I. WORLD ENERGY ASSESSMENT

World Energy Assessment: United Nations Development Programme, United Nations Department of Economic and Social Affairs, World Energy Council, World Energy Assessment and the Challenge of Sustainability (2000)

World Energy Assessment (New York, UNDP) 2000

http://www.undp.org/seed/eap/activities/wea/drafts-frame.html

One way of looking at human development is in terms of the choices and opportunities available to individuals. Energy can dramatically widen these choices. Simply harnessing oxen, for example, multiplied the power available to a human being by a factor of 10. The invention of the vertical waterwheel increased productivity by another factor of 6; the steam engine increased it by yet another order of magnitude. The use of motor vehicles greatly reduced journey times and expanded human ability to transport goods to markets.

Today the ready availability of plentiful, affordable energy allows many people to enjoy unprecedented comfort, mobility, and productivity. In industrialised countries people use more than 100 times as much energy, on a per capita basis, as humans did before they learned to exploit the energy potential of fire.[1]

Although energy fuels economic growth, and is therefore a key concern for all countries, access to and use of energy vary widely among them, as well as between the rich and poor within each country. In fact, 2 billion people – one-third of the world's population – rely almost completely on traditional energy sources and so are not able to take advantage of the opportunities made possible by modern forms of energy (World Bank, 1996; WEC-FAO, 1999; UNDP, 1997).[2] Moreover, most current energy generation and use are accompanied by environmental impacts at local, regional, and global levels that threaten human well-being now and well into the future.

In Agenda 21 the United Nations and its member states have strongly endorsed the goal of sustainable development, which implies meeting the needs of the present without compromising the ability of future generations to meet their needs (WCED, 1987, p. 8).[3] The importance of energy as a tool for meeting this goal was acknowledged at every major United Nations conference in the 1990s, starting with the Rio Earth Summit (UN Conference on Environment and Development) in 1992.[4] But current energy systems, as analysed in this report and summarised here, are not addressing the basic needs of all people, and the continuation of business-as-usual practices may compromise the prospects of future generations.

Energy produced and used in ways that support human development over the long term, in all its social, economic, and environmental dimensions, is what is meant in this report by the term *sustainable energy*. In other words, this term does not refer simply to a continuing supply of energy, but to the production and use of energy resources in ways that promote – or at least are compatible with – long-term human well-being and ecological balance.

Many current energy practices do not fit this definition. As noted in Agenda 21, "Much of the world's energy . . . 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" (UN, 1992, chapter 9.9).[5] Energy's link to global warming through greenhouse gas emissions (most of which are produced by fossil fuel consumption) was addressed by the United Nations Framework Convention on Climate Change, adopted in 1992. And in 1997 a United Nations General Assembly Special Session identified energy and transport issues as being central to achieving a sustainable future, and set key objectives in these areas.

The energy industry also recognises the need to address energy issues within a broad context. For

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example, the conclusions and recommendations of the 17th Congress of the World Energy Council discuss the need to provide commercial energy to those without it, and to address energy-linked environmental impacts at all levels (WEC, 1998).[6]

Although there seem to be no physical limits to the world's energy supply for at least the next 50 years, today's energy system is unsustainable because of equity issues as well as environmental, economic, and geopolitical concerns that have implications far into the future. Aspects of the unsustainability of the current system include:

- Modern fuels and electricity are not universally accessible, an inequity that has moral, political, and practical dimensions in a world that is becoming increasingly interconnected.
- The current energy system is not sufficiently reliable or affordable to support widespread economic growth. The productivity of one-third of the world's people is compromised by lack of access to commercial energy, and perhaps another third suffer economic hardship and insecurity due to unreliable energy supplies.
- Negative local, regional, and global environmental impacts of energy production and use threaten the health and well-being of current and future generations.

More specific – and more quantifiable – elements of sustainability are identified below in the section on energy scenarios. Before looking into the future, however, some basic features of energy and its relationship to economic development are described, and the linkages between energy and major global challenges are analysed.

PART 1. ENERGY AND MAJOR GLOBAL ISSUES

Part 1 analyses the linkages between energy and the economy, social and health issues, environmental protection, and security, and describes aspects of energy use that are incompatible with the goal of sustainable development. It shows that:

- Affordable, modern energy supplies – including gaseous and liquid fuels, electricity, and more efficient end-use technologies – are not accessible by 2 billion people. This constrains their opportunities for economic development and improved living standards. Women and children are disproportionately burdened by a dependence on traditional fuels.
- Wide disparities in access to affordable commercial energy and energy services are inequitable, run counter to the concept of human development, and threaten social stability.
- Unreliable supplies are a hardship and economic burden for a large portion of the world's population. In addition, dependence on imported fuels leaves many countries vulnerable to disruptions in supply.
- Human health is threatened by high levels of pollution resulting from energy use at the household, community, and regional levels.
- The environmental impacts of a host of energy-linked emissions – including suspended fine particles and precursors of acid deposition – contribute to air pollution and ecosystem degradation.
- Emissions of anthropogenic greenhouse gases, mostly from the production and use of energy, are altering the atmosphere in ways that may already be having a discernible influence on the global climate.

Finding ways to expand energy services while simultaneously addressing the environmental impacts associated with energy use represents a critical challenge to humanity. The resources and options available to meet this challenge – energy efficiency, renewables, and advanced energy technologies – are analysed in the next sections.

AN INTRODUCTION TO ENERGY

An energy system is made up of an energy supply sector and energy end-use technologies. The object of the energy system is to deliver to consumers the benefits that energy offers. The term *energy services* is used to describe these benefits, which in households include illumination, cooked food, comfortable indoor temperatures, refrigeration, and transportation. Energy services are also required for virtually every commercial and industrial activity. For instance, heating and cooling are needed for many industrial processes, motive power is needed for agriculture, and electricity is needed for telecommunications and electronics.

The energy chain that delivers these services begins with the collection or extraction of primary

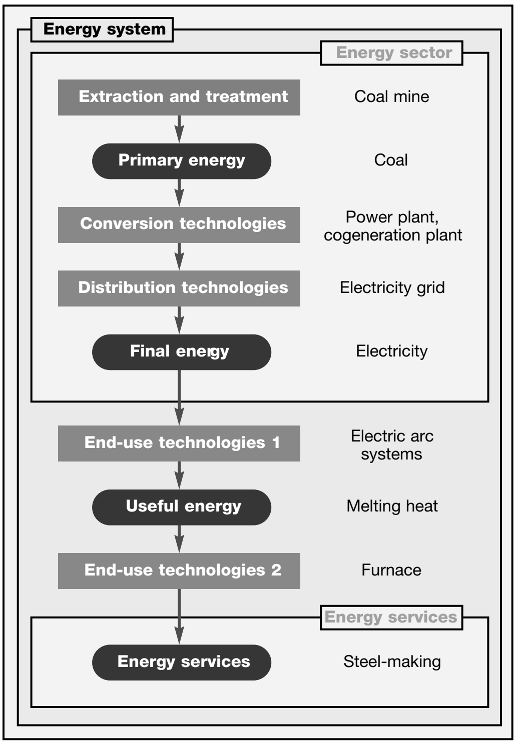

Figure 1: An example of the energy chain from extraction to services. *Source:* Adapted from Chapter 6.

energy that, in one or several steps, may be converted into energy carriers, such as electricity or diesel oil, that are suitable for end uses. Energy end-use equipment – stoves, light bulbs, vehicles, machinery – converts final energy into useful energy, which provides the desired benefits: the energy services. An example of an energy chain – beginning with coal extraction from a mine (primary energy) and ending with produced steel as an energy service – is shown in figure 1.

Energy services are the result of a combination of various technologies, infrastructure (capital), labour (know-how), materials, and primary energy. Each of these inputs carries a price tag, and they are partly substitutable for one another. From the consumer's perspective, the important issues are the economic value or utility derived from the services. Consumers are often unaware of the upstream activities required to produce energy services.

Per capita consumption of primary energy in the United States was 330 gigajoules in 1995, more than eight times as much as used by an average Sub-Saharan African (who used 40 gigajoules that year when both commercial and traditional energy are included). Many people in the least developed countries use much less. Figure 2 shows commercial and non-commercial energy consumption in various regions.

In most low-income developing countries, a small, affluent minority uses various forms of commercial energy in much the same way as do most people in the industrialised world. But most people in low-income developing countries rely on traditional, non-commercial sources of energy using inefficient technologies such as unventilated stoves or open fires. Traditional energy sources are generally not reflected in energy statistics. Analysis based on per capita consumption of commercially distributed energy resources is common because the data are much easier to collect. The resulting analysis, however, does not accurately reflect the world's energy situation, which is why estimates of non-commercial energy use are included in table 1 and figure 2. Though less well documented, non-commercial energy is very significant globally, and is used far more widely than commercial energy in rural areas of many developing countries, particularly the least developed countries.

The rate of global commercial energy consumption is thousands of times smaller than the energy flows from the sun to the earth. Primary energy

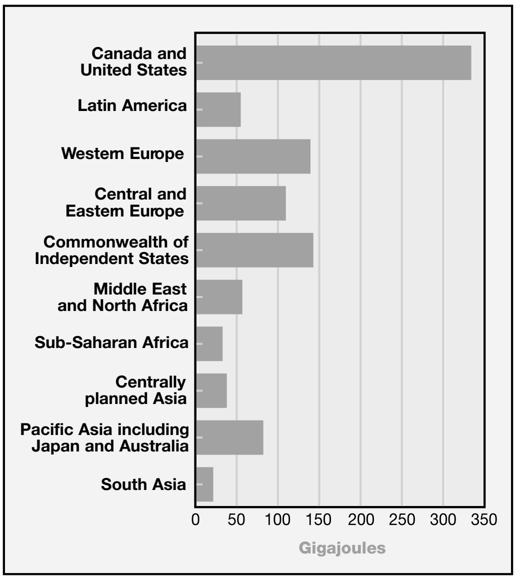

Figure 2: Primary per capita energy consumption (commercial and non-commercial) by region, 1995. *Source:* World Bank, 1997; WRI, 1998.

Table 1: World primary energy consumption, 1998

Source	Primary energy (exajoules)	Primary energy (10^9 tonnes of oil equivalent)	Percentage of total	Static reserve-production ratio (years)[a]	Static resource base-production ratio (years)[b]	Dynamic resource base-production ratio (years)[c]
Fossil fuels	320	7.63	79.6			
Oil	142	3.39	35.3	45	~200	95
Natural gas	85	2.02	21.1	69	~400	230
Coal	93	2.22	23.1	452	~1,500	1,000
Renewables	56	1.33	13.9			
Large hydro	9	0.21	2.2		Renewable	
Traditional biomass	38	0.91	9.5		Renewable	
'New' renewables[d]	9	0.21	2.2		Renewable	
Nuclear	26	0.62	6.5			
Nuclear[e]	26	0.62	6.5	50[f]	>>300[f]	
Total	**402**	**9.58**	**100.0**			

[a] Based on constant production and static reserves.
[b] Includes both conventional and unconventional reserves and resources.
[c] Data refer to the energy use of a business-as-usual scenario – that is, production is dynamic and a function of demand (see chapter 9). Thus these ratios are subject to change under different scenarios.
[d] Includes modern biomass, small hydropower, geothermal energy, wind energy, solar energy, and marine energy (see chapter 7). Modern biomass accounts for about 7 exajoules, and 2 exajoules comes from all other renewables.
[e] Converted from electricity produced to fuels consumed assuming a 33 percent thermal efficiency of power plants.
[f] Based on once-through uranium fuel cycles excluding thorium and low-concentration uranium from seawater. The uranium resource base is effectively 60 times larger if fast breeder reactors are used.
Source: Chapter 5.

consumption is reliant on fossil fuels (oil, natural gas, and coal), which represent nearly 80 percent of the total fuel mix (table 1). Nuclear power contributes slightly more than 6 percent, and hydropower and new renewables each contribute about 2 percent.

World-wide, traditional (often non-commercial) energy accounts for about 10 percent of the total fuel mix. But the distribution is uneven: non-commercial energy accounts for perhaps 2 percent of energy consumption in industrialised countries, but an average of 30 percent in developing ones. In some low-income developing countries, traditional biomass accounts for 90 percent or more of total energy consumption.

If the global growth rate of about 2 percent a year of primary energy use continues, it will mean a doubling of energy consumption by 2035 relative to 1998, and a tripling by 2055. In the past 30 years developing countries' commercial energy use has increased at a rate three and a half times that of OECD countries, the result of life-style changes made possible by rising personal incomes, coupled with higher population growth rates and a shift from traditional to commercial energy. On a per capita basis, however, the increase in total primary energy use has not resulted in any notable way in more equitable access to energy services between industrialised and developing countries. Clearly, more energy will be needed to fuel global economic growth and to deliver opportunities to the billions of people in developing countries who do not have access to adequate energy services.

However, the amount of additional energy required to provide the energy services needed in the future will depend on the efficiencies with which the energy is produced, delivered, and used. Energy efficiency improvements could help reduce financial investments in new energy supply systems, as they have over the past 200 years. The degree of interdependence between economic activity and energy use is neither static nor uniform across regions. Energy intensity (the ratio of energy demand to GDP) often depends on a country's stage of development. In OECD countries, which enjoy abundant energy services, growth in energy demand is less tightly linked to economic productivity than it was in the past (figure 3).

The trend towards a reduction in energy intensity as economic development proceeds can be

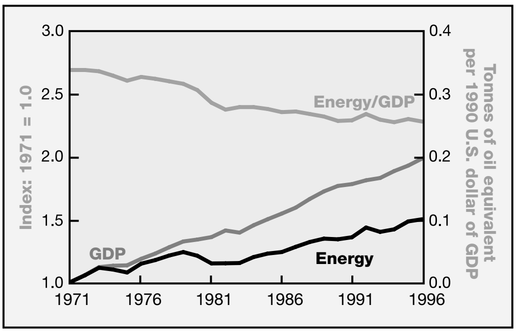

Figure 3: GDP and primary energy consumption in OECD countries, 1971–96. *Source:* IEA, 1999.

discerned over a long historical period, as shown in figure 4, which includes the developing country examples of China and India. A detailed, long-term analysis of energy intensity for a number of countries reveals a common pattern of energy use driven by the following factors:

- The shift from non-commercial to commercial forms of energy, industrialisation, and motorisation initially increase the commercial energy-GDP ratio. (In the 1990s this ratio increased in transition in economies, mainly because of slower economic growth.)
- As industrialisation proceeds and incomes rise, saturation effects, as well as an expansion of the service sector (which is less energy intensive), decrease the ratio of commercial energy to GDP after it reaches a peak. This maximum energy intensity has been passed by many countries, but not by low-income developing countries.
- As a result of world-wide technology transfer and diffusion, energy efficiency improvements can be the main limiting factor in the growth of energy demand arising from increasing populations and growing production and incomes.
- The more efficient use of materials in better-quality, well-designed, miniaturised products, the recycling of energy-intensive materials, and the saturation of bulk markets for basic materials in industrialised countries contribute to additional decreases in energy intensity.
- In developing countries, technological leapfrogging to the use of highly efficient appliances, machinery, processes, vehicles, and transportation systems offers considerable potential for energy efficiency improvements.

These drivers are leading to a common pattern of energy use per unit of GDP in industrialised and developing countries.

Energy prices influence consumer choices and behaviour and can affect economic development and growth. High energy prices can lead to increasing import bills, with adverse consequences for business, employment, and social welfare. High energy prices can also stimulate exploration and development of additional resources, create a pull for innovation, and provide incentives for efficiency improvements.

Although some impacts of energy prices are fairly steady, others are more transient. For example, different absolute price levels have had little effect on economic development in OECD European countries or Japan relative to the much lower energy prices in the United States and some developing countries. What affected economic growth in all energy-importing countries were the price hikes of the 1970s. It appears that economies are more sensitive to price changes than to prices per se.

Capital investment is a prerequisite for energy development. Energy system development and structural change are the results of investment in plants, equipment, and energy system infrastructure. Difficulties in attracting capital for energy investment may impede economic development, especially in the least developed countries. Scarce public funds, especially in developing countries, are needed for many projects – ranging from rural development, education, and health care to energy supplies. Because energy supply, more than any other alternative, is often seen as more readily capable of generating early revenues, energy investments are increasingly viewed as a private sector affair. Yet private funds are not flowing into many developing countries for a variety of reasons, especially risks to investors.

Foreign direct investment approached $400 billion in 1997 – up from $50 billion in 1984 – and represents an increasing share of international investment flows.[7] Foreign direct investment is generally commercially motivated, and investors not only expect to recover the initial capital but also count on competitive returns. These outcomes cannot be guaranteed in developing countries with potentially fragile governments or without free markets. In fact, very little foreign direct investment reaches the least developed countries.

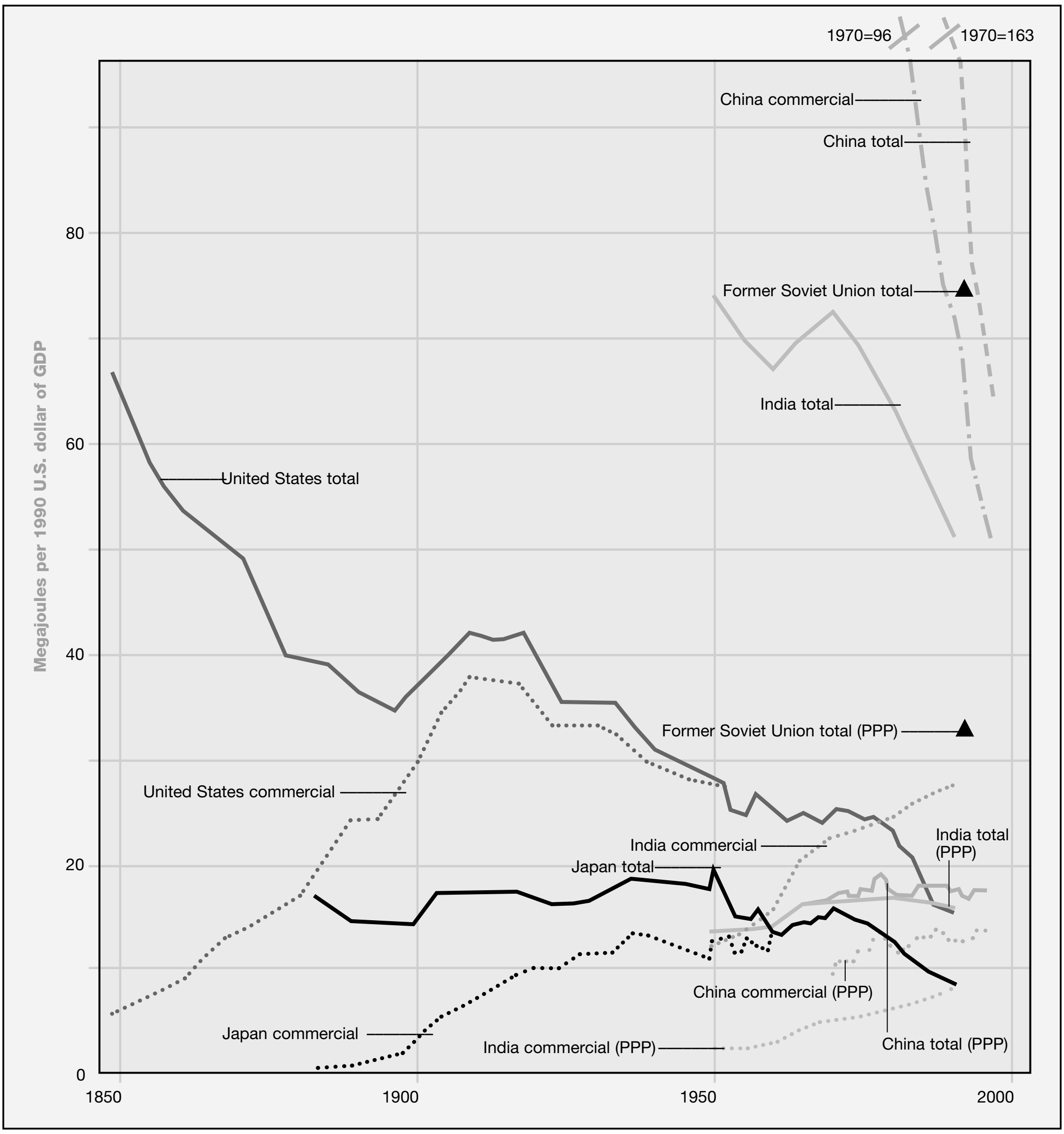

Figure 4: Primary energy intensities in various countries, 1850–2000. Two energy intensity paths are shown for Japan and the United States, one based on total energy consumption from all sources and the other only on commercial energy. The paths converge where traditional sources have been replaced by commercial energy. Because of distortions from market fluctuations, energy intensity paths for China and India are calculated in two ways: using total and commercial energy divided by GDP measured at market exchange rates (as with Japan and the United States), and divided by GDP measured at purchasing power parities (PPP). Energy intensities for the former Soviet Union, derived using both market exchange rates and PPP, are data points only. *Source:* Nakićenović, Grübler, and McDonald, 1998.

Unlike foreign direct investment, official development assistance has remained flat relative to gross world product. In 1997 it totaled \$56 billion, or 0.25 percent of the GDP of OECD countries – which have agreed in principle to a target of 0.7 percent of GDP.[8] Against this backdrop, financing is inadequate for energy projects in developing countries. Until the economic risks to foreign investors can be managed (for example, through clear and stable rules for energy and financial markets, steady revenue generation through bill collection, and profit transfers), most developing countries may have to continue to finance their energy development from domestic savings.

Although energy investment as a share of total investment varies greatly among countries and at different stages of economic development, on balance, 1.0–1.5 percent of GDP is invested in the energy sector. This ratio is expected to remain relatively stable. Based on these rules of thumb, current energy supply sector investment totals $290–430 billion a year. But this does not include investment in end-use energy efficiency.

ENERGY AND SOCIAL ISSUES

Energy use is closely linked to a range of social issues, including poverty alleviation, population growth, urbanisation, and a lack of opportunities for women. Although these issues affect energy demand, the relationship is two-way: the quality and quantity of energy services, and how they are achieved, have an effect on social issues as well.

Poverty is the overriding social consideration for developing countries. Some 1.3 billion people in the developing world live on less than $1 a day. Income measurement alone, however, does not fully capture the misery and the absence of choice that poverty represents. The energy consumption patterns of poor people – especially their reliance on traditional fuels in rural areas – tend to keep them impoverished.

World-wide, 2 billion people are without access to electricity and an equal number continue to use traditional solid fuels for cooking. As shown in the next section, cooking with poorly vented stoves has significant health impacts. In addition, hundreds of millions of people – mainly women and children – spend several hours a day in the drudgery of gathering firewood and carrying water, often from considerable distances, for household needs. Because of these demands on their time and energy, women and children often miss out on opportunities for education and other productive activities.

Lack of electricity usually means inadequate illumination and few labour-saving appliances, as well as limited telecommunications and possibilities for commercial enterprise. Greater access to electricity and modern fuels and stoves for cooking can enable people to enjoy both short-term and self-reinforcing, long-term advances in their quality of life. Table 2 summarises some of the specific improvements that may result.

Limited income may force households to use traditional fuels and inefficient technologies. Figure 5 shows the average primary energy demand for various fuels as a function of income levels in Brazil. For low-income households, firewood is the dominant fuel. At higher incomes, wood is replaced by commercial fuels and electricity, which offer much greater convenience, energy efficiency, and cleanliness. Because convenient, affordable energy can contribute to a household's productivity and income-generating potential, its availability can become a lever for breaking out of a cycle of poverty.

Although population growth tends to increase energy demand, it is less widely understood that the availability of adequate energy services can lower birth rates. Adequate energy services can shift the relative benefits and costs of fertility towards a lower number of desired births in a family. An acceleration of the demographic transition to low mortality and low fertility (as has occurred in industrialised countries) depends on crucial developmental tasks, including improving the local environment, educating women, and ameliorating the extreme poverty that may make child labour a necessity. All these tasks have links to the availability of low-cost energy services.

The growing concentration of people in urban centres is another key demographic issue linked to energy. Although the general trend towards urbanisation has many components and may be inevitable, providing more options to rural residents through energy interventions could potentially slow migration and reduce pressure on rapidly growing cities. Although the negative externalities associated with energy use in urban areas can be severe, various strategies can mitigate their effects and promote energy conservation. Taking energy into consideration in land-use planning, and in designing physical infrastructure, construction standards, and transportation systems, can reduce some of the growth in energy demand that accompanies rapid urbanisation.

Transportation systems may be especially important in this regard, given the rapid growth in the number of motor vehicles world-wide. Since about 1970 the global fleet has been increasing by 16 million vehicles a year, and more than 1 billion cars will likely be on the road by 2020. Most of these cars will be driven in the cities of the developing world, where they will create more congestion, aggravate

Table 2: Energy-related options to address social issues

Social challenge	Energy linkages and interventions
Alleviating poverty in developing countries	• Improve health and increase productivity by providing universal access to adequate energy services – particularly for cooking, lighting, and transport – through affordable, high-quality, safe, and environmentally acceptable energy carriers and end-use devices. • Make commercial energy available to increase income-generating opportunities.
Increasing opportunities for women	• Encourage the use of improved stoves and liquid or gaseous fuels to reduce indoor air pollution and improve women's health. • Support the use of affordable commercial energy to minimise arduous and time-consuming physical labour at home and at work. • Use women's managerial and entrepreneurial skills to develop, run, and profit from decentralised energy systems.
Speeding the demographic transition (to low mortality and low fertility)	• Reduce child mortality by introducing cleaner fuels and cooking devices and providing safe, potable water. • Use energy initiatives to shift the relative benefits and costs of fertility – for example, adequate energy services can reduce the need for children's physical labour for household chores. • Influence attitudes about family size and opportunities for women through communications made accessible through modern energy carriers.
Mitigating the problems associated with rapid urbanization	• Reduce the 'push' factor in rural-urban migration by improving the energy services in rural areas. • Exploit the advantages of high-density settlements through land planning. • Provide universal access to affordable multi-modal transport services and public transportation. • Take advantage of new technologies to avoid energy-intensive, environmentally unsound development paths.

Source: Adapted from chapter 2.

urban pollution, and undermine human health – even with optimistic projections about efficiency improvements and alternative fuels.

In developing countries, addressing the energy needs of the poor, who represent a large majority, will require major structural changes. On the other hand, in industrialised countries adequate access to affordable energy is problematic only for a minority, and thus more amenable to social policy solutions. Throughout the world, however, poor households pay a larger fraction of their incomes for energy than do the rich, and so are vulnerable to rapid increases in the price of energy. Increases in the price of oil in the winter of 1999/2000, for example, posed a hardship for many people, even in some industrialised countries.

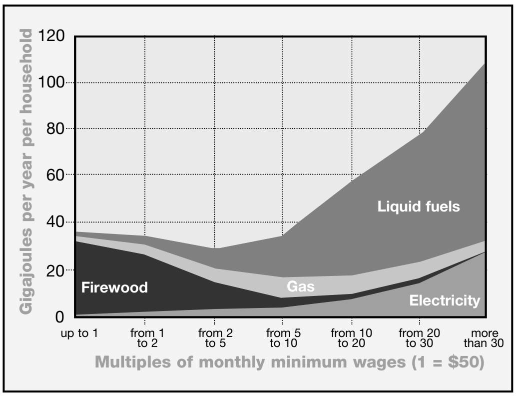

Figure 5: Average energy demand by income segment in Brazil, 1988. *Source:* De Almeida and de Oliveira, 1995.

Eradicating poverty is a long-term goal of development. But long before that goal is achieved, convenient and affordable energy services could dramatically improve living standards and offer more opportunities to people. Today's inequity is unsustainable. Satisfying the energy needs of the poor with modern technologies has the potential to improve standards of living and health, and to create new jobs and business opportunities. Allowing one-third of the world's population to continue

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to endure the constraints associated with traditional energy is unacceptable from a humanitarian and moral standpoint. Making commercial energy more widely available makes sense from a political perspective as well. The wave of democratisation sweeping the world is putting political power in the hands of the economically disenfranchised. Societies with grave inequalities and disparities tend to be unstable, and large populations below the poverty line are fertile ground for social upheavals.

ENERGY, THE ENVIRONMENT, AND HEALTH

The environmental impacts of energy use are not new. For centuries, wood burning has contributed to the deforestation of many areas. Even in the early stages of industrialisation, local air, water, and land pollution reached high levels. What is relatively new is an acknowledgement of energy linkages to regional and global environmental problems and of their implications. Although energy's potential for enhancing human well-being is unquestionable, conventional energy[9] production and consumption are closely linked to environmental degradation. This degradation threatens human health and quality of life, and affects ecological balance and biological diversity.

The environment-energy linkage is illustrated in table 3, which shows the share of toxic emissions and other pollutants attributable to the energy supply. The human disruption index is the ratio of the human-generated flow of a given pollutant (such as sulphur dioxide) to the natural, or baseline, flow. Thus, in the case of sulphur, the index is 2.7, which means that human-generated emissions of 84 million tonnes a year are 2.7 times the natural baseline flow of 31 million tonnes a year. The table indicates that, together with other human activities, energy systems significantly affect the global cycling of important chemicals. Although by itself the index does not demonstrate that these emissions translate into negative impacts, their magnitudes provide warning that such impacts could be considerable. Some impacts, as discussed below, are already significant.

Just in the course of the past 100 years, during which the world's population more than tripled, human environmental insults[10] grew from local perturbations to global disruptions. The human disruptions 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 – have amounted to no less than the emergence of civilisation as a global ecological and geochemical force. In other words, the accelerating impact of human life is altering the world at the global level.

At every level (local, regional, global), the environmental consequences of current patterns of energy generation and use make up a significant fraction of human impacts on the environment. At the household level, solid fuel use for cooking and heat has significant health impacts. Poor air quality – at the household, local, and regional levels – is associated with increased sickness and premature death. About 2 million premature deaths a year – disproportionately of women and children – are estimated to occur from exposure to indoor air pollution caused by burning solid fuels in poorly ventilated spaces. Particulate matter (which is both emitted directly and formed in the air as the result of the emissions of gaseous precursors in the form of oxides of sulphur and nitrogen) and hydrocarbons are growing concerns world-wide. They are especially troublesome in many parts of the developing world, where dirtier fuels predominate with little emissions abatement. No safe threshold level for exposure to small particulate matter has been established.

Fossil fuel combustion is problematic on several levels (although natural gas produces significantly fewer harmful emissions than do oil or coal). The main pollutants emitted in the combustion of fossil fuels are sulphur and nitrogen oxides, carbon monoxide, and suspended particulate matter. Ozone is formed in the troposphere from interactions among hydrocarbons, nitrogen oxides, and sunlight. Energy-related emissions from fossil fuel combustion, including in the transport sector, are major contributors to urban air pollution. Precursors of acid deposition from fuel combustion can be precipitated thousands of kilometres from their point of origin – often crossing national boundaries. The resulting acidification is causing significant damage to natural systems, crops, and human-made structures; and can, over time, alter the composition and function of entire ecosystems. In many regions acidification has diminished the productivity of forests, fisheries, and farmlands. Large hydropower projects often raise environmental issues related to flooding, whereas in the case of nuclear power, issues such as waste disposal raise concern.

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Table 3: Environmental insults due to human activities by sector, mid-1990s

Insult	Natural baseline (tones per 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 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 emissions to atmosphere	3,100 million^d	0.12	35% (fossil fuel burning)	10% (traditional fuel burning)	40% (agricultural burning)	15% (smelting, 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 human-induced lead emissions in this table 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: Chapter 3.