012	2030	2050	2060	2075

Source: IPCC, 1996b.

Even more challenging, given the justifiable economic aspirations of developing countries, the unwillingness of many industrialised countries to take the steps needed to reduce emissions, and the common expectations of all countries to rely heavily on expanded fossil fuel use, is that the per capita emissions of both industrialised and developing countries would need to fall sharply after 2030 to stay on this 550 ppmv stabilisation trajectory. (See chapter 9 for more discussion of carbon emission scenarios, particularly the C scenario, which achieves the required emissions reduction discussed here.)

International agreements to address global climate change

The UNFCCC is the first binding international legal instrument that deals directly with the threat of climate change. Since its enactment at the 1992 'Earth Summit' in Rio de Janeiro, the convention has been signed by more than 165 states (plus the European Union). It came into force in March 1994.

Signatory countries agreed to take action to realise the goal outlined in article 2 of the convention, namely the "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." To achieve this, all parties to the convention, both industrialised and developing, are committed under article 4 to adopt national programs for mitigating climate change; to promote the sustainable management and conservation of greenhouse gas 'sinks' (such as forests); to develop adaptation strategies; to take climate change into account when setting relevant social, economic, and environmental policies; to cooperate in technical, scientific, and educational matters; and to promote scientific research and information exchange.

BOX 3.7. GREENHOUSE GASES AND NATURAL DEBT

Countries take on national debt when they spend money faster than their economies produce it. Building up national debt is essentially a way of borrowing from the country's future earnings. A little national debt can be beneficial, by providing resources so that the economy grows faster than it otherwise might. But a lot of national debt can be quite disruptive. Countries can also take on 'natural debt' by putting pollutants into the environment faster than they are naturally removed. In this way they borrow from the environment's future assimilative capacity.

Humanity has been adding greenhouse gases to the atmosphere faster than they can be naturally removed. As a result the global atmospheric burden of carbon dioxide and other greenhouse gases has been rising. The extra burden of greenhouse gases in the atmosphere above pre-industrial levels is a measure of the global natural debt. Indeed, this natural greenhouse gas debt is the principal driver of climate change, since it determines the extra radiative forcing (warming).

Although most discussions of greenhouse gas control address the current emissions of countries, cumulative emissions (natural debt) are the chief determinant of the impact on the climate. The natural debts of countries differ substantially more than do current emissions, because some countries have been emitting large amounts for much longer than others have. The largest natural debts have been accrued by industrialised countries, which started burning large amounts of fossil fuels early in the 20th century. Some of those greenhouse gases have been removed naturally from the atmosphere, but some remain because of long residence times. The table below compares the natural debts of a number of countries that together account for 55 percent of the world's population and about 75 percent of global carbon dioxide emissions.

It has been argued that it would be more appropriate to determine a country's responsibility for reducing emissions based on its natural debt relative to that of other countries rather than on current emissions, since natural debt (cumulative greenhouse gases in the atmosphere) is more closely related to actual climate impact. Such proposals are not welcomed by negotiators for most industrialised countries.

Natural debt: Carbon as carbon dioxide remaining in the global atmosphere from fossil fuel combustion

	Current emissions 1996 (tonnes per capita)	**Cumulative emissions 1950-96 (tonnes per capita)**
United States	5.3	119
Canada	4.2	91
Germany	3.3	87
Russia	3.9	78
United Kingdom	2.7	78
Australia	4.1	70
Sweden	1.7	54
France	1.8	49
Japan	2.4	41
Korea, Dem. Rep.	3.0	32

Korea, Rep.	1.7	16
China	0.6	8
India	0.2	3

One argument against using natural debt as a measure of responsibility is that it would be unfair. After all, it is argued, the ancestors of today's populations in industrialised countries did not know they were causing a problem by emitting greenhouse gases. Thus today's populations, who did not do the polluting, should not have to pay for past mistakes. This view is partly accounted for in the table, which only shows emissions from 1950. But there are two important counter-arguments:

- Today's rich populations have enjoyed the (considerable) benefits derived from past use of fossil fuels and other greenhouse gas-generating activities and thus should accept the debts that go along with those benefits. It is not a matter of punishment, but one of recognising the debits as well as the credits (the polluter pays principle).

- Saying that if someone did not know they were doing a risky thing that they need not be held responsible is a sure way to encourage people not to make the effort to discover whether their activities might cause problems for future generations. It essentially rewards ignorance. A sustainable world energy system, on the other hand, is one in which cross-generational responsibility is accepted by all.

Source: Smith, 1991a; Hayes and Smith, 1994; Smith, 1997.

The UNFCCC also establishes more demanding obligations for industrialised countries, which agreed to try to reduce emissions of carbon dioxide and other greenhouse gases to 1990 levels by 2000. OECD countries are also committed to facilitating the transfer of financial and technological resources to developing countries, beyond those already available through existing development assistance. The convention requires industrialised

countries to take the lead in adopting measures to combat climate change, recognising that they are mainly responsible for historic and current emissions of greenhouse gases, and that developing countries will need assistance to meet the treaty's obligations (box 3.7).

The structure provided by the UNFCCC is being built on with additions agreed in a series of conferences of the parties. Most notably:

- **The first conference of the parties, held in Berlin (Germany) in March 1995, focused on the need to reinforce the commitments in article 4 of the UNFCCC with "quantified limitation and reduction" objectives for annex 1 countries after 2000.[24] The mandate did not call for new commitments for developing country parties but only for enhanced efforts at implementing the existing commitments relating to these countries in article 4.**

- **The third conference of the parties, held in Kyoto (Japan) in December 1997, produced a protocol to the framework convention codifying commitments for reductions in greenhouse gas emissions after 2000. The protocol commits annex I parties (except Australia, Iceland, New Zealand, Norway, Russia, and Ukraine) to reduce greenhouse gas emissions by 5-8 percent below 1990 levels between 2008 and 2012 and to make "demonstrable progress" towards achieving these commitments by 2005. Overall emissions are to be computed on a net basis, accounting for afforestation, reforestation, and deforestation as well as emissions from energy supply and other industrial activities. (See box 3.7 for a discussion of another approach to measuring a country's greenhouse gas contributions.)**

The Kyoto Protocol, having not yet been ratified by the requisite number of nations, is not in force. It has been criticised by some (especially in the United States) as demanding too much too soon of industrialised nations while not requiring anything of developing

countries. It has been criticised by others as not requiring enough of anyone, representing only a small 'down payment' on the kinds of emission reductions that will be required over the 21st century to avoid intolerable climate change from greenhouse gases.

Cross-scale impacts

Some types of pollutants are created and create problems at every scale and easily transfer between scales. Aerosols (particulates) are a good example. At the household and community scales, they are probably the chief source of human ill health from energy systems. At the workplace scale, in the form of coal dust for example, they are a principal contributor. At the regional scale, secondary particulates from sulphur and nitrogen gases contribute to ill health and form the basis for acid deposition. At the global scale, they contribute to climate change through local warming or cooling, depending on particle composition and ground characteristics. Overall, it is believed that human-caused aerosols had a net cooling effect during the 20th century, masking some of the warming that would have occurred through greenhouse gas build-up.

Climate change is likely to have wide-ranging and mostly adverse impacts on human health, with significant loss of life.

The transfer of aerosols from one scale to another is governed by complicated processes involving geography, elevation, wind, moisture, size, composition, and so on. Nevertheless, in general it can be said that reducing emissions at one scale will have impacts at other scales. In most cases these benefits are beneficial. As particulates and their precursors such as sulphur oxides are brought under control because of concerns at other scales, however, greenhouse gas warming may actually become greater than in the

immediate past because of the apparent net cooling effect in the atmosphere.

Environmental risk transition

During development, societies tend to push off environmental problems from smaller to larger scales (Smith, 1990, 1997). For energy, household hazards dominate fuel cycles in the poorest parts of the world, while community impacts dominate fuel cycles in middle-income cities through industrial and vehicular pollution. In the richest countries, household and community problems have mostly been pushed off to the global level in the form of greenhouse gases (figure 3.10). In all countries, however, occupational risks per worker-hour tend to be much higher than risk per hour of public exposure. As with other exposures, however, occupational risks also tend to be higher in poorer countries (box 3.8).

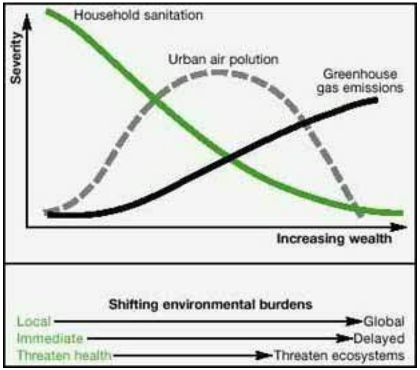


FIGURE 3.10. ENVIRONMENTAL RISK TRANSITION

Source: McGranahan and others, 2000; Smith and Akbar, 1999.

The environmental risk transition curves in figure 3.10 should not be considered fixed in

the sense that today's developing nations will be forced to go through them in the same way that today's industrialised countries have done. Rather, the curves should be viewed as a management framework by which to judge the progress of development policy. The task in developing countries is to avoid the excesses of the past, to continue to push down the household curve, and to not let the community curve rise out of hand. This might be considered a kind of 'tunnelling' through the curves to avoid climbing over the peaks by applying cleaner, more efficient energy supply and use technologies earlier in the development process than has occurred to date.

Win-win strategies to link environmental improvements at different scales

The most convincing argument for spending resources to reduce current greenhouse gas emissions is that the benefits from reduced impacts of climate change will be greater than the costs. Among the important benefits are avoiding or reducing the direct impacts on human health that might accompany climate change, and avoiding ecosystem effects that could have significant indirect impacts on humanity. Reducing current greenhouse gas emissions could generate long-term health benefits such as fewer malarial mosquitoes, fewer extreme climatic events (including tropical cyclones and heat episodes), shifts in atmospheric composition towards less pollution, reduced impacts on food production, and decreasing refugee populations from reduced sea level rise and other factors (McMichael and others, 1996). Similarly, reduced greenhouse gas emissions could lead to less damage to important ecosystems.

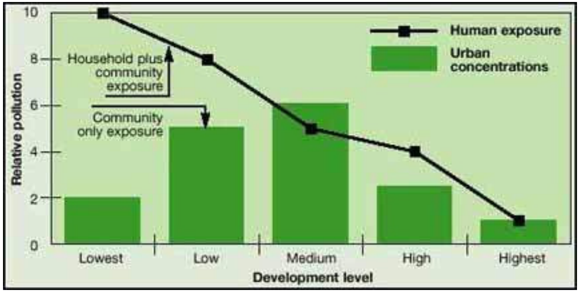
Each step of the causal chain from greenhouse gas emissions to global warming to direct effects on health and ecosystems is not understood with certainty, however. As a result of that uncertainty, many observers are still unconvinced that the potential but distant health and ecosystem benefits justify large spending on greenhouse gas reductions today. Although the consensus scientific opinion (as represented by the IPCC) is that such ill effects are likely if current trends in greenhouse gas emissions continue, scepticism holds

back international agreements to significantly alter current greenhouse gas emissions. This is particularly so in developing countries, which must contend with many urgent problems related to human health and welfare. But it also applies to many groups in industrialised countries.

BOX 3.8. THE KUZNETS ENVIRONMENTAL CURVE: FACT OR FALLACY?

An illustration of the environmental risk transition between scales is seen in the figure below, which plots the relationship between urban PM_{10} (particulates smaller than 10 microns in diameter) concentrations and countries' development status as indicated by their UNDP human development index (a function of income, literacy, and life expectancy). Superficially, urban PM_{10} concentrations seem to follow the so-called Kuznets environmental curve-that is, they first rise during development, reach a peak, then decline (Grossman and Kruger, 1994). (The curve is named after the Nobel Prize-winning economist Simon Kuznets, who noted in the 1960s that many countries go through a period of increasing income inequality during development before becoming more equitable.) From the standpoint of the risk transition, however, this curve only addresses the community scale in the form of ambient urban air pollution. It ignores what happens at other scales, which may be more important.

The main concern about particulates is their impact on human health. From a health standpoint, it is not so much urban concentrations that are critical but human exposure, which is a function of not only where the pollution is but also where the people are. Because people spend a lot of time indoors and in other places close to local sources of pollution, exposure patterns can be quite different from patterns of ambient pollution. Thus, as shown in the figure, because household sources dominate exposure in the poorest countries, the pattern of exposures is quite different than that of urban ambient concentrations. Instead of rising and then falling, exposures decline continuously-illustrating that the Kuznets curve misses the actual trend, which is that overall risk tends to fall even though community risk rises, because of the shift of household to community impacts (Smith, 1993)



Urban particulate concentrations, human exposure, and national development

BOX 3.9. WIN-WIN CROSS-SCALE ENVIRONMENTAL STRATEGIES IN CHINA

A recent study found that greenhouse gas reductions resulting from changes in energy use would generally be accompanied by substantial near-term human health benefits in China (Wang and Smith, 1998). But the level of health benefits would vary greatly with the choice of energy technologies and sectors. Shifting from conventional coal-fired power plants to natural gas, for example, has larger health benefits than reducing global warming potential, while shifting from coal power to hydropower results in the same percentage reduction in emissions of health-damaging pollutants and greenhouse gases.

This variation in health benefits is even larger between sectors. The conservative estimates in the study show that the health benefits of a 1 tonne reduction in particulate emissions from household stoves are at least 40 times those from reduction of the same amount from coal-fired power plants. In terms of human health benefits, the choice of energy technologies and sectors in which to conduct greenhouse gas reduction efforts is more important than choice of a particular target for greenhouse gas reduction.

In many developing country households the particulate emissions from burning unprocessed solid fuels (biomass and coal) routinely exceed by an order of magnitude or more the safe levels specified by the World Health Organization. Thus a 15 percent reduction by 2020 in Chinese households' greenhouse gas emissions below the 'business-as-usual' level would avoid more than 100,000 premature deaths a year. Reduced emissions of health-damaging pollutants through household improvements in energy efficiency and changes in the fuel mix would also reduce greenhouse gases. Thus reducing greenhouse gas emissions at the global scale could significantly ease human health impacts at the household scale.

On a national scale, a 15 percent reduction in greenhouse gases below business as usual by 2020 would result in 125,000-185,000 fewer premature deaths in both the power and household sectors, depending on different control pathways (energy efficiency or fuel substitution). This range represents about 1 percent of the total mortality in China by 2020. Other countries with high household and industrial dependence on solid fuels, such as India, could be expected to see similar benefits.

Acid deposition is increasingly serious in many regions, damaging forests, crops, and aquatic animals. The RAINS-ASIA model (Foell and others, 1995) indicates that large areas in Asia have acidity levels in excess of critical loads due to sulphur deposition, posing significant environmental threats to a variety of ecosystems. The model also projects that sulphur deposition will eventually exceed critical loads by a factor of more than 10 in many parts of Asia as a result of the growing dependence on fossil fuels. This increase will threaten the sustainability of many natural and agricultural ecosystems in the region. The model develops a series of emission control scenarios and shows that energy efficiency and fuel substitution pathways, which are also the main mitigation options for greenhouse gases, can be important instruments for controlling acid-forming emissions

One approach to resolving this impasse is to promote 'no regrets' scenarios for reducing greenhouse gases. Such scenarios achieve significant near-term benefits for human health and ecosystems in addition to reducing greenhouse gases. Thus such immediate actions

can be justified even if climate sensitivity to additional greenhouse gases turns out to be less than is now thought (Repetto and Austin, 1997). Examples of such near-term benefits include the environmental and energy-security advantages that would accrue through less dependence on fossil fuels, and the human welfare benefits that could emerge if an international greenhouse gas control regime were oriented towards assisting economic development and reducing vulnerability among poor populations (Hayes and Smith, 1994).

Among the significant near-term benefits of greenhouse gas reductions are the human health benefits resulting from changes in the efficiency and structure of energy use that would be a large part of most greenhouse gas reduction scenarios. Although fuel cycles have several effects on health and ecosystems-for example, through water pollution, the potential for large accidents, and occupational health and safety-the largest and most sensitive to change are probably those related to pollutant emissions from the processing and burning of fuels. The same combustion processes that produce greenhouse gas emissions such as carbon dioxide and methane also generate local and regional airborne health-damaging and acid-precursor pollutants such as particulates and sulphur oxides. Thus a reduction in greenhouse gases at the global scale, through improvements in energy efficiency and changes in the mix of fuels, can be expected to reduce health-damaging and acid-precursor pollutants as well, potentially bringing immediate environmental improvements at the household, community, and regional scales. This is a win-win strategy to link environmental improvements between scales.

The potential health benefits from reduced greenhouse gases can be estimated from the global burden of ill health from air pollution. Using airborne particulates as the indicator pollutant, the World Health Organization estimates that air pollution causes 2.7-3.0 million premature deaths a year, or 5-6 percent of global mortality (WHO, 1997). Since most of this pollution comes from the combustion of fossil and biomass fuels, which would be among the main targets of any effort to control greenhouse gases, the potential reduction in health-damaging emissions would seem to be at least as great as the target reduction in

greenhouse gas emissions. Arguably it is even greater, however, since switching from dirty, less efficient fuels (such as coal) to cleaner, more efficient fuels (such as natural gas) reduces emissions of health-damaging pollutants even more than greenhouse gas emissions. With greenhouse gas reduction targets on the order of 10-20 percent, the scale of emissions of health-damaging pollutants and associated reduction of ill health could be in the same range or somewhat higher-perhaps a 250,000-750,000 annual reduction in premature deaths world-wide.

To more accurately estimate these near-term health benefits, it is necessary to link each technological option in a particular greenhouse gas reduction scenario with the accompanying reduction in emissions of health-damaging pollutants. The health impact of these emissions, however, depends on the sector of the economy in which they are taken. This is because the degree of human exposure created by a unit of emissions of health-damaging pollutants depends on where they are released relative to where people spend time, their 'exposure effectiveness'. Thus a tonne of emissions averted in the household or transportation sectors close to where people spend much of the time will generally cause a much greater reduction in human exposure (and improvement in health) than a tonne averted in the industrial or power sectors. An example of such a win-win possibility in China is presented in box 3.9.

On a community scale, more than 1.1 billion people living in urban areas world-wide are exposed to particulate or sulphur dioxide levels in excess of World Health Organization guidelines (Schwela, 1995). These pollutants are released by industrial, household, and transportation energy use. Air pollution is particularly severe in megacities. Again, reducing greenhouse gas emissions by changing energy use and structure can also reduce the particulate and sulphur dioxide emissions that cause severe urban air pollution.

The same principle applies in the cities of the industrialised world, although the scale of absolute benefits is less because air pollution levels are lower. From an economic

standpoint, however, there can still be substantial secondary benefits from greenhouse gas controls through associated reductions in health-damaging pollutants, acid precipitation, and the like. The value of these benefits could in many cases rival the costs of the greenhouse gas controls, making a win-win result (Elkins, 1996; Burtraw and Mansur, 1999).

As noted, the near-term health and ecosystem benefits of reducing greenhouse gases provide the opportunity for a true no-regrets reduction policy in which substantial advantages accrue at various scales even if the risk of human-induced climate change turns out to be less than many people now fear. Increases in energy production and end-use efficiency and changes in the mix of fuels can reduce environmental impacts at the household, community, regional, and global scales, while meeting greenhouse gas targets. To achieve these benefits effectively, however, considerations of health and other secondary benefits should be included from the start in designing greenhouse gas control strategies.

This no-regrets strategy also has important implications for emissions trading in the form, for example, of joint implementation and clean development mechanisms. Because the near-term health improvements are local, they accrue almost entirely to the nation in which greenhouse gas control projects are undertaken-unlike the benefits of greenhouse gas reductions, which accrue globally. These large local benefits may provide a significant extra incentive for other developing countries to enter into arrangements in which local greenhouse gas controls are financed externally and the emission credits are shared. Indeed, a greenhouse gas reduction strategy can be consistent with such critical national development objectives as reducing local air pollution, increasing energy efficiency, and improving social equity by providing energy services to remote areas through renewable energy.

The World Health Organization

The World Health Organization estimates that air pollution causes 2.7-3.0 million premature deaths a year, or 5-6 percent of global mortality

Assessment methods

A number of methods have been developed to compare the disparate effects of energy systems on a common basis. Here we discuss perhaps the two most common, economic valuation and fuel-cycle analysis. In both cases there is still much uncertainty and some controversy on the fundamental nature of the analyses and on the data inputs required. Thus we present these examples not as definitive, but as illustrative of the type of information they can provide.

How much is clean air worth? Because it generally becomes increasingly expensive to reduce pollution as emission controls tighten, a fundamental question is how much money each bit of emissions control is worth. If the value of averting damage were known, then the degree of control could be set such that the total cost (control cost plus residual damage cost) is minimised. Normally, the cost of control is fairly well known. Similarly, damage is fairly easy to value for simple property destruction, such as corrosion of buildings and reduction of crop yields. But valuing damage to critical ecosystems or human health is not straightforward. As a result there are no universally accepted methods.

Several approaches are used to value human health, including:

- **Human capital-the value of lost wages and associated medical costs from illness or injury and premature death.**
- **Value of statistical life-the imputed value from extrapolating human risk-averting**

behaviour. For example, if the labour market shows that inducing a worker to accept a job with an additional death risk of 1/1,000 a year requires extra wages of X dollars a year, then X multiplied by 1,000 would equal the value of a lost life.

- **Willingness to pay-in which people are asked how much they would be willing to pay to avoid certain risks. These amounts are then extrapolated to find the equivalent value of a life.**

In recent years the willingness to pay approach has become more widely used, because it holds more theoretical appeal for economists than other approaches. But beyond the obvious difficulty of finding accurate data, there are three important problems with this approach. First, measured willingness to pay can be quite different for the same issue depending on how the question is phrased, raising doubt about the measure's intrinsic utility. Second, willingness to pay to avoid a certain risk depends on the respondent's knowledge about the risk, which varies dramatically by geography, demography, education, and time, and which is quite difficult to account for in surveys. Finally, although it is clear that willingness to pay varies with income, it is not clear by how much. As people grow richer, their willingness to pay to avoid a given risk generally increases even faster. But this relationship is not clear across different periods and cultures.

Consider some examples of how willingness to pay has been used to value air pollution in developing and industrialised countries. In China, the dirtiest fossil fuel, coal is widely used, its use is expected to grow rapidly in the next few decades, and effective pollution controls are not widely used. A recent study estimated that air pollution cost China about $48 billion in 1995 (7 percent of GDP), including impacts of acid deposition as well as health effects from outdoor and indoor air pollution (World Bank, 1997). The study found that the dominant cost came from health costs for urban residents, some $32 billion (5 percent of GDP). Moreover, it projected that under business-as-usual conditions, pollution-related health costs for urban residents would increase to $98 billion by 2020 at

current income levels, or $390 billion (13 percent of GDP) with adjustments to willingness to pay related to growth in income. This is substantially more than the estimated economic damage of greenhouse gas emissions from the same facilities.

China's high pollution-related health costs are partly due to relatively limited pollution controls. Even in countries with relatively extensive pollution controls, however, pollution-related health costs can be high because aggregate energy-related emissions can be high even if emissions per unit of energy provided are low. Moreover, the willingness to pay to avoid pollution damages will be high in high-income countries. And in densely populated regions such as Europe and Japan, large populations are generally exposed to air pollution.

Recent studies in Europe have shown that health impacts dominate the external social costs of pollution, and estimate that the costs of health impacts due to fine particle air pollution are especially high (Rabl and Spadaro, 2000; Spadaro and Rabl, 1998; Spadaro and others, 1998; Krewitt and others, 1999). These economic calculations reflect recent epidemiological studies indicating that fine particles are associated with serious health effects, including premature death (see the section on community scale).

Although considerable uncertainty remains about health impacts from small particles, the economic value of these impacts is expected to be high-at least in densely populated regions of high-income countries, where large populations are exposed to air pollution that can shorten lives by a few months. These populations are willing to pay considerable amounts to avoid this life shortening. Table 3.8 presents recent estimates of the health impacts of coal and natural gas power plants equipped with the best available control technologies. For natural gas combined-cycle plants the only significant health costs are associated with nitrogen oxide emissions, and these costs are relatively low (typically about 5 percent of the electricity generation cost). But for coal the estimated health costs (mostly due to health damage from fine particle air pollutants) are large and comparable

to the electricity generation cost. These estimates are quite uncertain, however.

Table 3.9 presents estimates of health costs in France for air pollution from gasoline-fuelled cars equipped with pollution controls and for diesel-fuelled cars. The estimated health impacts, measured per litre of fuel sold, are high (though, as with power generation, quite uncertain), especially for urban driving-about twice the retail price (excluding retail taxes) for gasoline cars and 25 times the retail price for diesel cars. As in China, the economic costs of greenhouse gas emissions from European cars and power plants would seem to be much lower.

These costs will vary significantly by region depending on the mix of rural and urban driving, whether emissions are at ground level or from tall stacks, local and regional population densities, and income, which affects willingness to pay. Applying the results in table 3.9 to developing countries, where per capita income averaged about $2,800 in 1995, the imputed health costs would be 0.1-0.5 times those estimated for France when all other factors are equal, depending on how willingness to pay varies with income.

If willingness to pay continues to increase more rapidly than income, health impacts will become increasingly important for developing countries even if emission controls are put in place. That is because their income and energy consumption levels will rise more rapidly than energy consumption levels, even with emission controls in place. To illustrate, consider the WEC projection that in developing countries the number of cars will increase 6-fold between 1990 and 2020 (WEC, 1995). Even if all were gasoline-fuelled cars equipped with three-way catalytic converters, health costs in developing countries would increase to $40-120 billion in 2020, depending on the rate of increase in willingness to pay. If all cars were diesel, health costs would be six times as high. These health cost estimates do not include health impacts associated with buses, trucks, and locomotives.

TABLE 3.8. AIR POLLUTANT EMISSIONS AND ESTIMATED HEALTH COSTS FOR EUROPEAN

POWER PLANTS EQUIPPED WITH THE BEST AVAILABLE CONTROL TECHNOLOGIES

Siting	Unit health cost (cents per gram)			Emission rate (grams per kilowatt-hour)				Unit health cost (cents per k hour)			
				Pulverised coal steam-electric			Natural gas combined cycle	Pulverised coal steam-electric			
	Sulphur dioxide	Nitrogen oxides	PM_{10}	Sulphur dioxide	Nitrogen oxides	PM_{10}	Nitrogen oxides	Sulphur dioxide	Nitrogen oxides	PM_{10}	Total
Typical	1.0	1.6	1.7	1.0	2.0	0.2	0.1[a]	1.0	3.2	0.3	4.5
Urban	1.6	2.3	5.1	1.0	2.0	0.2	0.1[a]	1.6	4.6	0.5	6.7
Rural	0.7	1.1	0.5	1.0	2.0	0.2	0.1[a]	0.7	2.2	0.1	3.0

Note: These calculations were carried out as part of the European Commission's ExternE Program. Studies under the program have estimated the economic values of health impacts by assessing people's willingness to pay to avoid adverse health effects. The health cost estimates shown are median values; the 68 percent confidence interval is 0.25-4.0 times the median cost.

Source: Rabl and Spadaro, 2000.

TABLE 3.9. AUTOMOTIVE NITROGEN OXIDE AND PARTICULATE EMISSIONS AND ASSOCIATED PUBLIC HEALTH COSTS IN FRANCE

Fuel and	Fuel	Emission rate(grams	Health costs (dollar

driving environment	economy (kilometres per litre)	per kilometre)						
				Per gram		Per kilometre		
		Nitrogen oxides	Particulates	Nitrogen oxides	Particulates	Nitrogen oxides	Particulates	Tot
Gasoline								
Urban	8.7	0.68	0.017	0.022	2.750	0.015	0.047	0.0
Rural	10.3	0.79	0.015	0.027	0.188	0.021	0.003	0.0
Diesel								
Urban	10.4	0.75	0.174	0.022	2.750	0.017	0.479	0.4
Rural	12.7	0.62	0.150	0.027	0.188	0.017	0.028	0.0

Note: These calculations were carried out as part of the European Commission's ExternE Program. Studies under the program have estimated the economic values of health impacts by assessing people's willingness to pay to avoid adverse health effects. The health cost estimates shown are median values; the 68 percent confidence interval is 0.25-4.0 times the median cost. The gasoline cases are for cars equipped with catalytic converters.

Source: Spadaro and Rabl, 1998; Spadaro and others, 1998.

Health costs might end up being much higher than these estimates because real world emission levels tend to be considerably higher than regulated emission levels (Ross and others, 1995). That happens for a variety of reasons, including that regulated emissions are for well-maintained cars and that regulations tend to be for driving cycles that often do not reflect the way people actually drive.

These high estimated future health costs argue for much tighter emission controls than can be achieved with widely used current technologies. How much additional control will be needed? This is one of the critical questions for providing sustainable transport systems for the world's cities. Nevertheless, despite large uncertainties due to the willingness to pay method as well as to basic understanding of air pollution health effects, it seems safe to conclude that the economic value of air pollution abatement is substantial in developing and industrialised countries alike.

Fuel cycle analysis. Supplying modern energy often involves processes at a chain of facilities that may be quite physically distinct from one another. These processes are usually referred to as 'fuel cycles', although they rarely rely on any cycling. Comparisons based on fuel cycles are useful for organising impact analyses of energy supply and demand.

Consider the fuel cycle supporting the operation of an electric appliance. It may involve a coal mine, coal washery, coal train, coal power plant, and transmission lines, as well as ancillary facilities such as coal tailings piles, washery settling lagoons, and power-plant ash disposal. Each of these facilities has environmental impacts and is, in a sense, 'switched on' whenever the appliance is used even though it may be physically unconnected and thousands of kilometres away. Furthermore, environmental impacts occur not only during normal operations of these facilities, but also during their construction, repair, and dismantling-what is called their life cycle. Even non-fuel energy systems, such as photovoltaic power plants, have fuel cycles and life cycles, including the harvesting, processing, and transport of the materials used to construct the facility.

Comparative risk assessment is one term used for studies of the life-cycle impacts of alternative fuel cycles, such as different ways to produce electric power. Such studies are usually normalised according to an appropriate unit of energy output-for example, impacts may be scaled per kilowatt-hour or per barrel of oil equivalent. The idea is that in this way

all the impacts can be fairly compared across alternative energy systems, giving full and consistent information to decision-makers. Such studies first account for insults over the life cycle of each part of the fuel cycle, such as land used, tonnes of pollution released, long-term waste generated, water consumed, and labour required per unit of output. Then most comparative risk assessments try to convert as many insults as possible into impacts with common measures, such as deaths, injuries, illnesses, and financial damage costs. Since the occupational impacts of energy systems can be significant (see the section on workplace scale), often both public and worker risks are determined (box 3.10).

In addition to the methodological and other problems of fuel-cycle analysis and comparative risk assessment mentioned in box 3.10, there are some fundamental concerns with these kinds of comparisons that revolve around this unit of analysis-that is, the production of a certain amount of energy. For occupational impacts, for example, the number of accidents or illnesses per unit of energy output is just as much a measure of labour intensity as of safety. Indeed, from a societal standpoint, putting many people to work in low-risk activities is much better than employing a few people in high-risk activities. But both may look the same in the comparisons.

In addition, by using energy as the output measure, such analyses reveal little about the impact of such facilities on overall public health, which uses time as the risk denominator. It may be that one way of producing electricity has slightly different public health implications than another, but neither may have much significance overall or, conversely, neither may be acceptable. Entirely different kinds of analyses are needed to evaluate these kinds of questions.

Implications for the future

As noted in the introduction, there has not been space in this chapter to present what is known and suspected about the many environmental insults of different energy systems

and the resulting impacts on ecosystems and human health. But we have addressed a large fraction of the most important ones. The central task of this report is to outline the main characteristics of a sustainable energy future. Thus it is appropriate to examine the main categories of insults and impacts discussed in this chapter to see what requirements they impose on such a future.

Household scale

About half of the world's households use solid fuels (biomass and coal) for cooking and heating in simple devices that produce large amounts of air pollution. Because the pollution is released at the times and places where people spend time, the health impact is high, accounting for 4-5 percent of the global burden of disease. The chief ecosystem impact relates to charcoal production and urban fuelwood harvesting, which puts pressure on forests near cities and may account for a few percentage points of global deforestation.

It is difficult to envisage a sustainable energy future in which unprocessed solid fuels remain an important source of energy for a significant fraction of the world's households. Gases, liquids, and electricity are the main clean alternatives. Although today these alternatives mostly derive from fossil fuels, this need not be the case in the future. In the future these alternatives may be made from renewable biomass fuels such as wood and crop residues (see chapters 7, 8, and 10). Indeed, a further criterion for sustainable energy is that any biomass harvested to make household fuels should be done on a renewable basis to ease pressure on forests and other natural ecosystems.

Workplace scale

The harvesting of solid fuels (biomass, coal, uranium) creates the highest risks per energy worker and the largest impacts on the energy workforce world-wide. Risks to coal miners, for example, are many times those for the average industrial worker. To be sustainable, average miner risks will probably have to be lowered to those in the safest mines today.

It is difficult to envisage a sustainable energy future in which unprocessed solid fuels remain an important source of energy for a significant fraction of the world's households

Community scale

Fuel use is the chief cause of urban air pollution, though there is substantial variation among cities in the relative contributions of vehicles and stationary sources. Diesel-fuelled vehicles, which are more prominent in developing countries, pose a growing challenge to meeting urban health-related pollution guidelines (responsible for about 1 percent of the global burden of disease).

To be sustainable, mean urban air pollution around the world will need to be no greater than what is common in rich countries today-for example, less than 30 micrograms per cubic metre of PM_{10}. An additional requirement for sustainability is that urban ambient ozone levels not rise as vehicle fleets grow. Sufficiently clean power generation by fossil and nuclear sources is technically feasible, although costs are uncertain (see chapter 8). Similarly, hybrid vehicles are substantially cleaner than current types (see box 3.5). Achieving sustainability, however, will probably require moving most of the world's fleet to fuel cells or comparably clean systems by the middle of the 21st century.

Regional scale

The problem of regional atmospheric emissions will not go away quickly. The increasing demand for energy, especially in developing countries, will put heavy pressure on cheap

and easily obtainable fossil fuels such as coal and oil. Prospects for constraining increases in regional emissions are better for some pollutants and source types. An ambitious goal for sulphur dioxide emissions, for example, would be a 50 percent reduction world-wide by 2050. This goal could be achieved by reducing the sulphur content of fossil fuels and using emission controls on new, large power plants and industrial facilities. Switching to natural gas in developing countries would also considerably aid the achievement of this goal. Increases in sulphur dioxide emissions in the developing world will be offset by legislatively driven reductions in industrialised countries.

Nitrogen oxide emissions are a bigger problem. The expansion of transportation systems in developing countries will add to the nitrogen oxide burden from industrial production and power generation. Moreover, nitrogen oxides are much harder to control than sulphur dioxide. An ambitious goal would be to stabilise nitrogen oxide emissions at current levels by 2050. Only a major shift away from fossil fuels in all parts of the world or a shift to alternative energy carriers such as hydrogen derived from fossil fuels will enable this goal to be achieved.

Carbon monoxide emissions will likely fall significantly as developing countries move away from biofuels and as automobiles become more efficient world-wide. Emissions of volatile organic compounds from energy sources will likely be reduced, but large increases can be expected from non-energy sources, particularly as the commercial and residential use of solvents increases in the developing world. Holding global emissions of volatile organic compounds to a 20-50 percent increase by 2050 will be a challenge. The faster that clean and efficient vehicles and fuels can replace current vehicles and fuels, the greater will be the reduction in emissions of nitrogen oxides, carbon monoxide, and volatile organic compounds.

BOX 3.10. COMPARATIVE RISK ASSESSMENT USING FUEL-CYCLE ANALYSIS

A number of concerns drive the need to assess the environmental and human health damage associated with electricity production. These include informing utility planning decisions in terms of total social costs, enlightening cost-benefit analyses of pollution mitigation technologies, facilitating formulation of regulatory procedures, and delineating the secondary benefits of reducing greenhouse gas emissions. Attempts to quantify damages incurred by electricity generation technologies date to the 1970s and are known as fuel-cycle analyses or comparative risk assessments. Most fuel-cycle analyses have been undertaken in industrialised countries, but a few have considered electricity production in developing countries (such as Lazarus and others, 1995).

Fuel-cycle analyses attempt to account for all damages caused by physical and chemical processes and activities undertaken to generate electricity from a specific fuel or resource, from fuel acquisition to waste disposal in a steady-state operations approach, or from construction to decommissioning in a facility lifetime approach. Because different insults exert their impacts over different temporal and spatial scales, the geographic extent and time horizon of an analysis must be carefully defined to cover all significant impacts. Contemporary fuel-cycle analyses generally follow a damage function or impact pathway approach whereby dominant impacts are identified; stresses (incremental population exposures to air pollution, occupational hazards, transportation risks) are quantified; stresses are translated to impacts, typically through exposure-response functions or actuarial data; and impacts are quantified and aggregated in terms of the study's chosen metric (ORNL and RFF, 1992; Curtiss and Rabl, 1996). The study design stage entails a number of choices on impacts to be considered (public and occupational health, ecological damage, agricultural losses, material corrosion, visual amenity), temporal and spatial assessment boundaries, models and hypotheses for analysis, economic parameters such as the discount rate, and the treatment of accident scenarios for which no actuarial data exist (such as expected and worst case).

A fuel-cycle analysis typically results in a list of impacts per unit of output in the form of premature deaths, ecosystem damage, global warming, and the like. To provide a common metric for comparison, many studies then attempt to monetise these impacts. This process introduces substantially more uncertainty and controversy into the process.

Fuel-cycle analyses have typically generated ‘total cost’ figures in terms of m$ ($0.001) or mECU per kilowatt-hour, with recent (post-1990) European and U.S. estimates ranging from 0.016-80 m$ per kilowatt-hour for coal and from 0.002-23 m$ per kilowatt-hour for nuclear (Rabl and Spadaro, 2000). Given the four orders of magnitude spanned by these fuel chain damage costs, it is clear that they are sensitive to the particular designs and metrics of the studies. Accordingly, interpretation of studies’ results requires extensive supplementary information to illuminate, for example, the specific impacts assessed and the study-specific approaches to valuation of life, valuation of non-fatal outcomes, weighting of public and occupational health outcomes, and discount rates. Thus fuel-cycle analysis damage costs cannot stand alone and are difficult to compare, despite the fact that they may superficially appear to be based on comparable metrics (dollars per kilowatt-hour).

Although comparative risk assessment using fuel-cycle analysis cannot yet indicate unambiguous preferences or even readily allow for comparisons between studies, recent studies suggest that public health and occupational health effects dominate the externalities associated with the nuclear fuel chain. Health effects and global warming dominate conventional coal technologies (Rabl and Spadaro, 2000). Biomass as an energy resource is less easily characterised even in terms of dominant impacts because it is highly dispersed, the nature of its production and use is extremely site-specific, and its associated damages and benefits depend on other local activities such as agriculture (Lazarus and others, 1995). Similarly, hydroelectric utilities elude concise generalisation due to the wide range of sophistication among technologies and the site-specificity of ecological and human health risks. Fuel-cycle analyses yield widely disparate conclusions for solar thermal and dispersed photovoltaic technologies. Some studies, particularly those focusing on operation of energy systems, suggest that these solar technologies confer negligible human health and ecological risks (Rabl and Spadaro, 2000). Other studies assert that the occupational risks and short-term environmental damage associated with solar technologies can exceed those of conventional electricity generation methods (Hallenbeck, 1995; Bezdek, 1993).

Pitfalls associated with fuel-cycle analysis include the use of poorly defined or inconsistent study boundaries, confusion of average and marginal effects, underestimation of the uncertainty associated with quantification of damages, neglect or inadequate treatment of environmental stochasticity, and focus on what is easily quantified rather than on what is actually significant (Koomey, 1990).

A number of outstanding issues remain for streamlining approaches to fuel-cycle analysis. These issues include identifying the functional relations and key parameters defining uncertainty, the variation in damages with key parameters, the degree of accuracy and resolution with regard to atmospheric modelling and receptor distribution (needed to capture the site-specificity of impacts), and the magnitude of error incurred by using ‘typical’ average values rather than detailed, site-specific data (Curtiss and Rabl, 1996). In addition, metrics used in fuel-cycle analysis to deal with incommensurate impacts-such as the soiling of buildings, crop damage, and human morbidity and mortality-are not uniform between studies

A sampling of results from fuel-cycle analyses, which have been used in a variety of contexts, follows:

- An investigation of externalities of electricity production from biomass and coal in the Netherlands suggests that while average private costs for the biomass strategy assessed are projected to be about twice those for coal in 2005, internalisation of external damages and benefits would yield about equal social costs. The most important distinguishing factors between coal and biomass are differences in carbon dioxide emissions and indirect economic effects such as employment (Faaij and others, 1998).

- A comparison of fuel-intensive combustion-based utilities (coal, oil, gas, and biomass), selected renewable energy technologies (solar thermal, photovoltaic, wind, and hydroelectric), and nuclear technologies (light water reactor, fast breeder reactor, and hypothetical fusion reactor) suggests that coal inflicts the greatest delayed occupational health burden (such as disease), with a central estimate of 0.1 fatalities per gigawatt-year of electricity and an upper estimate of about 3 fatalities per GWy(e). Acute occupational risks (such as accidents) posed by combustion technologies are purported to be marginally less than those associated with renewable energy technologies-with central estimates on the order of 1 fatality per GWy(e)-but greater by an order of magnitude than those associated with fission technologies and comparable to those for fusion. In the public health domain, with central estimates of about 2 fatalities per GWy(e), coal and oil appear to confer greater delayed mortality burdens by a factor of two (relative to photovoltaic systems) to three or four orders of magnitude (relative to wind, hydroelectric, and nuclear technologies). While acute risks associated with renewable energy technologies are highly uncertain, this study places them as comparable to or somewhat higher than those associated with fuel-intensive combustion technologies, at 0.1-1.0 fatalities per GWy(e) (Fritzsche, 1989).

- A study by the Stockholm Environmental Institute suggests that in terms of greenhouse gas emissions, natural gas is preferred to residual fuel for electricity generation in Venezuela, even under the assumption of relatively high methane emissions through natural gas system losses. In this context the global warming potential per kilowatt-hour of natural gas electricity generation is projected to be 12-27 percent lower than that associated with residual fuel (Lazarus and others, 1995).

- Since the early 1990s several studies have tried to quantify greenhouse gas emissions associated with different fuel cycles (see table below). Some of the variability arises from the different conversion efficiencies of the technologies assessed-for example, biomass configurations include a wood steam boiler, an atmospheric fluidised bed combustor, and an integrated gasifier combined-cycle turbine. But methodological issues and assumptions associated with activities outside the generation stage account for a large portion of the variability. For example, one study credits product heat from cogeneration cycles for displacing greenhouse gases from gas heating systems

(Fritsche, 1992). In this framework the greenhouse gas intensity of biomass can become negative, and that of natural gas fuel cycles can be reduced 50 percent below the next lowest estimate. Among fossil fuels, the greenhouse gas intensity of natural gas is most variable, primarily due to different assumptions about methane emissions during drilling, processing, and transport. For non-fossil fuels, estimates generally span at least an order of magnitude, primarily because of the sensitivity of these cycles to assumptions on the operation life of the facility and the greenhouse gas intensity of the electric and manufacturing sectors on which equipment production depends. In addition, the hydroelectric cycle's greenhouse gas intensity is sensitive to the area of land flooded and, for projects with multiple generating units per reservoir, the boundary of the system considered

Greenhouse gas emission intensities for selected fuels (grams of carbon dioxide equivalent per kilowatt-hour)

Conventional coal	Advanced coal	Oil	Gas	Nuclear	Biomass	Photovoltaic	Hydroelectric	Wind
960-1,300	800-860	690-870	460-1,230[a]	9-100	37-166[a]	30-150	2-410	11-75

Note: These estimates encompass a range of technologies and countries as described in Pearce and Bann, 1992; Fritsche, 1992; Yasukawa and others, 1992; ORNL and RFF, 1992-98; Gagnon and van de Vate, 1997; and Rogner and Khan, 1998.

a. Natural gas and biomass fuel cycles were also analysed in cogeneration configurations, with product heat credited for displacing greenhouse gas emissions from gas heating systems. That approach reduced greenhouse gas emissions to 220 grams of carbon dioxide equivalent per kilowatt-hour for natural gas and -400 for biomass (Fritsche, 1992). Other cycles could incorporate cogeneration and be analysed in this manner.

It seems that acid deposition world-wide will increasingly become a nitrogen oxide (and possibly an ammonia) problem rather than a sulphur dioxide problem. On balance, reductions in acidification in Europe and North America are likely to continue, but hotspots of damage in the developing world (such as southwestern China) may persist for years and worsen. Regional ozone will increasingly be the biggest problem because of the expected difficulties in mitigating emissions of nitrogen oxides and volatile organic compounds, the two main precursors of ozone. Only small improvements in regional ozone levels may occur in North America and Europe in the next 10-20 years. And considerable deterioration is likely in Asia, Africa, and Latin America, endangering human health and agricultural production.

Large dams will continue to provide potential for significant benefits and severe environmental impacts, depending on their location and design. For sustainability, much better evaluation will be needed to maximise the benefits and minimise the environmental impacts.

Global scale

Energy systems generate two-thirds of human-caused greenhouse gases. Thus energy use is the human activity most closely linked to the potential for climate change. Climate change is feared to entail significant direct impacts on human health as well as on Earth's ecosystems. As noted, there has been a tendency for environmental problems at the local level to be solved partly by pushing off the impacts to larger scales. Greenhouse gases and their potential for global climate change represent the final and, in many ways, most challenging of the stages. Although there are promising technologies for fossil systems that capture and sequester the greenhouse gases resulting from combustion, as well as fossil, nuclear, and solar systems releasing no greenhouse gases, their prospects are not entirely understood (see chapters 7 and 8).

It is difficult to define a sustainable level of greenhouse warming above the natural background. Achieving something akin to the natural background, on the other hand, will not be possible for many centuries, barring major, unprecedented, and unforeseen technical breakthroughs, global catastrophes, or changes in human behaviour. What then, might be considered a workable definition of 'sustainable' for the climate change impacts of the world energy system?

The coming climate change can be considered in two parts: magnitude (total warming) and rate (annual increase). Some types of impacts are more sensitive to one than the other. For example, sea level rise is more sensitive to magnitude, and ecosystem damage is more sensitive to rate. Perhaps the most worrisome aspect of human-engendered warming, however, is that it threatens to cause warming at rates completely unprecedented in Earth's recent geologic history. The magnitude of potential change is somewhat less unprecedented. Thus it may be reasonable to establish a somewhat less stringent definition of sustainability for greenhouse gas emissions-one that calls for stabilising atmospheric levels as quickly as possible, recognising that the resulting levels (and their warming) will be considerably higher than the natural background.

Achieving stable atmospheric levels during the 21st century will require bringing human greenhouse gas emissions to annual rates substantially below those today. Doing so will not be easy. Indeed, it will require major commitments of resources and political will (see the section on the global scale and chapter 9). The longer such efforts are delayed, the higher and longer will be the eventual stable warming level and accompanying impacts.

Reaching emission levels in 2050 below those in 2000 will probably require annual declines in energy intensity of at least 1.4 percent and in carbon intensity of energy of at least 0.4 percent. With the assumptions in table 9.1, even these major accomplishments would still allow emissions growth of 0.4 percent a year to 22 percent above 2000 emissions by 2050. With such modest growth, however, and 50 years of experience

promoting efficient and low-carbon energy sources, it might be possible to achieve emissions below 2000 levels within a few years after 2050.

Cross-scale

There are important opportunities for 'no regrets' strategies that achieve benefits at more than one scale. For example, if greenhouse gas controls are targeted towards reducing solid fuel use in households and in other energy systems with large health impacts (such as vehicle fleets), significant improvements can occur at the local, community, and global scales. Fine particles are generated and have impacts at all scales, so control measures will benefit from integrated approaches. Similarly, the regional impacts from sulphur and nitrogen emissions can be reduced in conjunction with control efforts at the community and global scales. Much additional effort is needed to identify environmental control pathways that optimise these multiple benefits.

Conclusion

Impacts other than those discussed in this chapter need to be considered, particularly in local situations. But if the environmental insults and their ecosystem and health impacts focused on here were controlled as indicated, the world would have moved most of the way towards a sustainable energy system.

Among the other impacts requiring careful consideration are the relationships between energy systems and military, political, and economic security-the subjects of the next chapter.

Notes

1. *Insult* is defined here as the physical stressor (such as air pollution) produced by an energy system. *Impact,* in contrast, is defined as the potential negative (or positive)

outcome (such as respiratory disease or forest destruction) affecting humanity. As with other useful terms (diagnosis, prognosis, pathology) the term insult is borrowed from medicine, where it is defined as "a generic term for any stressful stimulus, which under normal circumstances does not affect the host organism, but may result in morbidity when it occurs in a background of pre-existing compromising conditions" (Segen, 1992). It has been used in environmental discussions, however, since at least the mid-1970s (see Ehrlich and others, 1977).

2. Modern fuels involve extensive fuel cycles with relevant environmental impacts and energy efficiencies at several points. The air pollution exposures per meal are still lower than that from solid fuels, however.

3. The burden of disease refers to the total healthy life years lost due to this risk factor. It is composed of two parts that are added together: life years lost to deaths and life years lost to diseases and injuries weighted by a severity factor.

4. These include the main gaseous pollutants as well as particulates. For lead emissions, the overall reduction in hazard per vehicle mile was about 75 percent (US Census Bureau, 1996; USEPA, 1996).

5. PM_{10} are particles less than 10 microns (millionths of a meter) in size, which penetrate deeper into the respiratory system than larger particles.

6. The World Commission on Dams, which began deliberating in 1998, is publishing its reports in mid-2000 (WCD, 1999). These will include 8-10 case studies examining social, economic, environmental, energy, financial, managerial, and other aspects plus a database of 150 dams in different countries.

7. This section draws heavily on IPCC (1996a, b). The IPCC was established by the World Meteorological Organization and United Nations Environment Programme in 1988 to

assess the scientific, technological, economic, and social aspects of anthropogenic climate change. Some 2,000 scientists and other specialists from more than 40 countries served as authors and reviewers of the 17 volumes of exposition and analysis issued by the IPCC through 1996. The IPCC's first assessment report, completed in late 1990, served as the basis for the negotiations of the United Nations Framework Convention on Climate Change, concluded in 1992 and discussed below.

8. The mean global surface temperature of the Earth is about 15 degrees Celsius (59 degrees Fahrenheit). Without greenhouse gases, it would be -18 degrees Celsius (0 degrees Fahrenheit).

9. Combustion emits water vapour and carbon dioxide in comparable quantities. But the rate of water addition to the global atmosphere by combustion is tens of thousands of times smaller than the rates of addition and removal by evaporation and precipitation. And because the added water remains in the atmosphere only a few days, these human additions cause at most local effects and no long-term build-up. In contrast, the quantity of carbon dioxide added by combustion is only about 10 times smaller than what is added and removed by natural photosynthesis and decomposition, and a large part of the anthropogenic increment remains in the atmosphere for decades. Thus it has time to become uniformly distributed around the globe, irrespective of where it was emitted, and to accumulate over long periods (as long as the sum of the natural and anthropogenic addition rates is greater than the removal rate).

10. There is no net accumulation of carbon dioxide in the atmosphere from combustion of wood and other biomass fuels, as long as new plant growth replaces what is burned. This is because a growing plant removes from the atmosphere exactly as much carbon dioxide as is released when the plant decomposes or burns. When new growth does not replace what is burned or decomposed, as in deforestation, a net addition of carbon dioxide to the atmosphere results. (See the section on greenhouse gas emissions at the household scale,

for a discussion of non-carbon dioxide greenhouse gas emissions from incomplete biomass combustion.)

11. Feedbacks are phenomena wherein the consequences of a disturbance act back on its cause, making the disturbance either bigger (positive feedback) or smaller (negative feedback) than it started out.

12. The first and longest-running series of measurements was initiated by Charles Keeling at a monitoring station atop the Mauna Loa volcano on the island of Hawaii.

13. The main such terrestrial ‘sinks’ for atmospheric carbon are in the Northern hemisphere (see Houghton, 1996; Fan and others, 1998).

14. Particles in the atmosphere exert both cooling and warming effects on the Earth’s surface temperature, depending on the characteristics of the specific particles in terms of absorption and scattering of incoming solar and outgoing terrestrial radiation, and on the roles of different particles in cloud formation. Averaged over the globe and the different types of anthropogenic particles, the net effect is cooling.

15. Because particulate matter and its gaseous precursors have much shorter residence times in the atmosphere than any of the major greenhouse gases, its offset of part of the greenhouse effect will shrink in line with declining particulate and precursor emissions.

16. This range corresponds to 0.54-1.08 degrees Fahrenheit, but the two-significant-figure precision resulting from applying the exact conversion (1 degree Celsius = 1.8 degrees Fahrenheit) is illusory. The warming is not uniform, however, being generally greater near the poles than near the equator. And because of the complexity of the heat transfer processes of the climatic system, some regions may get colder even as the globe gets warmer on average.

17. The most sophisticated models demonstrate the fundamental soundness of their representations of global climatic processes by simulating quite accurately the undisturbed climate of the planet in respects such as the variation of geographic patterns of temperature and precipitation with the changes of the seasons.

18. Temperatures would continue to rise thereafter, even in the cases in which the atmospheric concentrations of greenhouse gases had been stabilised by then, because of the climate-response lag time caused by the thermal inertia of the oceans.

19. *Non-linear* means that small disturbances can have large consequences. *Forcing* is the technical term for an externally imposed disturbance, such as a change in greenhouse gas concentrations. An example of a potential positive feedback on global warming from terrestrial ecosystems is that the warming could increase the rate of release of greenhouse gases into the atmosphere from decomposition of dead organic matter in forests and swamps.

20. The discussion here is drawn from a treatment prepared by one of the authors (Holdren) for the report of the Panel on International Cooperation in Energy Research, Development, Demonstration, and Deployment, President's Committee of Advisors on Science and Technology (PCAST, 1999).

21. See IPCC (1996b). Both trends-an increase in rainfall and an increase in the fraction of it occurring in extreme events-have been convincingly documented for the period since 1900 in the United States (Karl and Knight, 1998).

22. The improvements in agricultural productivity foreseen for some regions by the IPCC are due partly to carbon dioxide fertilisation of plant growth, partly to increased water availability from increased precipitation, and partly to technological change. Although the IPCC discusses at length how plant pests and pathogens could prove increasingly problematic in a greenhouse gas-warmed world, these possibilities do not seem to be fully

reflected in the productivity projections.

23. This section draws heavily on material written by one of the authors (Holdren) for the report of the Panel on Federal Energy Research and Development, President's Committee of Advisors on Science and Technology (PCAST, 1997).

24. Annex 1 countries, as defined in the UNFCCC, are OECD countries plus the countries of Eastern Europe and some of those of the former Soviet Union (the Baltics, Belarus, Russia, Ukraine).

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Chapter 4. Energy Security

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ABSTRACT

Energy security - the continuous availability of energy in varied forms, in sufficient quantities, and at reasonable prices - has many aspects. It means limited vulnerability to transient or longer disruptions of imported supplies. It also means the availability of local and imported resources to meet, over time and at reasonable prices, the growing demand for energy. Environmental challenges, liberalisation and deregulation, and the growing dominance of market forces all have profound implications for energy security. These forces have introduced new elements into energy security, affecting the traditionally vital role of government.

In the past, and especially since the early 1970s, energy security has been narrowly viewed as reduced dependence on oil consumption and imports, particularly in OECD and other major oil-importing countries. But changes in oil and other energy markets have altered that view. Suppliers have increased, as have proven reserves and stocks, and prices have become flexible and transparent, dictated by market forces rather than by cartel arrangements. Global tensions as well as regional conflicts are lessening, and trade is flourishing and becoming freer. Suppliers have not imposed any oil sanctions since the early 1980s, nor have there been any real shortages anywhere in the world. Instead, the

United Nations and other actors have applied sanctions to some oil suppliers, but without affecting world oil trade or creating shortages. All this points to the present availability of abundant oil supplies at all times, an availability that has been greatly enhanced thanks in large part to technological advances. Moreover, in today's market environment energy security is a shared issue for importing and exporting countries.

Energy security can be ensured through local adequacy - abundant and varied forms of indigenous energy resources. But for countries that face local shortages, as most do, energy security can be enhanced through:

- **The ability, of the state or of market players, to draw on foreign energy resources and products that can be freely imported through ports or other transport channels and through cross-boundary energy grids (pipelines and electricity networks). This is increasingly aided by energy treaties and charters and by investment and trade agreements.**

- **Adequate national (or regional) strategic reserves to address any transient interruption, shortages, or unpredictably high demand.**

- **Technological and financial resources and know-how to develop indigenous renewable energy sources and domestic power generating facilities to meet part of local energy requirements.**

- **Adequate attention to environmental challenges.**

- **Diversification of import sources and types of fuels.**

Energy security can also be greatly enhanced by energy conservation and efficiency measures, because reducing energy intensity will reduce the dependence of the economy on energy consumption and imports.

But while all this is very encouraging, new threats to energy security have appeared in recent years. Regional shortages are becoming more acute, and the possibility of insecurity of supplies - due to disruption of trade and reduction in strategic reserves, as a result of conflicts or sabotage - still exists, although it is decreasing. All this points to a need to strengthen global as well as regional and national energy security. This chapter discusses some means and instruments for doing so.

The world has generally seen considerable development and progress in the past 50 years. Living standards have improved, people have become healthier and longer-lived, and science and technology have considerably enhanced human welfare. No doubt the availability of abundant and cheap sources of energy, mainly in the form of crude oil from the Middle East, contributed to these achievements. Adequate global energy supplies, for the world as a whole as well as for individual countries, are essential for sustainable development, proper functioning of the economy, and human well-being. Thus the continuous availability of energy - in the quantities and forms required by the economy and society - must be ensured and secured.

Energy security - the continuous availability of energy in varied forms, in sufficient quantities, and at reasonable prices - has several aspects. It means limited vulnerability to transient or longer disruptions of imported supplies. It also means the availability of local and imported resources to meet growing demand over time and at reasonable prices.

Beginning in the early 1970s energy security was narrowly viewed as reduced dependence on oil consumption and imports, particularly in OECD and other major oil-importing countries. Since that time considerable changes in oil and other energy markets have altered the picture. Suppliers have increased, as have proven reserves and stocks, and prices have become flexible and transparent, dictated by market forces rather than by cartel arrangements. Global tensions and regional conflicts are lessening, and trade is

flourishing and becoming freer. Suppliers have not imposed any oil sanctions since the early 1980s, nor have there been any real shortages anywhere in the world. Instead, the United Nations and other actors have applied sanctions to some oil suppliers, but without affecting world oil trade or creating shortages.

All this points to the present abundance of oil supplies. Moreover, in today's market environment energy security is a shared issue for importing and exporting countries. As much as importing countries are anxious to ensure security by having sustainable sources, exporting countries are anxious to export to ensure sustainable income (Mitchell, 1997).

However, although all these developments are very encouraging, they are no cause for complacency. New threats to energy security have emerged in recent years. Regional shortages are becoming more acute, and the possibility of insecurity of supplies - due to disruption of trade and reduction in strategic reserves, as a result of conflicts or sabotage - persists, although it is decreasing. These situations point to a need to strengthen global as well as regional and national energy security (some means for doing this are discussed later in the chapter). There is also a need for a strong plea, under the auspices of the World Trade Organization (WTO), to refrain from restrictions on trade in energy products on grounds of competition or differences in environmental or labour standards.

Environmental challenges to sustainable development are gaining momentum and have profound implications for energy security, as do the current trends of liberalisation, deregulation, and the growing dominance of market forces. These forces have introduced new elements into energy security, affecting the traditionally vital role of government, as described below. They also have consequences for medium-size companies and individual consumers, who may be tempted by cheap competitive prices and lack of information to sacrifice, sometimes temporarily, supply security.

Energy insecurity

Energy insecurity and shortages handicap productive activities and undermine consumer welfare.

Energy has always been important to humanity. But its importance is increasing each year. Interruptions of energy supply - even if brief - can cause serious financial, economic, and social losses. Some energy products and carriers have become absolutely essential for modern life and business. Interruption of electricity supply can cause major financial losses and create havoc in cities and urban centres. The absolute security of the energy supply, particularly electricity, is therefore critical. With the widespread use of computers and other voltage- and frequency-sensitive electronic equipment, the quality of supply has also become vital. In the electricity supply industry, a significant share of investment goes into reserve generating plants, standby equipment, and other redundant facilities needed to protect the continuity and quality of supply.

Energy insecurity and shortages affect countries in two ways: they handicap productive activities, and they undermine consumer welfare. Energy insecurity discourages investors by threatening production and increasing costs. Shortages in electricity supplies (as in many developing countries) require more investment for on-site electricity production or standby supplies. For small investors, the cost of operation is increased, since electricity from private small-scale generation is more expensive than public national supplies. Electricity interruptions at home cause consumers great inconvenience, frustration, and loss of productivity, sometimes threatening their well-being.

For any economy, an unreliable energy supply results in both short- and long-term costs. The costs are measured in terms of loss of welfare and production, and the adjustments that consumers (such as firms) facing unreliable fuel and electric power supplies undertake to mitigate their losses. Interruptions in supply may trigger loss of production, costs related to product spoilage, and damage to equipment. The extent of these direct

economic costs depends on a host of factors, such as advance notification, duration of the interruption, and timing of the interruption, which relates to the time of day or season and to the prevailing market conditions and demand for the firm's output. These direct costs can be very high. In addition, the economy is affected indirectly because of the secondary costs that arise from the interdependence between one firm's output and another firm's input.

New dimensions and challenges to energy security

Energy security needs to be investigated at several levels: globally, to ensure adequacy of resources; regionally, to ensure that networking and trade can take place; at the country level, to ensure national security of supply; and at the consumer level, to ensure that consumer demand can be satisfied. At the country level, energy security is based on the availability of all energy consumption requirements at all times from indigenous sources or imports and from stocks. Normally in most countries, this is a state responsibility. However, markets in some OECD countries are increasingly shouldering part of this responsibility. To ensure energy security, projections, plans, and supply arrangements should look beyond short-term requirements to medium- and long-term demand as well.

With the increasing deregulation and competition among private and independent suppliers, supply security at the consumer level can become more vulnerable and correspondingly more important in some cases. Consumer demand for energy services can be met by different suppliers competing to deliver different forms of energy at different prices, while the consumer remains unaware of the degree of supply security.

As explained above, environmental challenges, deregulation, and market forces have introduced new players to the energy security scene. This chapter considers energy security at the national (and regional) level as well as consumer security in terms of energy services. In most countries these two levels of security are one and the same. But

in some OECD countries, with markets and competition emerging at the consumer level, the two may diverge. The chapter also covers the geopolitical aspects of energy security as well as the limitations of the resource base and other factors that may affect long-term energy security.

Of all energy sources, crude oil and its products are the most versatile, capable of meeting every requirement for energy use and services, particularly in transport. The other fossil fuels, coal and natural gas, are well suited for electricity production and such stationary uses as generation of heat and steam. Coal, increasingly used for electricity production, requires relatively expensive clean technologies, and treatment for liquefaction and gasification to make it more versatile. Natural gas also requires expensive infrastructure, and special treatment to make it useful for transport. Hydropower, newer renewable resources such as wind and photovoltaics, and nuclear energy have limited use beyond electricity production.

Given the versatility of crude oil and its products and the limitations of other energy sources, energy security depends more than anything else on the availability of crude oil in the required amounts (by ship or pipeline) to any importing country in the world. Thus, although energy security has to be interpreted more broadly than in the past, the uninterrupted supply of crude oil in the required amounts and at reasonable prices will continue to be the most important determinant of energy security. Uninterrupted supply - of oil and other forms of energy - includes uninterrupted transit through third countries. As the chapter details later, work is under way, through the Energy Charter Treaty, to improve security for exporters and importers and to promote a favourable climate for investments in upgrading and building new and diversified pipeline routes.

Reducing energy intensity will reduce the dependence of the economy on

energy consumption and imports.

Security of electric power supply

Chronic energy shortages and poor security of the electric power supply trigger long-term adjustments. If firms expect shortages and unreliable service to persist, they will respond in one or more ways. The most common long-term adjustment by commercial consumers and small industrial firms is to install back-up diesel generator sets. It has been estimated that in many developing countries such standby generation on customer premises accounts for 20 percent or more of the total installed generating capacity (USAID, 1988).

The shortages and inadequate maintenance of the grid also add to poor security. In some developing countries half the public electricity supply is inoperable at any given time. Many manufacturing firms have had to purchase their own generators to meet their demand for electricity. In Nigeria about 92 percent of firms surveyed in the mid-1990s had their own generators. This purchase added to their fixed costs, raised production costs, and tended to discourage new investments. For small firms, the investment in generating capacity represented almost a quarter of their total investment, and for large firms, a tenth (ADB, 1999). Moreover, in many developing countries the electric power system losses (technical and non-technical) are very high, exceeding a quarter of generation in some and as much as half in a few.

Shortages of electric power and supply interruptions are not uncommon, particularly in many developing countries. They occur for two main reasons:

- **System inadequacy - shortfalls of delivered electricity under even the best conditions in the electric power system. Such shortfalls, most common in developing countries, usually occur because of an inadequate number of generating facilities capable of meeting peak demand and limitations in the transmission and**

distribution system, particularly to rural areas.

- **Supply insecurity - unreliability of supply due to non-availability of generating plants or breakdowns in the transmission and distribution system. This can occur in varying degrees in any power system in the world.**

To ensure system adequacy - the ability of a power system to meet demand and deliver adequate electricity to consumers - requires investment. Most investments in electric power security are meant to reduce the likelihood of shortages and maintain and improve reliability. Most shortages occur as a result of growth in demand, which necessitates expanding generation capacity and strengthening networks. But even with large investments, interruptions are inevitable. And the costs of improving continuity of supply can become very high once a certain level of reliability has been reached.

The function of the electric power system is to provide electricity as economically as possible and with an acceptable degree of security and quality. The economics of electric power security (reliability) involve striking a reasonable balance between cost and quality of service. This balance varies from country to country, and from one category of consumers to another.

To improve supply security, countries invest in redundant facilities. These investments, in reserve generating capacity and other network facilities, normally amount to at least a third of the investments by the electricity supply industry. Low-income developing countries cannot afford such huge investments, leading to supply insecurity. Thus in many developing countries, electricity supplies are enhanced by standby plants on consumer premises. Many industries and commercial outlets have to spend heavily on in-house generation or standby plants to attain a reasonable standard of continuity. This greatly increases the cost of attaining supply security and places an added burden on the limited economic resources of these countries.

Supply interruptions occur not only because of shortages in generating plants or limitations in the grid. They are also attributed to inadequate maintenance due to lack of skilled staff or shortage of spare parts. Attaining a reasonable standard of performance in developing countries' public systems is essential not only to improve electricity supply security but also to limit the wasted resources in standby plants and reserve generating capacity. This can be achieved through proper planning of the system and by investing in training and maintenance rather than only in system expansion.

The cost of insecurity of the electricity system in developing countries varies by country depending on the extent of electrification and quality of the supply. However, in industrialised countries the costs of supply insecurity for non-deferrable economic activities are huge. In the United States it was estimated that these costs might exceed $5 billion a year (Newton-Evans Research Company, 1998). Most of these costs are borne by industrial and commercial consumers (box 4.1).

Routes to enhanced energy security

Energy security can be ensured by local adequacy - abundant and varied forms of indigenous energy resources. In the case of local shortages, which occur in most countries, energy security can be enhanced through:

- **The ability, of the state or of market players, to draw on foreign energy resources and products that can be freely imported through ports or other transport channels and through cross-boundary energy grids (pipelines and electricity networks).**

- **Adequate national (or regional) strategic reserves to address any transient interruption, shortages, or unpredictable surge in demand.**

- **Technological and financial resources and know-how to develop indigenous renewable sources and power generating facilities to meet part of local energy**

requirements.

- **Adequate attention to environmental challenges.**

Energy security can also be enhanced through energy conservation and efficiency measures. Reducing energy intensity will reduce the dependence of the economy on energy consumption and imports.

To achieve energy security requires first of all ensuring global energy adequacy - the existence of enough energy resources, or other prospects, to meet long-term world energy needs.

Energy adequacy

Although energy resources are examined in detail elsewhere in this report (see chapter 5), a quick review is provided here because energy security depends, to a great extent, on the availability of an adequate resource base. The resource base is the sum of reserves and resources. Reserves are occurrences (of all types and forms of hydrocarbon deposits, natural uranium, and thorium) that are known and economically recoverable with present technologies. Resources are less certain, are not economically recoverable with present technologies, or are both. In the future, with advances in technology and geophysics, many of today's resources are likely to become reserves (McKelvey, 1972).

Most of the world's future energy requirements, at least until the middle of the 21st century, will have to be met by fossil fuels (figure 4.1). Many attempts have been made to assess the global fossil fuel resource base. Table 4.1 shows the results of two.

BOX 4.1 VALUING THE COST OF ELECTRICITY SUPPLY SECURITY

The cost of electricity to a consumer - the consumer's valuation of the electricity supply (ignoring consumer surplus) - equals payments for electricity consumed plus the economic (social) cost of interruptions.

Supply insecurity causes disutility and inconvenience, in varying degrees and in different ways, to different classes of consumers - domestic, commercial, and industrial. The costs and losses (L) for the average consumer from supply interruptions are a function of the following:

- Dependence of the consumer on the supply (*C*).
- Duration of the interruptions (*D*).
- Frequency of their occurrence during the year (*F*).
- Time of day in which they occur (*T*).

That is, $L = C\ (D^d \times F^f, T^t)$, where *d, f,* and *t* are constants that vary from one consumer category to another.

The table shows estimates of the annual cost of electricity supply interruptions for the U.S. economy.

Economic cost of electricity supply interruptions for non-deferrable economic activities the United States, 1997

Consumer class and average duration of interruption	Cost to consumer per outage (U.S. dollars)	Cost to consumer per lengthy outage (U.S. dollars)	Estimated total annual losses (billions of U.S. dollars)
Residential (20 minutes)	0 - 20	50 - 250	0.9 - 2.7
Commercial (10 minutes)	25 - 500	5 - 20 (per minute)	2.9 - 11.7
Industrial (less than 30 seconds)	200 - 500 (small plant)	5,000 - 50,000 (per 8-hour day)	1.1 - 13.5

	1,000 - 10,000 (large plant)		

Note: Assumes nine outages a year for each class of consumer.

Source: Newton-Evans Research Company, 1998.

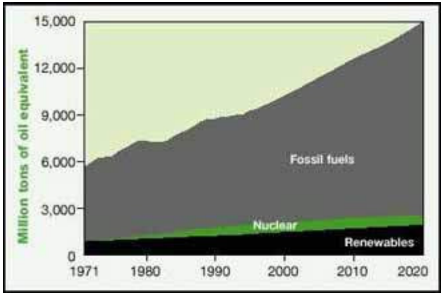

FIGURE 4.1. SHARE OF FUELS IN GLOBAL ENERGY SUPPLY, 1971 - 2020

Source: IEA, 1998.

In 1998 world consumption of primary energy totalled almost 355 exajoules, or 8,460 million tonnes of oil equivalent (Mtoe) - 7,630 Mtoe of fossil fuels, 620 Mtoe of nuclear energy, and 210 Mtoe of hydropower. To this should be added around 47 exajoules (1,120 Mtoe) of biomass and other renewables, for a total of 402 exajoules (9,580 Mtoe). The huge resource base of fossil and nuclear fuels will be adequate to meet such global requirements for decades to come.

Crude oil

Proven oil reserves have increased steadily over the past 20 years, mainly because oil

companies have expanded their estimates of the reserves in already discovered fields. This optimism stems from better knowledge of the fields, increased productivity, and advances in technology. New technologies have led to more accurate estimates of reserves through better seismic (three- and four-dimensional) exploration, have improved drilling techniques (such as horizontal and offshore drilling), and have increased recovery factors - the share of oil that can be recovered - from 30 percent to 40 - 50 percent (Campbell and Laherrere, 1998).

Huge amounts of untapped unconventional oil also exist, augmenting conventional oil reserves. Some 1.2 trillion barrels of heavy oil are found in the Orinoco oil belt in Venezuela. And the tar sands of Canada and oil shale deposits of the Russian Federation may contain 300 billion barrels of oil. The U.S. Geological Survey assessed ultimate oil and gas reserves at the beginning of 1993 (IEA 1998; WEC, 1998). The results, which tally with the World Energy Council (WEC) and International Energy Agency (IEA) figures (see table 4.1), point to ultimate conventional oil reserves of 2,300 billion barrels, with cumulative production until 1993 amounting to 700 billion barrels and unidentified reserves to 470 billion. No shortage of conventional liquid fuels is foreseen before 2020. Any deficiencies after that can be met by the ample reserves of unconventional oil.

Natural gas

The U.S. Geological Survey also assessed ultimate natural gas reserves in 1993 (Masters, 1994). It estimated ultimate reserves at 11,448 trillion cubic feet (11,214 exajoules, or 267 gigatonnes of oil equivalent [Gtoe]), with cumulative production until 1993 amounting to 1,750 trillion cubic feet (1,722 exajoules, or 41 Gtoe). Cumulative world gas production through the end of 1995 was only 17.1 percent of the U.S. Geological Survey's estimate of conventional gas reserves.

Natural gas consumption is projected to grow 2.6 percent a year, mostly as a result of

growth in electricity generation in non-OECD countries. Despite this growth, cumulative production is expected to be no more than 41 percent of the U.S. Geological Survey's estimate of conventional gas reserves by 2020. This points to a resource base large enough to serve global requirements for natural gas well into the second half of the 21st century.

TABLE 4.1. GLOBAL ENERGY RESOURCE BASE (EXAJOULES EXCEPT WHERE OTHERWISE INDICATED)

Term	World Energy Council estimates		Institute for Applied Systems Analysis estimates			Consumption
	Proven reserves	Ultimately recoverable	Reserves	Resources	Resource base	1998
Conventional oil	6,300 (150)	8,400 (200)	6,300 (150)	6,090 (145)	12,390 (295)	142.8 (3.4)
Unconventional oil	-	23,100 (550)	8,190 (195)	13,944 (332)	22,050 (525)	n.a.
Conventional gas	5,586 (133)	9,240 (220)	5,922 (141)	11,718 (279)	17,640 (420)	85 (2.0)
Unconventional gas	-	-	8,064 (192)	10,836 (258)	18,900 (450)	n.a.
Coal and lignite	18,060 (430)	142,800 (3,400)	25,452 (606)	117,348 (2,794)	142,800 (3,400)	93 (2.2)
Uranium	3.4×10^9 tonnes	17×10^9 tonnes	(57)	(203)	(260)	64,000 tonnes

- Not available; n.a. Not applicable.

Note: Numbers in parentheses are in gigatonnes of oil equivalent. For definitions of conventional and unconventional resources, see chapter 5. a. Because of uncertainties about the method of conversion, quantities of uranium have been left in the units reported by the sources.

Source: WEC, 1998; IIASA, 1998.

Coal

Coal is the world's most abundant fossil fuel, with reserves estimated at almost 1,000 billion tonnes, equivalent to 27,300 exajoules, or 650,000 Mtoe (WEC, 1998). At the present rate of production, these reserves should last for more than 220 years. Thus the resource base of coal is much larger than that of oil and gas. In addition, coal reserves are more evenly distributed across the world. And coal is cheap. Efforts are being made to reduce production costs and to apply clean coal technologies to reduce the environmental impact.

Coal demand is forecast to grow at a rate slightly higher than global energy growth. Most of this growth will be for power generation in non-OECD countries, mostly in Asia. Although trade in coal is still low, it is likely to increase slowly over time. Long-term trends in direct coal utilisation are difficult to predict because of the potential impact of climate change policies. Coal gasification and liquefaction will augment global oil and gas resources in the future.

Nuclear energy

Although nuclear energy is sometimes grouped with fossil fuels, it relies on a different resource base. In 1998 nuclear energy production amounted to 2,350 terawatt-hours of electricity, replacing 620 Mtoe of other fuels. Uranium requirements amounted to 63,700 tonnes in 1997, against reasonably assured resources (reserves) of 3.4 million tonnes.

Ultimately recoverable reserves amount to almost 17 million tonnes. Considering the relative stagnation in the growth of nuclear power, the enormous occurrences of low-grade uranium, and the prospects for recycling nuclear fuels, such reserves will suffice for many decades.

Renewables

Renewable energy sources - especially hydroelectric power, biomass, wind power, and geothermal energy - account for a growing share of world energy consumption. Today hydropower and biomass together contribute around 15 percent.

Hydroelectric power contributes around 2,500 terawatt-hours of electricity a year, slightly more than nuclear power does. It replaces almost 675 Mtoe of fuels a year, although its direct contribution to primary energy consumption is only a third of this. But it has still more potential. Technically exploitable hydro resources could potentially produce more than 14,000 terawatt-hours of electricity a year, equivalent to the world's total electricity requirements in 1998 (WEC, 1998). For environmental and economic reasons, however, most of these resources will not be exploited.

Still, hydropower will continue to develop. Hydropower is the most important among renewable energy sources. It is a clean, cheap source of energy, requiring only minimal running costs and with a conversion efficiency of almost 100 percent. Thus its annual growth could exceed the growth of global energy demand, slightly improving hydropower's modest contribution towards meeting world requirements.

Techniques for gasification, fermentation, and anaerobic digestion are all increasing the potential of biomass as a sustainable

energy source.

Renewable energy sources other than hydro are substantial. These take the form mainly of biomass. Traditional biomass includes fuelwood - the main source of biomass energy - dung, and crop and forest residues. Lack of statistics makes it difficult to accurately estimate the contribution of renewables to the world's primary energy consumption. But it is estimated that the world consumed around 1.20 Gtoe in 1998. About two-thirds of this was from fuelwood, and the remainder from crop residues and dung. Much of this contribution is sustainable from a supply standpoint. But the resulting energy services could be substantially increased by improving conversion efficiencies, which are typically very low.

The contribution of biomass to world energy consumption is expected to increase slightly. It is mainly used as an energy source in developing countries. While energy demand in these countries is steadily increasing, some of the demand is being met by switching from traditional to commercial energy sources.

Biomass energy technology is rapidly advancing. Besides direct combustion, techniques for gasification, fermentation, and anaerobic digestion are all increasing the potential of biomass as a sustainable energy source. The viability of wind energy is increasing as well. Some 2,100 megawatts of new capacity was commissioned in 1998, pushing global wind generating capacity to 9,600 megawatts. Wind power accounted for an estimated 21 terawatt-hours of electricity production in 1999. While that still amounts to only 0.15 percent of global electricity production, the competitiveness of wind power is improving and its growth potential is substantial. Use of geothermal energy for electricity generation is also increasing, with a present generating capacity of more than 8,300 megawatts.

The resource outlook

To summarise, no serious global shortage of energy resources is likely during at least the

first half of the 21st century. Reserves of traditional commercial fuels - oil, gas, and coal - will suffice for decades to come. When conventional oil resources are depleted, the huge unconventional oil and gas reserves will be tapped as new extraction and clean generating technologies mature. Coal reserves are also huge: the resource base is more than twice that of conventional and unconventional oil and gas. Clean technologies for coal will allow greater exploitation of this huge resource base, mainly in electricity production, but also through conversion into oil and gas, minimising environmentally harmful emissions.

The uranium resource base is also immense, and it is unlikely, at least in the short term, to be tapped in increasing amounts. The ultimately recoverable uranium reserves will easily meet any nuclear power requirements during this century.

The renewable resource base is also promising. Only part of the global hydro potential has been tapped. Hydropower plants will continue to be built as demand for electricity grows and the economics of long-distance, extra-high-voltage transmission improve. Biomass has substantial potential and will continue to be used not only as a traditional fuel but also in increasingly sophisticated ways, through thermochemical and biochemical applications. New renewable sources, particularly wind power, will gradually increase the contribution of renewables to global energy supplies as the economies and technologies of these environmentally attractive sources continue to improve.

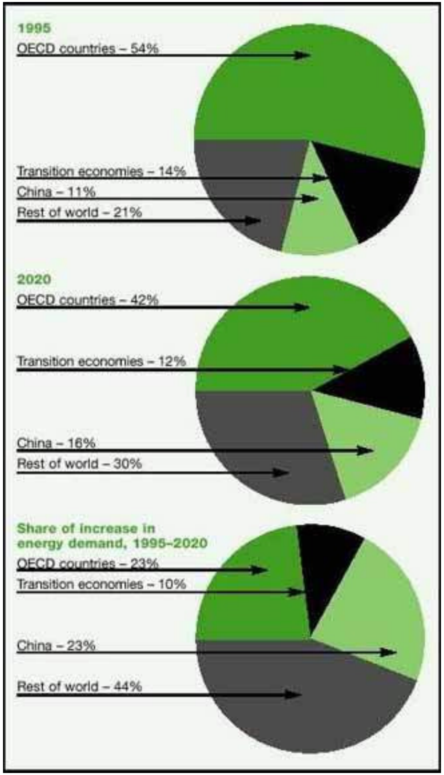

FIGURE 4.2. SHIFTING CONCENTRATION OF WORLD ENERGY DEMAND, 1995 - 2020

Source: IEA, 1998.

In short, the world's energy supplies offer good prospects for energy security in the 21st century. The fossil fuel reserves amount to 1,300 Gtoe and the fossil fuel resource base to

around 5,000 Gtoe (see table 4.1), amounts sufficient to cover global requirements throughout this century, even with a high-growth scenario. That does not mean there will be no temporary or structural energy shortages, but as long as the energy resources are being explored and exploited, these shortages will not be due to resource inadequacy.

Supply security

Energy resources are not evenly distributed across the world. Oil in particular, and natural gas to a lesser extent, are concentrated in a few regions. The concentration of oil reserves in the Persian Gulf region has always caused concerns about continuity of supply. Most countries, particularly OECD countries, experienced oil shortages and high prices in the 1970s and early 1980s, with physical disruption in supply leading to economic disruption. Energy importers are anxious not to repeat such experiences.

The oil supply situation has improved significantly since then. OECD countries' share of the energy market is decreasing, while that of developing countries is increasing (figure 4.2). This adds to the security of oil supplies because many developing countries are oil producers or have supply arrangements with producers. OECD countries, which accounted for 70 percent of the energy market in the 1970s, will see their market share fall to less than half by 2010. Technological advance has allowed the discovery and development of new energy reserves and reduced the cost of supplies. It has also helped increase efficiency in energy use, loosening the historically tight link between economic development and energy consumption.

Another major favourable development is the reduction in the sources of conflict that can affect global energy security. The cold war is over, and stability in the Middle East, although still precarious, is improving, with the Arab-Israeli conflict moving towards resolution.

However, some other global developments present both opportunities and new challenges

to the energy sector. The policy emphasis on environmentally sustainable development, particularly in OECD countries, has important long-term implications for energy security. And the market liberalisation taking place in most industrialised countries has reduced the state's role in energy security - and increased that of consumers.

Energy security is also important for energy producers and exporters. History shows that oil supply disruptions have negative effects on oil-exporting economies. As consumers in importing economies shift away from oil, the lower demand causes severe economic damage to the exporters. In addition, many oil-exporting countries have recently obtained stakes in downstream operations in importing countries. This involvement in OECD economies will contribute towards energy security, as supply disruptions could mean a loss of business opportunities for both oil exporters and importers.

Causes of supply disruption are not limited to disturbances in production facilities. Disruptions can also occur in the long supply chains, such as serious tanker accidents in the most heavily travelled zones - the Strait of Malacca, for example. Vulnerability to disruption may grow as energy supplies are increasingly delivered through grids (gas pipelines and extra-high-voltage transmission networks). Some of these cross national boundaries and are at least theoretically vulnerable to damage through sabotage and other political disturbances. Terrorist actions could damage liquefied natural gas (LNG) conversion and receiving stations and tankers. But such possibilities are remote. Most energy supplies are delivered under long-term contracts that commit governments to ensuring safe transit and security.

Despite the favourable developments in the energy market, energy security continues to concern planners and strategists in most importing countries. Long-term energy security can be enhanced in several ways:

- **Increasing energy independence by fostering and developing local resources**

(although some may not be economical). Supply security should not be measured solely by energy independence, however. An intelligent supply policy that includes external energy sources can offset many of the drawbacks of dependence and be more economical than a policy that precludes energy imports.

- **Diversifying sources of supply and forms of energy used (box 4.2).**

- **Encouraging international cooperation and agreements among energy-importing countries and between consumer and supplier countries, whether between governments or between companies.**

- **Investing in and transferring technology to developing countries. Enabling developing countries to develop more energy supplies will enhance the availability of global supplies. Helping these countries increase the efficiency of energy use and improve environmental management will have a similar effect.**

- **Enhancing and increasing national and regional strategic reserves of crude oil and its products.**

No serious global shortage of energy resources is likely during at least the first half of the 21st century.

Of all the forms of energy, crude oil and its products are still the most important for energy security, because of oil's versatility and because it is the optimal form of energy for the transport sector. Natural gas, because of its affordability and cleanliness, is gaining in importance. Nuclear energy, despite its past promise, faces many difficulties. The

security of all these energy forms, as well as coal, is discussed below. Energy intensity is also discussed, because improvements in this area could yield a wider range of benefits for energy security than could providing new sources of energy.

Security of crude oil supply

Over the past 20 years many changes in the oil market have improved the overall security of the energy market. The world economy has become less dependent on oil, as most regions have diversified their energy sources. Oil constituted almost 46 percent of world commercial energy sources in 1973, compared with 40 percent now. There has also been diversification of supply. In the early 1970s the Organization of Petroleum Exporting Countries (OPEC) accounted for more than half the world's oil; today it provides only 42 percent. The world now has 80 oil-producing countries (although very few have the surge capacity needed in emergencies). The oil markets have become more like traditional commodity markets (with futures markets), transparent and able to respond quickly to changing circumstances.

BOX 4.2. FRANCE'S EFFORTS TO ENHANCE ENERGY SECURITY

France has few energy resources and yet is highly industrialised and thus heavily dependent on adequate and reliable energy supplies. Its total energy consumption is estimated at 240 million tonnes of oil equivalent (Mtoe) a year, while domestic primary energy production of oil, gas, and coal amounts to only 8 Mtoe and is declining.

France, which produced half its total energy requirements in the early 1960s, saw its energy self-sufficiency decline sharply by the 1970s, when it produced only 22 percent of its requirements. But through intensive effort and ambitious energy planning, France reversed this trend of increasing dependence on imported energy. Thanks to its advanced technological skills, France was able to undertake an ambitious nuclear energy programme that helped it regain its 50 percent energy self-sufficiency in the late 1980s and to maintain it since.

To enhance its energy security, France pursued the following actions, which take into account its high standard of living, extensive industrialisation, and limited indigenous sources of primary energy:

- Diversification of energy sources and structure of energy use. France significantly reduced its dependence on imported oil from the Middle East, increased its dependence on gas, mainly from European and Algerian sources, and considerably increased its dependence on domestic electricity produced by nuclear power stations (see the table below).
- Participation in regional cooperation and joint actions, including the International Energy Agency and the Energy Charter Treaty.
- Reduction and rationalisation of demand by improving energy efficiency and encouraging conservation through pricing and taxation, particularly of petroleum products.
- Regional interconnection of gas and electricity networks, helping to mitigate temporary problems in the supply chain.
- Substitution of natural gas and nuclear electricity for petroleum products wherever possible.

By focusing on nuclear energy, France no doubt enhanced its energy security. But it also introduced a new vulnerability into its system. Nuclear power is a viable link in the energy chain as long as it is safe and publicly accepted. With the accidents at U.S., Russian, and Japanese nuclear plants and the growing strength of anti-nuclear parties in Europe, there is no guarantee that it will remain publicly accepted over the long term.

Energy supply structure in France, 1973 and 1997 (percent)

Cost	1973	1997

Primary energy		
Coal	14.5	5.6
Oil	66.3	39.7
Gas	7.0	13.1
Primary electricity[a]	7.0	36.6
Renewables[b]	5.2	5.0
Final energy		
Coal	11.0	4.0
Oil	56.4	37.1
Gas	5.5	13.9
Electricity	20.9	39.1
Renewables[b]	6.2	5.9

a. Most primary electricity is from nuclear fuels. b. Excluding hydroelectricity but including non-commercial uses.

Source: Maillard, 1999.

Big strides have been made in energy efficiency, gradually reducing the dependence of economic growth on increased oil consumption. Advances in technology have led to discoveries of more oil, reduced the cost of discoveries, and significantly improved the recovery rate, increasing the oil resource base to an estimated 2,300 trillion barrels. World trade has flourished in recent years. In 1998 it was three times that in 1980, and now accounts for 44 percent of global GDP, compared with 39 percent in 1980. Both energy exporters and importers benefit from trade. Most exporters are low-income

countries that badly need oil income for development.

Even with the increase in oil-producing countries, the fact remains that almost two-thirds of the world's oil resources are in the Middle East, mostly in the Gulf region (the Islamic Republic of Iran, Iraq, Kuwait, Qatar, Saudi Arabia, and the United Arab Emirates). Although these six countries now account for only 27 percent of global crude oil supplies, they are expected to double their share to 52 percent in 2010. The Middle East, particularly the Gulf region, has not been historically known for political stability and security. But as mentioned, the situation is improving.

OECD countries, which account for almost 80 percent of the world's economic activity and 63 percent of global oil consumption, are particularly dependent on oil imports. All OECD countries are expected to increase their dependence on oil imports over the next few years. Their oil imports, 56 percent of their energy requirements in 1996, are expected to rise to 76 percent in 2020 (table 4.2).

Asia-Pacific countries' crude oil imports are expected to increase to 72 percent of their requirements in 2005 (up from 56 percent in 1993). The Middle East is expected to account for 92 percent of the region's imports, with the Gulf countries the main source of supply. The Gulf region is expected to supply 18 million barrels a day to Asia-Pacific countries in 2010 (figure 4.3), far more than its expected total supplies to Europe and the United States of 12 million barrels a day. That is why oil security, particularly for the major oil-importing countries, and the stability of the Gulf region have such importance to overall energy security and the world economy. This importance will only increase in the future.

TABLE 4.2. OIL IMPORTS AS A SHARE OF TOTAL ENERGY REQUIREMENTS IN OECD COUNTRIES (PERCENT)

OECD country group	1996	2010	2020

North America	45	63	63
Europe	53	74	85
Pacific	90	96	96
Total OECD	56	72	76

Source: IEA, 1998.

Despite the favourable developments in the energy market, energy security continues to concern planners and strategists in most importing countries.

Differences between regional requirements and regional supplies will be accentuated in the future. Nowhere will this be more serious than in Asia, particularly among the large oil-consuming countries - China, India, Japan, and the Republic of Korea. Competition for supplies may intensify during emergencies, creating a potential for severe strains among Asian powers. Shortages may tempt some of these countries to project political and even military power to ensure adequate oil supplies. Already some of them - as well as the United States - have increased their naval presence in the Asian and Indian oceans (Jaffe, 1998). And U.S efforts for cooperation and conflict resolution are linked to its military planning and presence in the Gulf region and key oil export sea routes (Kemp and Harkavy, 1997).

Threats to security in oil-exporting countries can be both internal and external. Continued supply from Saudi Arabia is the most important element of energy security. Saudi supplies, now more than 9 million barrels a day, will have to increase to 13 - 15 million barrels a

day in 2010 to meet growing world demand and offset resource depletion in non-OPEC suppliers. By that time the United States will be importing more than 60 percent of its oil. Saudi Arabia has both the potential and the reserves to meet projected demand, but the expansion will call for investment resources from that country as well as the world financial community. For a healthy oil sector, the availability of such financing should be no problem. Over the past few decades the Gulf countries have proved to be stable; continued internal and external stability is crucial to energy security. Disruption of the Gulf oil flow would lead to a deep world-wide recession. This has been presented as one of the gravest threats imaginable to U.S. interests, short of physical attack (David, 1999).

The cost of energy security goes beyond investing in redundant facilities and building pipelines, grids, and strategic reserves. Tremendous military expenditures - both visible and invisible - are required to head off any threats to the flow of oil, particularly from the Gulf countries. These costs cannot be easily computed or ascertained. The enormous expenditures on the 1990 - 91 Gulf War, totalling several hundred billion dollars, were meant to ensure energy security for major oil importers and the world oil markets in general. The six Gulf Cooperation Council (GCC) states, which control nearly 45 percent of the world's recoverable oil resources, contributed more than $60 billion to the U.S.-led allied offensive to eject Iraqi forces from Kuwait in 1991 (AFP, 1998). The GCC countries' contribution in 1991 exceeded their oil export income in 1998 or 1999. The United States maintains a costly military and naval presence in strategic locations to ensure the uninterrupted flow of GCC oil exports to world markets. At the beginning of 1998, along with the United Kingdom, it assembled large air and naval forces to address perceived threats to the security of oil supply from the Gulf.

Although short-term disruptions in energy supply due to regional conflicts cannot be ruled out, means to overcome such disruptions already exist. The best illustration of this is the minimal effect on oil markets from the Iraqi invasion of Kuwait in 1990. Although 4 million barrels of oil a day dropped out of the market, Saudi Arabia increased its production and

restored stability to the oil market and to prices within a few weeks. Instruments for stabilising the oil market are improving year after year - strategic stocks held by oil companies and major importing countries, development and liberalisation of markets, and regional and global energy agreements. And once transport and transit issues are resolved, the Caspian Sea countries' hydrocarbon resources, as a supplement to the North Sea resources, can be added to this list.

FIGURE 4.3. FLOW OF GULF OIL SUPPLIES, 2010

Source: Kemp and Harkavy, 1997.

Oil stocks: cushioning against supply disruptions. Oil stocks are usually held by oil companies for operational purposes, and by countries and state utilities to provide a cushion against unexpected surges in demand and possible disruptions in imports. Oil companies usually hold stocks that account for 55 - 65 days of consumption. International Energy Agency members are required to hold emergency oil stocks equivalent to at least 90 days of net imports. The European Union requires its members - also IEA members - to hold stocks equivalent to at least 90 days of consumption. It is not easy to estimate oil stocks held by developing countries. Because of the cost, their stocks are relatively smaller than those of OECD countries, but can amount to 25 - 55 days of consumption, which is also typical for oil companies in these countries. Correspondingly, world oil stocks in 1997 were about 5,500 million barrels, equal to 70 - 80 days of average global consumption. This, at present, is adequate for unexpected transient shortages or temporary interruptions.

With the continued growth of non-OECD oil consumption, oil stocks will function less

effectively. Their size relative to the global oil market will decline, since most developing countries do not maintain emergency oil stocks (many cannot afford them). If this trend continues, vulnerability to sudden and substantial oil supply disruptions will increase.

Liberalisation of markets: easing the flow of oil. Another aspect of security is the liberalisation of energy markets in importing countries. Liberalisation and deregulation, coupled with the development of oil futures and forwards markets, mean an easier and more secure flow of oil from exporting to importing countries. Most oil producers are now inviting foreign companies to participate in oil development, which will significantly enhance the security of the oil market. And the strengthening of the World Trade Organization will add further to the security of the energy market.

Although security in terms of flows of oil and gas to importing countries is improving, the security of supply to consumers faces new challenges. Liberalisation, the withdrawal of government responsibility for supply, and competition among private suppliers are creating challenges in securing reliable supply to individual consumers. These are discussed later in detail.

Energy treaties and agreements: enhancing energy security through cooperation. In response to insecurity after the first oil shocks, OECD countries convened a conference in Washington, D.C., in 1974 that led to the establishment of the International Energy Programme (IEP), the founding charter of the International Energy Agency(IEA). To improve energy security, the participating countries pledged to hold oil stocks equivalent to 90 days of net imports. They also developed an integrated set of emergency response measures that included demand restraint, fuel switching, and surge oil production. These measures also included the important provision of stock draw-down and sharing of available supplies in the event of oil supply disruptions involving a loss of 7 percent or more for any member country or for the group (Martin, Imai, and Steeg, 1996).

In 1977 the IEA developed another set of coordinated emergency response measures that allow for a rapid and flexible response to an impending oil security crisis. Also in that year, IEA countries agreed to long-term energy policies and programmes aimed at diversifying resources, employing energy efficiency measures, and developing new energy technologies. And in response to changing circumstances, the IEA updated its policies in a statement of shared goals at its ministerial meeting in 1993.

In 1991, 51 countries signed the European Energy Charter to enhance energy security throughout the Eurasian continent and promote the creation of an open and non-discriminatory energy market. The signatories included the European Communities and their member states, the countries of Central and Eastern Europe, all the members of the Commonwealth of Independent States (CIS), and Australia, Canada, Japan, and the United States. By applying the principles of non-discrimination and market-oriented policies, the charter was aimed at improving energy security, increasing the efficiency of all links in the energy chain, enhancing safety, and minimising environmental impacts.

Three years later, in 1994, all the signatories to the European Energy Charter (except Canada and the United States) signed the Energy Charter Treaty, along with a protocol on Energy Efficiency and Related Environmental Aspects, which entered into force in 1998. Japan and the Central Asian states have since signed the Charter Treaty and China is showing increasing interest in it, enhancing its geopolitical scope. The treaty applies to all economic activities related to a broadly defined energy sector. Its main purpose is to promote the creation of an open and non-discriminatory energy market throughout the Eurasian continent (Schuetterle, 1999). The Charter Treaty obligates signatories to encourage and create stable, equitable, and transparent conditions for foreign investors in their countries, stipulates that General Agreement on Tariffs and Trade (GATT) provisions will govern trade in energy materials and products, ensures the transit of energy exports through third countries, and sets out procedures for settling disputes relating to the treaty's provisions.

OECD countries, which account for almost 80 percent of the world's economic activity and 63 percent of global oil consumption, are particularly dependent on oil imports.

Also serving to enhance energy security are interregional and intraregional agreements established to foster economic cooperation between member countries, such as Asia-Pacific Economic Cooperation (APEC), which involves 21 economies of Asia, Oceania, and the Americas (box 4.3). Enhancing energy security is one of the aims of APEC, which set up its own Energy Work Group and the Asia Pacific Energy Research Centre (APERC) for this purpose.

No doubt the above-mentioned treaties and arrangements helped to foster energy investments and improve energy security - not only for their members, but also globally - by encouraging sustainable energy policies.

Oil in transport: a special point of vulnerability. The transport sector accounts for half of global oil demand, with heating, electricity generation, industrial processes, and petrochemicals accounting for the rest. Demand for oil in transport is growing rapidly, particularly in aviation. Over the next 20 years demand for oil in transport is expected to grow by 2.3 percent a year, compared with growth in total demand for oil of around 1.9 percent a year. Most of this growth will occur in non-OECD countries, where it is expected to average 3.6 percent a year, with the highest growth projected for China and East and South Asia. Demand in OECD countries, which are already witnessing some saturation in vehicle ownership, is expected to grow at one-third that rate.

In the near term there is no cheap and viable alternative to oil in transport, particularly in

private vehicles and aviation (Douaud, 1999). Use of oil for mobility will increase in all countries, as the transport fleet grows and uses exceed improvements in transport efficiency. An interruption in oil supply, however temporary, could cause major disruption to the transport sector and to the world economy.

Oil prices: a source of insecurity. The severe volatility of oil prices in the 1970s and early 1980s contributed to the insecurity in energy markets. The price of oil is the market leader for energy pricing. Gas and coal, because of competition, are priced accordingly.

OPEC has the power to influence oil prices by allocating supply and monitoring and restricting production by its members. With the growing discipline in its ranks, this influence may increase in the future. Moreover, the depletion of non-OPEC oil and future growth in its marginal cost will increase oil prices in the medium and long term. Prices will be further increased by the development of the more expensive non-conventional oil, once crude oil supply peaks around 2010. Although short-term price volatility, like that in 1998 - 2000, cannot be ruled out because of the many factors explained above, oil prices are not expected to be as volatile as in the past. After 2010 gradual, moderate price increases are expected. Many recent predictions have been made of future oil prices. Two of these are given in table 4.3.

BOX 4.3. ASIA-PACIFIC ECONOMIC COOPERATION'S EFFORTS TO ENHANCE ENERGY SECURITY

Asia-Pacific Economic Cooperation (APEC) includes the following member economies in six 'sub-regions':

- The United States.
- Other Americas - Canada, Chile, and Mexico.
- China.

- Other Asia - Hong Kong (China), Japan, Republic of Korea, and Taiwan (China).
- Oceania - Australia, New Zealand, and Papua New Guinea.
- Southeast Asia - Brunei Darussalam, Indonesia, Malaysia, Philippines, Singapore, and Thailand.

In addition, Peru, the Russian Federation, and Viet Nam joined APEC in November 1998.

APEC was formed to foster economic cooperation among its member economies, one aspect of which is energy cooperation and security. APEC economies' energy requirements account for more than half of the world's primary energy supply. The group has rich coal resources, and gas resources almost adequate for its requirements. But it is very short in crude oil resources. By 2010 APEC economies will have to import an estimated 55 percent of their energy requirements. The recent incorporation of Russia, with its enormous gas resources and its oil, has helped alleviate APEC's serious energy security problem. Nevertheless, APEC's significant crude oil shortages are expected to continue. APEC tries to enhance its energy security through the following actions:

- **Encouraging expansion of energy production.** The entry into APEC of Russia, with 40 percent of global gas reserves and 9 percent of oil reserves, should facilitate the development of energy resources in the Asian part of Russia and enhance the supply potential to the growing Asian energy market. The need for expanded production will lead to more energy development and greater cooperation between APEC economies and other energy-producing economies outside the traditional APEC region. The participation of firms from Asian oil-importing economies in upstream hydrocarbon resource activities will enhance efforts to expand oil and gas production. Similarly, the participation of firms from oil-exporting countries in downstream operations in Asian markets will contribute to the security of energy supply.

- **Allowing more flexible fuel choices.** As a group, APEC economies are heavily biased towards coal use. The main reason is that China, which accounts for a fifth of APEC's requirements, uses coal to meet more than 70 percent of energy demand. Institutional and technological changes to support more flexible choices that are compatible with sustainable development are being considered. Within APEC, nuclear options have been and will be pursued in the Americas and East Asia. In the Americas, however, nuclear power is expected to play a reduced role, while in East Asia nuclear power is expected to expand. In Southeast Asia there is no likelihood that nuclear power will be introduced before 2010.

- **Preparing for energy supply disruptions.** Emergency oil stocks, like those held by members of the International Energy Agency (IEA), are a key element of energy security. With the growth of non-IEA oil consumption, IEA emergency oil reserves will function less effectively, as their size relative to the global market will decline and most non-IEA countries do not maintain emergency oil stocks. If this situation persists, vulnerability to sudden and substantial oil supply disruptions will grow. The issue of emergency preparedness therefore needs to be examined in a broader context. For this reason the Asia Pacific Energy Research Centre is conducting a study to assess the value of emergency oil stocks in APEC economies.

- **Promoting energy reforms.** The increased competition resulting from regulatory reforms in energy markets promotes energy security in many ways. Yet despite the global trend towards energy sector liberalisation, some APEC economies in Asia still believe that energy security requires maintaining a regulated energy market. Attitudes towards deregulation are gradually softening, however, as long as it does not preclude the state from continuing to play a role when needed to enhance security.

- **Developing transborder energy delivery infrastructure.** APEC economies are examining the feasibility of developing transborder infrastructure. Members of the Association of Southeast Asian Nations (ASEAN) have studied the creation of both gas pipeline networks and electricity grids linking producer and consumer members. In Northeast Asia the concept of a gas pipeline network linking former Soviet economies (Russia and Turkmenistan, for example) with China, the Republic of Korea, and Japan has been discussed. Finally, Russia is promoting the idea of linking electricity grids with neighbouring economies. Besides economic viability, there are many other

considerations in such projects: improved regional political stability through cooperation, better use of untapped resources, and increased capacity utilisation, energy supply, and demand diversity.

Such moderate price increases, along with continuous improvement in energy efficiency, mean that oil prices are unlikely to place a more serious burden on the global economy than they do now. Moreover, the expected improvements in the real price of oil will spur producing countries to enhance and expand their production and provide them with the badly needed financial resources to do so.

Income security for oil-exporting countries. Some countries depend - for income and for development - on energy exports, particularly oil. This group is not limited to the Middle East; it includes a few countries in Sub-Saharan Africa and Latin America. Nor is this dependence on oil export income restricted to exporting countries; the benefits of oil export income spread to other countries in the region through wage remittances and financial assistance.

In the Gulf countries three-quarters of government revenue is derived from oil exports. Energy exports account for almost two-thirds of government revenue for other countries in the region, such as Algeria, the Islamic Republic of Iran, and Yemen. The dramatic drop in oil prices in 1998 and early 1999 led not only to budgetary problems in many energy-exporting countries, but also to unemployment and significant drops in incomes. Such economic problems were not only restricted to the oil exporters but were also experienced by their neighbours, which depend on revenues from exports of goods and services to the oil-rich countries and on remittances from workers in these countries. For energy-exporting countries, export security is becoming as important as energy import security is to resource-short countries. All this is enhancing the prospects for global energy security.

TABLE 4.3. OIL PRICE PROJECTIONS (1997 U.S. DOLLARS PER BARREL)

Source of projections	1997	1998 - 2010	2015 - 2020

Source of projections	1997	1998 - 2010	2015 - 2020
International Energy Agency	18.50	24.50	26.20
U.S. Department of Energy	18.55	21.30	22.73

Source: IEA, 1998; USDOE, 1998.

Dependence on oil exports has an additional implication for exporting countries. These countries, particularly OPEC members, are worried about the possible long-term impact on export demand of policies to mitigate environmental impacts, promote energy efficiency, and increase use of renewable energy sources. Although exaggerated in the short term, the potential impact could pose long-term problems for the countries, adversely affecting their economic and social development. Having met the needs of the global energy sector satisfactorily over the past 25 years, oil-exporting countries are asking for compensation if mitigation actions start to bite. This request is being reviewed in international negotiations. It may be many years before exporting countries' income is affected. Meantime, it is hoped that with international assistance and compensation, they will be able to diversify their income sources and reduce their dependence on oil exports.

Security of natural gas supply

Natural gas is slowly gaining importance in the energy market. Between 1987 and 1997 gas consumption increased from 1,756 giga cubic metres to 2,197, for an annual growth rate of 2.27 percent, compared with 1.47 percent for total primary commercial energy consumption. Over the period until 2020 natural gas demand is expected to grow still faster - at an annual rate of 2.6 percent, compared with 1.9 percent for oil. And natural gas supply, since it is starting from a much lower base than oil supply, is not expected to peak until well beyond 2020 (IEA, 1998).

Internationally traded natural gas accounted for 19 percent of gas consumption in 1997, compared with 44 percent for oil. So, just as for oil, though to a lesser extent, there is a

mismatch between the location of gas supply and its consumption. Security of supply is therefore critical. But the physical characteristics of natural gas make ensuring security of supply for gas more complicated than for oil. Crude oil is an eminently fungible commodity, portable by ship, pipeline, road tanker, or even barrel. In contrast, gas requires expensive pipelines or LNG infrastructure. These delivery systems are relatively inflexible: pipelines cannot be moved or built overnight, and LNG, although somewhat portable, still requires an expensive receiving terminal. Crude oil and, more important, refined oil products can be transported to any location that can receive a ship or road tanker. Moreover, gas is difficult to store in significant quantities. The energy content per unit of volume is much lower for gas than for oil. Gas is simply more difficult to handle than liquid. Its storage often depends on the suitability of geological structures, while oil tank farms can be built relatively easily and cheaply. All these factors mean that the solutions used to ensure security of oil supply (storage, diversification of supplies) do not apply as easily to gas.

At its simplest level, gas supply security can mean operational reliability - in other words, that gas flows to the consumer when it is required. In particular, this means meeting consumer needs on days of peak demand, usually in winter. The gas supply system must be configured to give the required flexibility.

Security of supply also involves reducing strategic risk, namely, the risk of a major disruption to supplies caused by, for example, political factors or major technical failure, such as the failure of a high-pressure pipeline. This is an extension of operational security, but of a different order of magnitude. Strategic risk is growing in parallel with the growing share of gas in meeting countries’ primary energy requirements. It can be reduced through:

- **Interconnectivity, the degree of physical interconnection with other gas systems, an important factor in ensuring strategic security of supply. Interconnectivity is**

more than simply a guard against potential failure; it also encourages diversity of supply.

- **Diversity of supply, which is fundamental to security of supply because it spreads risk. All sources of supply are unlikely to fail at the same time. Countries have often explicitly diversified supply by contracting with several countries. France, for example, buys gas from Algeria, the Netherlands, Norway, and Russia. In recent years there have been a number of spot LNG sales into Europe from LNG suppliers using spare capacity.**

Security of supply also entails guarding against long-term risk - ensuring that consuming countries can secure future and additional supplies as their existing supplies are depleted. This represents a challenge, as the bulk of the world's gas reserves are in areas that are far from current markets and also often have a high level of country risk.

Some gas-importing countries, such as France, use long-term strategic storage to guard against significant disruption of supply. Such storage can be in depleted oil or gas fields, aquifers, salt caverns, or other geological structures.

Political risks to gas supplies and security of interregional grids. With the increase in internationally traded natural gas and LNG, political risk to gas supplies and cross-boundary networks will increase. One of the measures taken to reduce political risk is the Energy Charter Treaty, which attempts to provide a legal framework for the transit of hydrocarbons and electricity through pipelines and grids. The treaty prohibits contracting parties from imposing unreasonable charges for the transit of energy or taking unreasonable or discriminatory actions. Most important, in the event of a dispute over transit, transit states may not interrupt or reduce existing transit until the parties have had an opportunity to resolve the dispute using the treaty's dispute resolution mechanisms. As a further aid to international gas trade, the treaty prohibits countries

from refusing new transit or new capacity to other treaty signatories solely on the basis of the origin, destination, or ownership of the energy being transported.

Political risk is also an issue for investment in the gas industry. Because of the capital intensity of the industry, a sound investment environment is needed to encourage companies to invest. This requires clear legal, fiscal, and contractual frameworks; transparent regulatory processes; and regulatory certainty. To improve the international investment environment for projects involving the transit of gas as well as oil and electricity across national boundaries, the Energy Charter Conference, an intergovernmental body made up of the 51 states that have signed the Energy Charter Treaty, began in 1999 to elaborate the Multilateral Transit Framework Agreement. The aim is to strengthen the international rule of law on transit issues by further developing the treaty's transit provisions.

With increasing utilisation of gas, lengthy gas pipeline grids across countries and boundaries are becoming familiar. This raises concerns about political and security problems relating to the integrity of the pipeline and continuity of supply - because of possible regional disputes, disagreements among firms, or accidents or sabotage. One of the principal aims of the Energy Charter Treaty is to provide for such contingencies. But not all countries are signatories to the treaty, though the numbers are increasing. However, the treaty provides guidelines (explained above) that non-member countries can incorporate in agreements relating to cross-boundary pipelines. Moreover, the increasing strength of markets, the World Trade Organization regulations, and the increasing interdependence of markets and countries enhance the security of supply from regional gas grids.

Natural gas is an ideal fuel for electricity generation. It is environmentally benign compared with coal and offers the potential for very high efficiencies in combined cycle plants. Like oil, natural gas resources are unevenly distributed across the world, but unlike

oil, gas is not easily transportable or tradable. Expensive interregional gas grids are a solution as long as security is guaranteed, an aim of the Multilateral Transit Framework Agreement. Interregional grids provide benefits to all - suppliers, consumers, and transit countries. In addition, the increased security inherent in pipeline systems enhances cooperation among the countries involved.

Satisfying the increasing energy demand in India and South and East Asia may require building a very large interregional pipeline from the Islamic Republic of Iran or the Gulf. This would require not only a huge investment but also a coordinated regional arrangement and guarantees. Such a pipeline could sustainably meet the increasing demand for electrification in parts of Asia that account for more than a third of the world's population and where electricity demand is growing at twice the world average.

Risks to internal security of supply. In addition to the external risks, internal security risks are on the increase. These include the risk of electricity shortages due to increasing dependence on gas in electricity production. This increasing reliance on gas also raises supply security issues because of the possible domino effect in the event of gas supply problems. As a result of an interruption in gas supply to gas-fired power stations, a national grid could find itself short of capacity just as demand is peaking. Such security risks can be reduced, however, through coordination between the gas grid and the electric utilities, by switching combined cycle gas turbines (CCGT) to other fuels in the event of gas shortages, and by diversifying the energy sources for power generation (coal, nuclear, oil, gas, and hydro).

Tremendous military expenditures - both visible and invisible - are required to head off any threats to the flow of oil.

Diversity is more important than origin of supply. The mechanisms for securing diversity can be based on market instruments (payments for reserve capacity) or regulation (requirements for storing a certain number of days' worth of backup fuel supply). The U.S. gas market has shown how the price mechanism can enhance security of supply during less severe shortages. Many power stations burn both fuel oil and natural gas. As gas prices rise and the supply-demand balance tightens, the generators switch to the cheaper fuel, freeing up supply for gas consumers who cannot switch.

Development of national gas markets. Traditionally, international gas trade has been conducted on the basis of long-term (several-year) take-or-pay contracts. Under these contracts, designed to manage risk, the buyer agrees to take a certain volume over a period of time and to pay for that volume regardless of whether it is actually used. In effect, the buyer takes all the volume risk (the risk as to how much gas the end-use market will actually consume). The seller agrees to sell a certain quantity at a price indexed to such factors as the price of competing fuels, the price of electricity, and producer inflation. The seller therefore takes the risk that this price will cover its costs of production and provide a return on its investment. This is completely different from a commodity market, where supply and demand balance at whatever is the market-clearing price.

The 'traditional' take-or-pay system also frequently involved either monopsony or oligopoly buyers such as the European utilities (including the old British Gas and Gaz de France) and the Japanese utilities (Tepco). It has been argued that such a system was the only way to match supply and demand, ensure orderly development of the market, and allow all parties to recoup their investments. The approach has evidently worked: the record on gas supply security in Europe and Japan has been exemplary.

Recently, however, attention has focused on the implications of the liberalisation of gas markets for security of supply. In the United States the natural monopoly aspect of gas

supply, gas transport by pipeline, has been separated from the other functions - production, wholesale, and retail. Regulated third-party access has given any gas producer the ability to transport its product to the end market, and any customer the ability to buy gas from any producer or wholesaler. In short, the approach has enhanced U.S. supply security. But the U.S. experience cannot necessarily be applied to other countries.

Long-term take-or-pay contracts do not completely eliminate political or commercial risks. If a country is unable or unwilling to export its gas reserves for whatever reason, who has legal title to them is irrelevant. What such contracts can do, and have done in the past, is to give the parties a degree of confidence in the viability of a project and help secure financing.

By separating transport from supply, liberalisation, over the long term, will encourage the producers able to supply the market at lowest cost to meet consumers' demand. Moreover, the U.S. experience suggests that as pricing of gas supply and associated services becomes more transparent and explicit, market participants will search for the most cost-effective way of ensuring gas supply. In the United States this has led to greater and more innovative use of storage. The results depend, however, on how the industry structure and regulations evolve - whether dominant players effectively keep out new entrants, for example, or a more level playing field develops.

In summary, while the physical characteristics of gas make supply security problematic, it can nevertheless be enhanced by a variety of mechanisms, enabling gas to continue to play its part in the world's energy balance. Liberalisation of energy markets is not incompatible with supply security, and can arguably enhance it.

Security of coal supply

Coal presents fewer challenges - other than environmental ones - to energy security than do oil and gas. It is abundant and more evenly distributed around the world than oil or

gas. It is cheap, and costs are continuously being reduced by competition. The many suppliers and the possibility of switching from one to another mean supply security. The global ratio of coal reserves to production is 225 years; for OECD countries, it is even higher. Coal is still a local fuel, however. International trade in coal is limited, amounting to only 13 percent of production, a smaller share than for gas.

The huge reserves of coal and their even distribution contribute to global energy security. Coal will continue to play a major part in ensuring the energy security of large energy consumers, particularly China (the largest coal consumer), the United States, and South Asia. Over the next few decades the growth in demand for coal is expected to continue to be healthy, exceeding the growth in overall energy demand.

Most of that growth will be for electricity generation, with coal consumption in the electricity sector expected to grow in all regions. But this is also the area where the main security challenge arises, because of the environmental effects of coal use - locally, regionally, and also possibly globally. Coal utilisation is very inefficient, particularly in power generation, where its efficiency is less than 25 percent (Ecoal, 1998). The efficiency of oil and gas in electricity generation is at least 50 percent higher.

For coal to play its deserved role in global energy security, its many detrimental environmental impacts must be addressed. This will require not only clean coal technologies for new plants, but also rehabilitation and refurbishment of existing inefficient plants. And this must happen not only in industrialised countries, but also in developing countries, which are expected to account for most coal use. All this calls for technology transfer and huge investments, which many developing countries will be unable to afford. Thus technical assistance to developing countries will be essential.

Nuclear energy and energy security

Nuclear energy could continue to add to the energy security of countries short of

hydropower and indigenous fossil fuel resources, for several reasons. Uranium resources are widely distributed and abundant world-wide (see chapter 5). Nuclear fuel is cheap: at the price of present long-term uranium supply contracts, the cost of natural uranium per kilowatt-hour is equivalent to an oil price of $0.35 per barrel, so several years' supply could be kept in reserve against possible future supply disruption at a low cost. And the cost of uranium contributes only about 2 percent to the cost of nuclear electricity generation, compared with 40 - 70 percent for fossil fuels in electricity generation,[1] making the cost of nuclear electricity relatively insensitive to possible future increases in the uranium price.

These considerations played a key part in the decisions of such economies as France, the Republic of Korea, Japan, and Taiwan (China) to launch major nuclear power programmes. In all likelihood, such considerations will also be important determinants in similar decisions by countries with a shortage of indigenous resources and a heavy reliance on imports. Moreover, the fact that nuclear power releases virtually no environmentally damaging emissions of carbon dioxide, sulphur dioxide, and nitrogen oxide could make it an attractive option for many countries seeking technologies leading to reduced greenhouse gas emissions or abatement of local and regional pollution.

In the 1960s and 1970s, particularly after the first oil shock, nuclear power promised to be a viable solution for industrialised countries looking for energy security and cheap power. Largely as a result of investment decisions made in that period, nuclear power has grown to the point where it dominates electricity generation in several industrialised countries, providing about a sixth of global electricity in 1998. But the outlook for nuclear power is not bright. Most of the promise of nuclear energy has evaporated as a result of loss of investor and public confidence in the technology. There is likely to be growth in nuclear power in some Asian countries in the period to 2020 and modest expansion at the global level until 2010. But most projections show nuclear power accounting for a smaller share of global electricity generation in 2020 than today, and many show its absolute

contribution staying the same or even shrinking.

The loss of investor and public confidence in nuclear technology is due to concerns about costs, nuclear safety, radioactive waste disposal, and proliferation or diversion (see chapter 8). Until these concerns are adequately dealt with, nuclear energy is unlikely to play an expanding role in enhancing global energy security. The energy security benefits provided by nuclear power might even be diminished if there is another reactor accident involving substantial releases of radioactivity or a proliferation or diversion incident that could be plausibly linked in the public mind to nuclear power.

Recognition that another major accident might not only diminish prospects for nuclear expansion but also trigger demands to shut down existing nuclear plants has catalysed private sector-led efforts, under the auspices of the World Association of Nuclear Operators, to instil a culture of safety in the world's nuclear industry. This situation has also prompted an international effort, led by the International Atomic Energy Agency, to bolster national nuclear regulatory regimes. This effort is embodied in the Convention on Nuclear Safety, adopted by the organisation's members. (For discussion of technological strategies for improving the safety of future reactors, see chapter 8.)

The Nuclear Non-Proliferation Treaty and associated international safeguards and nuclear supplier agreements have been implemented to minimise the nuclear weapons link to nuclear power (Murray, 1995). To date, all but a few states (apart from the five nuclear weapons states recognised in the 1968 Non-Proliferation Treaty, these are India, Israel, and Pakistan) have committed themselves to putting all nuclear material, including the material used for uranium enrichment and reprocessing, indefinitely under safeguard of the International Atomic Energy Agency.

Recent events and concerns about the limitations of existing policies have led various experts to call for further efforts to weaken the nuclear weapons link to nuclear power.

But because the risk of proliferation and diversion is not at the forefront of public concerns about nuclear power (and may not be until there is an incident), because national policies in this area differ widely, and because there is much disagreement in the technical community about the best approaches for minimising this risk, there has been less action in this area than there has been in improving reactor safety. Increasing the authority and resources of the International Atomic Energy Agency for monitoring enrichment plants and spent fuel is the principal way immediately available to reduce the proliferation risks associated with existing uranium enrichment and fuel reprocessing capabilities. (For a discussion of institutional strategies for further weakening the nuclear weapons link, see Walker, 1998. For a discussion of future options for weakening this link with advanced technologies, see chapter 8.)

In summary, for the next couple of decades the prospects for enhancing energy security through expansion of nuclear power are not bright at the global level, although they are somewhat better in some Asian countries. In the longer term whether nuclear power can contribute to energy security depends not only on technical and economic considerations to be sorted out by the market, but also on the extent to which the public can be convinced that nuclear power is safe and that wastes can be disposed of safely. It also depends on whether the industry can avoid major accidents and proliferation and diversion incidents, and whether national and international policy-makers and the technical community can reach consensus on what needs to be done to make nuclear energy technology widely acceptable.

If the world economy continues to grow at the expected average rate of 2.7 percent, in 2020 global energy demand will be 45-51 percent higher than in 1998.

Energy intensity

One way to improve energy security in any country is by reducing its energy intensity - the amount of energy required to produce one unit of GDP. The rate of change in energy intensity reflects the overall improvement in energy efficiency as well as structural changes in the economy. Declining rates of energy intensity indicate that economic growth is less tightly linked to increases in energy use.

Energy intensity has improved considerably in industrialised countries. In the United States over the past two centuries it has declined 1 percent a year on average. One unit of GDP now requires only a fifth of the primary energy required 200 years ago (IIASA and WEC, 1998). In the past 15 years energy intensity in the United States has improved 20 percent.

Energy intensity differs depending on the level of economic development. OECD countries generally have an energy intensity that is a fraction of that in developing countries. In 1996 the commercial energy intensity of middle-income developing countries was three times that of high-income countries. This finding remains whether GDP is measured in market dollars or in purchasing power parity (PPP) terms. In most developing countries energy intensity is stagnant or even increasing because these countries are in the early take-off stages of industrialisation, when energy-intensive industries and infrastructure are being established. Moreover, low-income developing countries usually show increasing commercial energy intensity because commercial energy sources are replacing non-commercial fuels.

The prospects for lowering energy intensity are reduced in many developing countries by the proliferation of energy price subsidies and by the use of inefficient and outdated plants and equipment. Generally, however, energy intensity in developing countries is similar to that in industrialised countries when they were at an earlier stage of development.

Economic growth in developing countries has been relatively high in recent years, averaging 2.8 percent a year in the 1990s, compared with 2.1 percent for industrialised countries and 2.3 percent for the world. This trend is likely to continue. If this growth is matched by measures to conserve energy - such as phasing out subsidies and improving environmental awareness - energy security in developing countries is likely to continue to improve as well.

Predicting the future of energy intensity is difficult, particularly for developing countries. In low-income countries energy intensity may increase in the next few years as these countries substitute commercial energy for traditional fuels. But for the world as a whole, energy intensity is likely to improve. Average improvements will range from 0.8 percent to 1.0 percent a year, depending on such factors as environmental awareness and energy prices (IIASA and WEC, 1998). If the world economy continues to grow at the expected average rate of 2.7 percent, energy demand growth will average 1.7 - 1.9 percent a year. That means that in 2020 global energy demand will be 45 - 51 percent higher than in 1998. This is a substantial increase. But without the expected efficiency improvements in global energy utilisation, the demand could grow as much as 80 percent.

The potential for efficiency improvements is high in many energy applications (see chapter 6). Some of the most important progress in energy efficiency is that taking place in the conversion of energy to electricity. Modern combined cycle gas turbines burning natural gas have efficiencies approaching 60 percent, and efficiencies of 70 percent are within reach in the foreseeable future. Such efficiencies are more than double the average of 31 percent for the world stock of existing generating plants. As old plants are phased out and new, CCGT-type plants - or the traditional thermal generating plant firing coal at more than 40 percent efficiency - take over, considerable improvements in energy utilisation will gradually occur. In addition, the increased use of electricity as an energy carrier world-wide will further improve energy efficiency. In some applications electricity is more efficient than other forms of energy, and its use is now growing 2.8 - 3.2 percent a year, a

rate more than 50 percent higher than that for primary energy overall (Khatib, 1997). All this will significantly lower energy intensity and thus improve prospects for global energy security.

The environment and energy security

The idea of sustainable development is gaining acceptance on the official level as well as among the public. Sustainable development demands environmental preservation. Energy production and utilisation, particularly in the case of fossil fuels, can be major sources of environmental degradation. These detrimental environmental impacts have a direct bearing on the future of energy - in terms of fuels and the extent of their use - and on energy security. (For a discussion of the environmental impacts of energy use, see chapter 3.)

The United Nations Framework Convention on Climate Change, adopted at the Rio Earth Summit in 1992, and the Kyoto Protocol, signed by more than 160 countries in 1997, call for major reductions of greenhouse gas emissions, which are caused mainly by energy use. Fulfilling the commitments as agreed and at the schedules approved would greatly affect the use of energy resources and could compromise global economic progress. There is a large gap between the commitments and the means for implementation. Targets agreed upon by negotiators were not necessarily implemented by legislators or other policy-makers. Implementation of such targets is hindered not only by cost but also by the need to maintain energy security.

All indications are that fossil fuels will continue to dominate global energy resources for at least the first decades of the 21st century. Moreover, the demand for energy services will continue to increase. Most of the growth will be in developing countries, which can ill afford the high cost of containment measures. It is therefore essential to find means to contain energy-related emissions without compromising energy security.

The environmental effects of energy use occur at the local, regional, and global levels. Local effects consist primarily of heavy hydrocarbons and particulate matter (including sulphur flakes) that are deposited within hours and can travel up to 100 kilometres from the source. Regional effects include emissions and effluents, the most important of which are sulphur and nitrogen oxides, which are converted into acids; these acids, which last for a few days in the atmosphere, may travel up to a few thousand kilometres before being deposited, often after crossing boundaries. Global environmental impacts are exemplified by emissions of carbon dioxide and other gases (mainly methane) that have long residence times in the atmosphere.

The increased use of electricity as an energy carrier world-wide will further improve energy efficiency.

Local and regional impacts can be addressed by technologies. However, some of these technologies are expensive for developing countries, where growth in the use of low-quality coal will be particularly high. There are no easy answers in dealing with greenhouse gas emissions. Mitigation and sequestration measures are still to be developed. The most practical solution is to reduce the growth in fossil fuel use by increasing efficiency in energy utilisation.

Enhancing efficiency in energy use not only helps greatly to mitigate emissions; it also improves energy security. But for greater benefits for energy security, energy use should also be made more compatible with the aims of sustainable development through better containment of emissions. Such simple measures as washing coal will rid it of 20 - 50 percent of its sulphur. Advanced burners and scrubbers remove pollutants and effluent

gases from smoke stacks and chimneys. Fuel substitution is another effective measure. A modern CCGT power station, firing gas, will emit only 40 percent as much carbon dioxide as a traditional coal-fired thermal power station. The slow but persistent growth in the use of electricity as an energy carrier will also contribute towards energy security. Besides offering greater efficiency than other forms of energy in many applications, electricity concentrates emissions in a single remote location - the site of the power station - making them easier and cheaper to deal with.

Markets and energy security

Approaches to ensuring energy supply security in the 21st century should differ from past approaches that concentrated on oil substitution. Besides sustainable growth challenges, new approaches need to tackle the new energy security issues raised by market liberalisation.

The enhanced role of markets is tied closely to the process of globalisation. Globalisation, which is still gaining momentum, has encouraged competition and strengthened markets and regional and international trade, particularly for crude oil and oil products, natural gas, and energy services. Globalisation is bringing new opportunities for energy security, such as better access to markets and services and the transfer of technologies that are helping to reduce the cost of energy exploration and expand proven reserves.

International trade in energy resources and services is vital for energy security. The creation of the World Trade Organization in 1995, built on the GATT, is the latest multilateral step towards creating an environment conducive to the exchange of goods and services. It will assist in trade liberalisation and allow countries greater recourse to trade dispute settlement mechanisms. Foreign trade has grown more quickly than the world economy in recent years, a trend that is likely to continue. For developing countries, trade is growing faster than national income, reaching 50 percent of GDP, and a good

share of that trade is in energy. The flow of information has become much easier and more transparent, increasing the resources and services available for trade and reducing prices. All this aids greatly in enhancing energy security.

The introduction of a single market in Europe will lead to more competition in energy services and supply of cheaper electricity. Improvements in transport networks and technology are reducing the cost of energy trade. The liberalisation of European gas and electricity markets will initiate major structural changes in European energy enterprises, increasing competition, improving economic performance, and contributing towards fuel diversification and greater energy security (EC, 1999).

In studying the influence of markets, there is a need to distinguish between OECD countries, where free markets prevail, and developing countries, where market liberalisation is still at a very early stage. Security of supply is a public policy objective. But in free markets decisions are made by market players rather than by governments. Markets allow even small and medium-size consumers - as well as suppliers - a say in energy decisions. That requires redefining the political dimension of energy security.

Markets clearly produce benefits for consumers: trade, innovation, cost reduction, technological advances, and better allocation of resources. Moreover, unbundling the supply chain enhances transparency and allows tariffs to reflect real costs. Markets have also taught us a few lessons: they have proven that they can adjust more easily than governments to changing circumstances in the energy market and that it is costly to intervene against the market for an extended period.

Market liberalisation is leaving much of the decision-making to consumers. Are the consumers capable of making the right choices? Or would they choose cheaper options (such as interruptible supply) even if that compromises their energy supply security? This possibility suggests a need for a government role. Moreover, liberalisation will not

necessarily cover the entire supply chain. Certain monopolies will remain in transmission and distribution. Governments therefore have a duty to protect consumers at the very end of the supply chain (retail consumers). In addition, the energy market may ignore the interests of other consumer classes, such as remote and isolated consumers. All this necessitates that government continue to be involved in the energy market to a certain extent in almost every country.

The argument applies particularly to the supply side. Energy development entails long-term, capital-intensive investments. Private investors may demand a higher rate of return in a liberalised market than in a government-controlled energy industry. In addition, markets usually look for short-term profits and may therefore forgo diversification of supplies, which is associated with high up-front investment and risk but long-term benefits. How will markets respond to the long-term requirements of sustainable development, which demands heavy investments in research and development? How can they meet societies' long-term interest in secure supplies at reasonable prices when their interest is mainly in the short term? How can markets respond to an emergency disruption of supply in exporting countries? The division between the production and supply functions does not allow full integration of the security function. Will the energy markets be able to internalise all the costs of security, including political risk?

Having said all that, there are several reasons to believe that regulatory reforms in the energy market that are aimed at enhancing competition would promote energy security. First, as discussed, reforms can lead to increased investment and trade in energy resources, which will, in turn, facilitate expansion of energy production, increase inter-fuel competition, and encourage the construction of trans-boundary energy delivery infrastructure, such as oil and gas pipelines.

Second, also as discussed, the participation in downstream operations by firms from oil-exporting economies, and the participation in upstream operations by firms from oil-

importing economies (all of which is facilitated by market liberalisation), will be mutually beneficial and thus increase both exporters' and importers' interest in energy security. In Asia deregulation and other energy sector liberalisation will also promote accelerated growth in energy supplies and a greater sense of energy security.

Third, regulatory reforms will enhance efficiency and effectiveness, even in the area of energy supply emergency response. The IEA's oil supply emergency systems place growing emphasis on drawdowns of oil stocks compared with such measures as demand restraint. The release of oil stocks into the market is more market-oriented than government intervention to restrain demand.

Thus energy sector regulatory reforms could be compatible with or even enhance energy supply security. Governments, while withdrawing from energy investments themselves, need to create a positive climate for trade and investment. With increasing market liberalisation, there is a growing need for governments to monitor private sector actors and deal with market failures. Certain investors might be looking for concentration through mergers and joint ventures, for example, which might conflict with government policy of promoting liberalisation and fostering competition.

In considering the role of markets, the following questions are increasingly asked: Can the important issue of energy security be left entirely to markets? What is the role of the state in ensuring energy security in a liberalised market environment?

The role of the state

Markets are playing an increasingly progressive role in energy. This role is prominent in most OECD countries, modest in some developing countries, and absent in others, where the state remains almost solely responsible for the energy market and the security of supplies and services.

In a globalised market economy, energy security becomes a matter of prices, economic growth rates, and wealth transfers. In an energy (oil) crisis it cannot be assumed that free market conditions will prevail throughout the crisis (Jaffe, 1998). Thus the state still has an important role to play in almost in every country:

- **Sending clear signals to markets so that they can be guided by the state's long-term energy policy.**

- **Continuing to act as a regulator to ensure fair play in the market.**

- **Ensuring long-term security by making the bold or costly decisions that the market cannot make on its own, such as diversifying fuels and encouraging renewables.**

- **Preserving the environment and enforcing environmental policies.**

- **Holding oil stocks for supply security and coordinating with other governments in such arrangements.**

- **Collecting and disseminating accurate energy market information in the event of emergencies. Left on their own, markets may respond nervously to rumours or distorted information, adding to the confusion and insecurity. Official information systems greatly helped to calm the markets in 1991 following the Gulf war and restored market stability.**

- **Financing and investing in research and development of new energy technologies and in improving efficiency, and encouraging markets to invest in research and development by offering tax and other incentives.**

- **Trying to incorporate the 'externalities' (such as long-term assurance of supply,**

environmental protection, and protection against possible disruptions) in a market-oriented setting.

Structural reforms are helping to foster competition by liberalising markets, but such competition and cost cutting should not be allowed to threaten long-term security of supplies to final consumers. That remains a government responsibility.

Regional cooperation and the growing importance of regional electricity grids and network energies

Use of electricity is growing more rapidly than use of all energy services. Over the next 20 years electricity production is expected to increase by about 3 percent a year, compared with average growth in total energy use of less than 2 percent a year. With this will come growth of electricity grids and regional interconnections. National and regional natural gas networks are also growing as reliance on gas increases because of its price and its environmental attractiveness. All this reflects consumers' growing preference for network energy. Energy security for consumers is thus no longer limited to the availability of resources and geo-political considerations. It is becoming increasingly dependent on markets and competition and on the security of regional networks, a vitally important issue.

Interconnection of neighbouring national grids (electricity and gas networks) into regional grids greatly enhances energy security. It also reduces the cost of supply by taking advantage of differences in peak demand and by allowing a reduction in standby power and reserve generating capacity and the use of cheaper resources. Today regional electricity grids exist not only in Europe but also in many other parts of the world. While the increasing interconnections across borders are providing great benefits to consumers, supply interruptions still occur, mainly because of problems in the local distribution system.

Markets usually look for short-term profits and may therefore forgo diversification of supplies.

Conclusion

- **All indications point to a gradual but steady improvement in energy security in all parts of the world, thanks to technological advances, adequacy of resources, and regional cooperation, energy agencies and treaties, and international trade organisations.**

- **Present energy security aims go beyond merely ensuring the availability of abundant oil supplies at affordable prices. They also include ensuring long-term energy adequacy in a new economic environment of deregulated and liberalised markets and fostering sustainable development.**

- **The resource base of fossil fuels is clearly adequate for meeting global energy service requirements well into the second half of the 21st century. But the resources - particularly crude oil and, to a lesser extent, gas - are mismatched between regions and between consuming and producing countries, raising geopolitical questions. Oil resources are heavily concentrated in the Gulf region, a part of the world that has experienced security problems. However, recent trends in energy utilisation and oil technologies are contributing greatly towards stability of supplies and prices in the oil market.**

- **The world will continue to depend on fossil fuels for decades to come. But these fuels have detrimental impacts on the environment that must be dealt with to**

achieve sustainable development. This requires promoting clean energy technologies, pursuing energy efficiency, developing renewable forms of energy, and providing technical assistance to developing countries, where most growth in energy use will take place.

- **Deregulation and market liberalisation pose questions for energy security and for the future role of the state with respect to energy security. Markets lead to innovation, reduce costs, increase trade, improve allocation of resources, and spur technological development, all of which enhance energy security. Markets also normally pursue short-term objectives, while energy security demands long-term planning, investment, and political will. The state therefore needs to continue to play a role in ensuring national long-term security of supplies and protecting consumers.**

- **Consumers are gradually opting for energy supplied by grid (electricity and gas). This greatly enhances security of supply, reduces costs, and fosters regional cooperation.**

- **With energy services increasingly being supplied by electricity, the security of the electric power supply, in terms of both continuity and quality, is becoming paramount. Interruptions, even transient ones, cause serious income and welfare losses for consumers. In many developing countries the security and availability of the electricity supply leave much to be desired, pointing to a need for capital investments. The steady expansion of regional electricity grids, however, is helping to improve the security of electricity supply.**

Note

1. The total nuclear fuel cycle cost, including enrichment and other fuel processing services, contributes 15 - 20 percent to the cost of nuclear electricity, but the cost of

uranium presently accounts for only about 10 percent of the nuclear fuel cycle cost.

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