Chapter 1

Introduction and Overview

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Introduction

Energy use in developing countries has risen more than fourfold over the past three decades and is expected to continue increasing rapidly in the future. The increase in the services that energy provides is necessary and desirable, since energy services are essential for economic growth, improved living standards, and to provide for increased human populations. But finding the energy supplies to provide these services could cause major economic and social problems. For many of the developing countries, much of the additional energy needed will be supplied by imported oil, and rising oil imports will further burden those countries already saddled with high oil import bills. Similarly, building dams or powerplants to meet higher demands for electricity could push these nations even deeper into debt. Energy development and use also contribute to local environmental damage in developing countries, including record levels of air pollution in some urban areas.

The rapid growth of energy use in developing countries has wide impacts. The economic development process has traditionally been accompanied by rapid increases in oil demand, which, together with rising demand in the industrial countries, contribute to upward pressures on world oil prices. High levels of indebtedness in the developing countries, partly energy-related, have already contributed to instability in the international money and banking system. Rapid increases in fossil fuel use in developing countries also represent a growing contribution to the increase in local and regional air pollution as well as atmospheric concentrations of greenhouse gases such as carbon dioxide (CO_2). International efforts to control greenhouse gas emissions require active participation by developing countries. Many developing countries could be adversely affected by climate change, some much more than most industrial nations.

An economically and environmentally sound approach to energy development offers potentially large benefits both for the developing countries and for the rest of the world. It can contribute to economic growth in the developing countries, leading to higher living standards, reduction of hunger and poverty, and better environmental quality. This strategy also holds benefits for the richer countries. The developing countries are important trading partners for the United States. More rapid economic growth in these countries could stimulate U.S. exports, including exports of energy technology products, and, therefore, could benefit the U.S. trade balance. Improved energy technologies can slow the rate of increase in greenhouse gas emissions-a global benefit.

The Purpose of This Assessment

This report is part of an assessment entitled "Fueling Development: Energy and Technology in the Developing Countries,' requested by the Senate Committee on Governmental Affairs; the House Committee on Energy and Commerce; the Subcommittee on Energy and Power of the House Committee on Energy and Commerce; the Subcommittee on Human Rights and International Organizations and the Subcommittee on Africa of the House Committee on Foreign Affairs; the Subcommittee on International Development, Finance, Trade and Monetary Policy of the House Banking Committee; and individual members of the Senate Environment and Public Works Committee, the House Select Committee on Hunger, and the Congressional Competitiveness Caucus.

The Office of Technology Assessment (OTA) was asked to examine the extent to which technology can provide the energy services that developing countries need for economic and social development in a cost-effective and socially viable manner, while minimizing the adverse environmental impacts; and to evaluate the role of the United States in accelerating the adoption of such technologies by developing countries.

This report, the frost product of the assessment, examines how energy is currently supplied and used in the developing countries and how energy is linked with economic and social development and the quality of the environment. Our emphasis is primarily on the present status of developing countries, and concerns about current energy trends. This report is intended to provide an introduction to the problems, challenges, and opportunities associated with providing energy services for economic and social development in the developing countries. These issues are examined under four broad topic areas: energy and economic development (ch. 2); energy services (ch. 3); energy supplies (ch. 4); and energy use and the environment (ch. 5). A subsequent report will present the results of OTA's assessment of technologies that can potentially improve the efficiency of both energy production and use in developing countries; an examination of the technology transfer process; and ways in which Congress can help promote the rapid adoption of such policies.

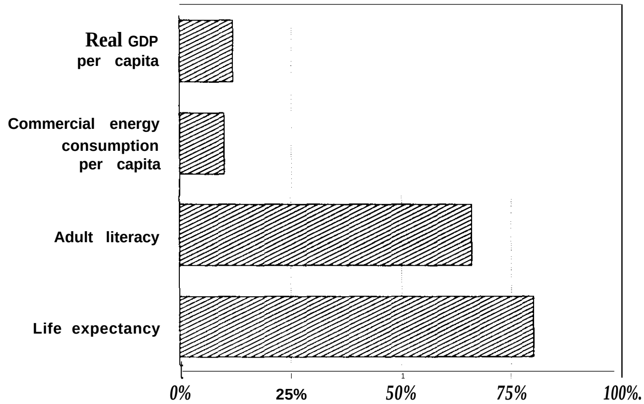
The Developing World and the Industrialized World

We largely follow the definition of "developing" countries-low- and middle-income countries (further divided into lower middle and upper middle countries)---used by the World Bank[1] (see app. 1A for a list of these countries), including all of the countries of Africa, Latin America, and Asia, excluding Japan.[2]

There are wide differences in *average* indicators of social and economic conditions between developing and industrial countries (figure l-l).

1. *Social: The* citizens of (OECD) countries have a longer life expectancy (76 years, compared with an average of 62 in developing countries), largely due to lower infant mortality rates (9 per 1,000 live births compared with 71 in developing countries). A much larger share of the population has access to secondary and higher education and health care.
2. *Economic:* Average per-capita incomes[3] (expressed in purchasing power parities[4]) are more than eight times higher in OECD countries than in the developing countries. This difference in income levels reflects major differences in economic structure, particularly the higher share of agriculture in total production in the developing countries. A much lower share of

Figure I-I—Differences Between Developing and Industrial Nations (developing nation average as a share of Industrlal* nation average)



How to Interpret thls flgure. The average values for the industrial countries are assigned 100 in all cases. The values for the developing countries are expressed as a share of 100. For example, average life expectancy in the industrial nations is 76 years and in the developing nations 62 years, or 82 percent of the industrial country level.

"Industrial excludes the U. S. S. R.; based on weighted average of high-income market economies.

SOURCE: United Nations, *Human DevelopmenfReport 199a* World Bank *WorldDevelopment Report.*

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[1] See, for example, World Bank, *World Development Report* 1989 (New York, NY: Oxford University Press, 1989), pp. 164-165.

[2] The definition of developing countries is based primarily on per-capita income levels. This ranking system is rather arbitrary, however; if all the countries of the world are ranked by ascending level of per-capita income, there is no obvious gap in the series to demarcate the two groups of countries. The World Bank distinguishes six categories of counties: low-income, lower-middle-income, upper-middle-income, high-income oil-exporters, industrial market economies, including OECD as a subset, and "non-reporting non-members" (the U.S.S.R., North Korea, East Germany, Angola, Bulgaria, Albania, Mongolia, and Namibia). The group of developing countries (low- anmiddle-income and upper-rniddle-income countries) does not include Saudi Arabia, Kuwait, and the United Arab Emirates by virtue of their high per-capita income. The World Bank does, however, include as developing countries some East and West European countries, such as Poland, Hungary, Yugoslavia, Greece, and Turkey, that qualify as developing countries by virtue of their income levels, but, due to their integration with industrial economies of East and West Europe, do not share other characteristics of underdevelopment, and are therefore not included in this report. Some other countries are excluded due to lack of reported data. Where group averages of general economic and social indicators are reporteddirectly from the *World Development Report,* these *countries are* included in the total. In more detailed analysis, they are excluded. While every effort is made to adhere to thesedefinitions, it is not always possible, especially when other sources of data with slightly differentdefinitions are used.

[3] Income is usually measured by Gross Domestic or Gross National Product. The difference between the two—typically small for most countries—is that GDP measures the total output of goods and services within the national border of a country, whereas GNPmeasures the output of goods andservices attributable to the nationals of a country wherever that activity occurs.

[4] If market exchange rates are used to convert the GDP of different countries to dollars, averageOECD per-capita income appears to be over 20 times *higher than* average developing country per-capita income. If, however, the comparison of income levels is adjusted to take inaccount differences in purchasing power of currencies (i.e., what a unit of currency such as the dollar will buy in different countries) the gap between average per-capita income levels in developing and OECD countries narrows, and OECD per-capita income levels are 8 times rather than 20 times higher tban the developing country average. In either case, the gap in income levels is substantial.

the population lives in urban areas-37 percent in the developing countries compared with 77 percent in the OECD countries. Population growth is more rapid in developing countries. It is estimated to double by 2040, while the population of the industrial world will increase by only 15 percent over the same period.

3. *Energy: The* economic and social contrasts are also reflected in energy consumption. Per-capita consumption of commercial energy (coal, oil, gas, and electricity)[5] in the OECD countries is on average 10 times higher than in the developing countries. On the other hand, commercial energy consumption is increasing much faster in the developing countries. Biomass energy consumption in the developing countries is higher than in the OECD countries and provides a much higher share of total energy consumption.

Similarities and Differences Among Developing Countries

The developing country averages shown in figure 1-1, though adequate to illustrate the broad contrasts between developing and industrial countries, obscure the wide economic and social differences among developing countries. Indeed, the range of differences between LDCs is greater than that between many of them and the industrial countries. A generation of exceptionally fast economic growth in the Newly Industrialized Countries (the NICs), combined with the slow growth, or in some cases, economic stagnation and decline, in many African countries, has widened the gap among developing countries. Thus the problems, energy or otherwise, faced by a relatively rich and developed country such as Brazil are different from those faced by a poor country like Ethiopia, as are the resources available for their solution. An appreciation of these differences is necessary for the realistic assessment of energy technologies.

Per-capita incomes in the upper middle-income developing countries (e.g., Brazil, Argentina, Algeria, Venezuela, and Korea) are almost seven times higher than in the low-income countries (table 1-1).[6] The income differential reflects major differences in economic structure. In the upper middle-income countries, industry has a much larger share in total output and agriculture a much lower share. India and China are exceptions, with atypically large shares of industry, given their levels of income. The share of the total population living in urban areas is much lower in the low-income countries. For example, in several African countries only about 10 percent of the total population is urban[7] dwellers, in contrast to countries like Brazil, Argentina, and Venezuela, whose levels of urbanization (about 80 percent of the population living in towns) are similar to those in the industrial countries.

Developing countries also show wide variations in social indicators. Life expectancy at birth rises from an average of 54 years in the low-income developing countries to an average of 67 in the upper middle-income countries. Infant mortality is twice as high in the low-income countries (over 100 per 1,000 births compared with an average of 50 in the upper middle-income developing countries). India and China are again exceptions: in both countries, despite lower average income, indicators of social development are similar to those found in countries with much higher incomes. The experience of these two countries testifies to the importance of social policies in achieving relatively high levels of social development despite low incomes.[8] Population growth rates also differ widely among developing countries. In recent years these have ranged from about 1 percent annually in some countries (e.g., China, Uruguay, Korea) to over 3 percent in several African countries.

The wide variations in social and economic conditions in developing countries are also reflected in their energy use. In the upper middle income de-

[5] The term "commercial energy" conventionally applies to coal, oil, gas, and electricity on the basis that they are widely traded in organized markets. These fuels are distinguished from other fuels such as firewood, charcoal, and animal and crop wastes, which are described as "biomass" or "noncommercial fuels." The distinction between them can be misleading, particularly in the context of developing countries, as some of the so-called "noncommercial" fuels, such as firewood and charcoal are also widely traded in highly organized markets. To minimize this ambiguity we use the term "biomass energy" here.

[6] See also app. 1A.

[7] Estimates of urban populations are based on country-specific criteria related to size of settlement and presence of urban characteristics.

[8] This theme is developed further in a recent publication by the United Nations Development Programme, *Human Development Report 1990 (New York, NY:* Oxford University Press, 1990).

[9] See footnote 5.

Table 1-1—Heterogeneity of the Developing World: Social, Economic, and Energy Indicators

Indicators	Year	Low-income countries	India and China	Lower middle-income countries	Upper middle-income countries
Economic:					
GNP per capita ($1987) (ppp)[a]	1987	840.0	900.0	3,000.0	5,420.0
Share agriculture in GDP (%)[b]	1987*	33.0	30.0	21.0	10.0*
Urban population as share of total (%)[c]	1987	24.0	33.0	51.0	66.0
Cars and trucks per 1,000 members of Population[d]	1980*	3.2	3.2	19.3	93.3
Social:					
Life expectancy at birth (years)[e]	1987	54.0	65.0	64.0	67.0
Infant mortality per 100 births[f]	1987	103.0	62.0	61.0	50.0
Share of age group with secondary education (%)9	1986	25.0	39.0	51.0	59.0
Energy:					
Commercial energy consumption per capita (gigajoules)[h]	1986	4.9	16.3	36.2	58.3
Total energy consumption per capita (gigajoules)[i]	1986	12.3	18.7	41.7	67.0**
Share of traditional energy in total (%}[j]	1986	60.0	13.0	13.0	13.0**

* Estimated.

If Brazil is excluded, the total per capita energy consumption would be 62 gigajoules and the share of traditional energy in total 2 percent.

SOURCES: [a]World Bank, *World Development Report 1989 (New York, NY:* Oxford University Press, 1969). Purchasing power parity (ppp) estimate based on data on pp. 164 and 222.

[b]Ibid., based on data in table 3.

[c]Ibid., table 31.

d JoY Dunkerley and Irving Hoch, *Transport Energy: Determinants* and *Policy* (Washington, DO: Resources for the Future, September 1985), table 5-1 and appendix table 13. Based on estimates. Note that totals are unweighed averages and the countries included differ slightly from *Work/ Development Report 1989.*

e World Bank, op. cit., table 1.

[f]Ibid., table 32.

g Ibid., table 29.

[h]Ibid, table 8.

[i]United Nations, *Energy Statistics Yearbook* 1986(New York, NY: United Nations, 1988), table 4.

[j]These values for the share of traditional energy are muoh lower than those found in field surveys. These values are presented herein order to have a consistent data set. Estimates based on field surveys suggest that biomass provides one-third of the energy used by developing countries overall (chs. 3 and 4).

Table 1-2-Commercial Energy Import Dependence in Developing Countries

Country income group	Number of countries in group[a]	Number of energy exporters	Number of energy importers	High importers (70-100%)b	Medium importers (30-70%)[b]	Low importers (0-30%)[b]
Low-income	38	4	34	29	3	2
China and India	2	1	1	0	0	1
Lower middle-income	30	10	20	15	3	2
Upper middle-income	10	6	4	2	1	1
Total	80	21	59	46	7	6

a Ind~es all countries for which import dependence data are available.
b shares of imports in total commercial energy Consumption.

SOURCE: Based on data in the United Nations, *1986 Energy Statistics Yearbook(New York, NY:* 1988).

veloping countries, per-capita annual *commercial* energy consumption (at 60 gigajoules[10]) is 12 times higher than in the low-income countries (5 GJ).[11] Again China and India differ from the other low-income countries, with per-capita consumption of commercial energy more than 3 times higher than other low-income countries. Per-capita consumption of *traditional* biomass fuels, on the other hand, is generally higher in the poorest countries, depending on the biomass resources available.[12]

There are similarly large variations in energy resource endowment. While many countries have some energy resources, three-quarters of the developing countries depend on imports for part or all of their commercial energy supplies (table 1-2). Levels of import dependence vary, but in many countries, imports (almost entirely oil) provide nearly all commercial energy supplies. Oil imports can be a considerable strain on already tight foreign exchange budgets. In several countries, particularly in Africa and Central America, oil imports represent over 30 percent of foreign exchange earnings from exports (see app. 1A).

Despite these differences in aggregate indicators, there are strong similarities among developing countries within specific sectors. Energy use in traditional villages throughout the developing world is fairly similar in terms of quantity used, source (biomass, muscle power), and services provided (cooking, subsistence agriculture). At the other end of the scale, energy use by the economically well off is also reasonably similar between developing and industrial countries, in terms of quantity used (to within a factor of 2 or 3), source (oil, gas, coal, electricity), and services provided (electric lighting and appliances, industrial goods, private automobiles, etc.). The large differences between countries are then in large part due to the relative share of the total traditional villagers and the economically well off in the population, and in the forms and quantities of energy used by those who are making the transition between these two extremes. The broad similarities *within* specific population sectors imply that it is possible to make generalizations about technology that are applicable to a wide range of otherwise disparate countries.

The Developing World in Global Energy[13]

The developing countries now account for about 30 percent of global energy use, including both commercial and traditional energy (see table 1-3), and their share is growing rapidly. Their use of the different fuels vary widely: they account for 85 percent of biomass fuel consumption but only 23 percent of commercial fuels (oil, gas, coal, and electricity). The main sources of energy for the developing countries as a group are coal, oil, and

[9]See footnote 5.

[10]A gigajoule (GJ), or 1 billion joules, is about& energy content of 8 gallons of gasoline. For reference, annual per-capita energy consumption in the United States is 327 million British thermal units (Btu) or 343 gigajoules. An exajoule (EJ), or 10^{18} joules, is about the same as a Quad (1.05 EJ = 1 Quad).

[11]World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989). Data, from p. 172, in tonnes Of oil equivalent (toe) converted to gigajoules at 1 toe = 41.9 gigajoules.

[12]Brazil, despite its relatively hi@ income, uses substantial quantities of biomass fuels in modern applications, such SS charcoal for steelmaking and ethanol for cars. This contrasts with the use of biomass in the poorer countries, as a cooking fuel using traditional technologies.

[13]The data in this section are taken from the World Energy Conference, *Global Energy Perspectives 2000-2020*, 14th Congress, Montreal 1989 (Paris 1989); and the United Nations, 1986 *Energy Statistics Yearbook (New* York, NY: 1988), updated to 1987 by data provided by the U.N. Secretariat.

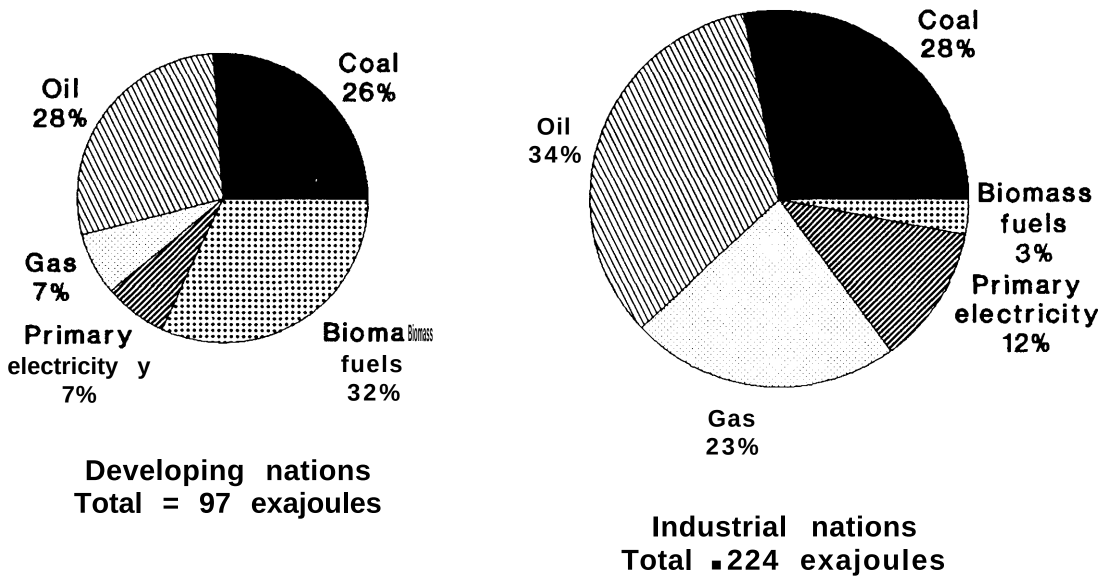
Table 1-3-1985 Primary Energy Supplies (exajoules)

	Coal	Oil	Gas	Primary electricity	Total commercial	Biomass	Total energy
World	88.7	104.6	58.2	33.0	284.5	36.9	321.3
Industrial countries	63.5	77.0	51.7	26.6	218.7	5.5	224.2
Developing countries	25.2	27.7	6.5	6.4	65.7	31.3	97.1
Share of industrial countries	72%	74%	89%	81%	7770	15%	70%
Share of developing countries	28%	26%	11%	19%	23%	85%	30?40

NOTE: As in table 1-1, the values reported for developing country biomass are too low. Field surveys indicate that biomass accounts for roughly one-third of the energy used in developing countries.

SOURCE: World Energy Conference, *Global Energy Perspectives 2000-2020,* 14th Congress, Montreal 1989 (Paris: 1989).

Figure 1-2—1985 Energy Consumption, Industrial and Developing Region Fuel Mix



SOURCE: World Energy Conference, *Global Energy Perspectives 2000-2020,* 14th Congress, Montreal 1989 (Paris: 1989).

biomass (see figure 1-2). However, much of the coal is used in India and China only. The other developing countries rely heavily on oil and biomass for their energy supplies. Several developing countries—China, India, Mexico, Brazil, and South Africa-are among the world's 20 largest commercial energy consumers (see table 1-4). China alone accounts for almost 10 percent of the world's total commercial energy use.

Three countries-China, India, and Brazil—together account for about 45 percent of total developing country consumption of both commercial and biomass fuels. And these countries plus four more-Indonesia, Mexico, Korea, and Venezuela--account for 57 percent of the total. At the other end of the scale are a large number of small countries that, combined, account for only a small part of global consumption. The 50 countries of Africa, for example, use under 3 percent of total world commercial energy consumption. Concerns about global energy use and its implications focus attention on the large consumers, but the energy needs of the small developing nations, though of lesser importance to global totals, are critical to their development prospects.

The developing countries are becoming increasingly important actors in global commercial energy. Their share of the total has risen sharply in recent years (see figure 1-3), from 17 percent of global commercial energy in 1973 to over 23 percent now. Despite their much lower levels of per-capita commercial energy consumption, developing coun-

Table 1-4-Largest Energy Consumers, 1987

Country	Total commercial energy consumption (exajoules)	Per-capita commercial energy consumption (gigajoules)
20 largest commercial energy consumers:		
Rank		
1 United States	68.1	280
2 U.S.S.R.	54.7	194
3 China	23.5	22
4 Japan	13.4	110
5 West Germany	10.0	165
6 United Kingdom	8.5	150
7 Canada	7.5	291
8 India	6.5	8
9 France	6.1	109
10 Italy	6.0	105
11 Poland	5.3	141
12 Mexico	4.1	50
13 East Germany	3.8	231
14 Australia	3.2	201
15 Brazil	3.2	22
16 South Africa	3.2	83
17 Romania	3.1	136
18 Netherlands	3.1	213
19 Czechoslovakia	2.9	185
20 Spain	2.4	147
10 largest developing country energy consumers:		
Rank		
1 China	23.5	22
2 India	6.5	8
3 Mexico	4.1	50
4 Brazil	3.2	22
5 South Africa	3.2	83
6 South Korea	2.2	52
7 Argentina	1.7	56
8 Venezuela	1.6	88
9 Indonesia	1.4	8
10 Egypt	1.0	20

NOTE: Data for the top 10 developing country energy consumers include only countries listed in app. 1A.

SOURCE: United Nations secretariat.

tries accounted for one-half of the total *increase in* global commercial energy consumption since 1973.

The increasing share of the developing countries in global commercial energy consumption is widely predicted to continue. The World Energy Conference projects an increase in their share to 40 percent by *2020 (see figure 1-3),* and this trend is confirmed in a large number of other studies.[14] The developing countries are projected to account for almost 60 percent of the global *increase* (over current levels) in commercial energy consumption by 2020. China alone accounts for over one-third of this increase. These increasing shares are sufficiently large to have a major impact on world energy markets. Despite the more rapid rate of growth in energy consumption in developing countries, their per-capita consumption of commercial energy will still continue to be far below the levels in industrial countries (see figure 1-4).

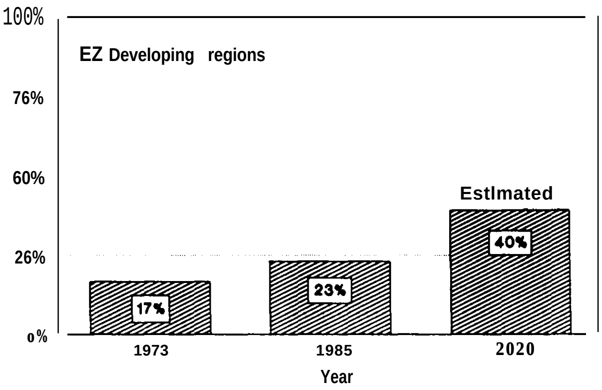
Analytic Focus

The analysis presented in this OTA study has three important features. First, rather than concentrating on energy supplies, the analysis focuses on the services energy provides. The reason for this approach is simple. Energy is not used for its own sake, but rather for the services it makes possible--cooking, heating water, cooling a house, heating an industrial boiler, transporting freight and people. Further, there may be many different means of providing a desired service, each with its own costs and benefits. For example, transport is provided in a number of ways-bicycle, motorcycle, car, bus, light rail, or aircraft. The consumer chooses among these according to such criteria as cost, comfort, convenience, speed, and even aesthetics. Within these consumer constraints, a more efficient car may be preferable to increasing refinery capacity in order to reduce capital and/or operating costs, or because of environmental benefits. More than just engineering and economics must be considered, including social, cultural, and institutional factors. Such factors are more readily included in a services framework than in a conventional energy supply analysis.

Second, within this services framework the changes in how energy is used are traced from traditional rural areas to their modem urban counterparts. This

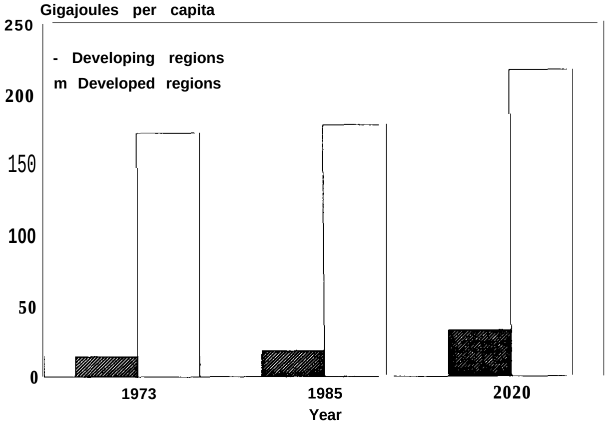
[14] An analysis of projections of global commercial energy consumption over the next 20 years in Allan S. Manne and Leo Schrattenholzer, *International Energy Workshop: Overview of Poll Responses* (Stanford University International Energy Project, July 1989), reports the results and assumptions of over 100 projections of global energy consumption and production and provides the means of the different studies. Not all studies report results fall regions. The coverage is nonetheless a comprehensive indicator of how energy forecasters view the futur They suggest that the developing countries' share could rise to over one-third by 2010. Longer term projections in general arrive at similar conclusions. For example, th *Emissions Scenarios* document, prepared by the Response Strategies Working Group of the Intergovemmental Panel on Climate Change, Appendix Report of the Expert Group on Emissions Scenarios (RSWG Steering Committee, Task A), April 1990, concludes that, overa wide range of scenarios, the share of developing countries (Centrally Planned Asia, Africa, Middle East, and South and East Asia) will increase from a 1985 reference level of 23 percent to between 40 and 60 percent of global energy in 2100, and that this group of developing countries would account for between 60 and 80 percent of the total increase in energy consumption over this period. Further, developments in the developing countries define much of the difference between the low and high growth scenarios.

Figure 1-3-Commercial Energy Consumption, 1973, 1985, and 2020 (developing nation energy demand as a percentage of world total)



SOURCE: World Energy Conference. *Global Energy Perspectives 2000-2020*, 14th Congress, Montreal 19S9 (Paris: 1989).

Figure 1-4-Per-Capita Commercial Energy Consumption, 1973, 1985, and 2020



SOURCE: World Energy Conference, Global *Energy Perspectives 2000-2020*, 14th Congress, Montreal 1989 (P&is: 1989).

progression from the traditional rural to the modern urban helps illuminate the dynamics of energy use, and how it can be expected to change in the future.

Third, the entire system needed to provide energy services-from the energy resource to the final energy service, including production, conversion, and use-is examined as a whole. This is done in order to show the total costs and consequences to society, as well as to the individual, of providing particular services, and how they might be provided more effectively in terms of financial, environmental, and other costs. For example, increased lighting services can be met by using more conventional lighting and increasing the amount of electricity generated, by increasing the use of more efficient light bulbs, or by a combination of the two. A systems approach permits the comparison of efficiency and supply options in achieving the desired end.

In our analysis of energy services and systems it is recognized that technology adoption and use is embedded in an institutional framework that provides both incentives and disincentives to users, and largely determines which and how technologies will be used. This approach has a number of implications both for the way technology is used now and for the adoption of new technologies in the future. Thus, the energy sector in many developing countries is frequently characterized as "inefficient" in the sense that more energy is used to provide a given service or output than is usual in industrial countries. In a wider context, however, taking into account the many other relevant factors (financial, infrastructural, managerial, and institutional), the technology may well be used to the best of human ability and often with considerable ingenuity and resourcefulness. In many cases, although energy *appears* to be used inefficiently, energy users may be acting logically given the framework of incentives and disincentives within which they make their decisions. It follows therefore that the adoption of a new technology will depend not only on the intrinsic superiority of the technology itself but also on whether institutional factors favor its adoption. The policy environment is of crucial importance to the adoption of new technologies.

Overview of the Report

Energy consumption in the developing world has risen rapidly in the past and is widely expected to continue increasing rapidly in the future. The World Energy Conference, for example, projects (in its "moderate" economic growth case) a tripling in consumption of commercial energy in developing countries between now and 2020. A survey of a large number of projections of commercial energy use broadly confirms this trend. The projected rate of increase in commercial energy consumption implicit in these forecasts is lower than that experienced between 1973 and 1985.[15] Increased supplies of biomass fuels (fuelwood and animal and crop wastes) will also be required. The World Energy Conference projects a 25 percent increase in biomass use. Population growth and economic development are the principal forces driving the rapid increase in energy use.

Population Growth

In many developing countries, fertility rates (the number of children expected to be born to a woman during the course of her life) have dropped dramatically over the past 20 years. Nevertheless, the population of the developing world continues to grow rapidly. Over 90 percent of world population growth is now occurring in the LDCs. At present, the population of the developing countries is about 4 billion, 77 percent of the world's population. Even assuming continued decreases in fertility rates, the population of these countries is projected to rise to 7 billion in 2025,[16] and could reach 10 billion in 2100, due to the large number of women of childbearing age. Developing countries would then account for 88 percent of the global population in 2100, and for virtually all of the increase in global population. The increase in population alone in developing countries would account for a 75 percent increase in their commercial energy consumption by 2025 even if per-capita consumption remained at current levels.

Economic Development

Securing higher living standards for the increasing population of the developing world implies high rates of economic growth. The World Energy Conference, for example, assumes in its "moderate" growth rate scenarios, an average annual gross rate of economic expansion of 4.4 percent to 2020, slightly lower than in the past. This would represent more than a fourfold increase in economic activity between now and 2020. Achieving such rates of growth will certainly not be easy, especially in light of the high levels of debt that have constrained economic growth in the 1980's, and increasing competition for foreign assistance from the countries of Eastern Europe; but failure to achieve high rates of growth could spell great hardship for the developing countries, as their populations are growing so rapidly.

The process of economic development that underlies improving living standards in developing countries involves a number of changes, including higher agricultural productivity, growth of manufacturing, construction of a modern public works infrastructure, urbanization, and increased transportation (table 1-5 shows the rapid increase in the road transport fleet). Higher standards of living also lead to expansion in the ownership of consumer appliances (table 1-6 illustrates saturation levels for some of the most widely used appliances). All of these changes have profound impacts on the amounts and types of energy used.

Commercial energy consumption typically rises faster than economic growth as the development process gets underway, and the share of commercial energy in total energy consumption grows as it takes the place of traditional biomass fuels. Even though the relative share of traditional fuels has declined, the absolute amounts consumed have continued to rise, by an estimated 2.5 percent per year.[17]

Despite the strong connection between commercial energy consumption and economic growth, there is evidence of considerable differences among developing nations in their energy intensity-the amount of commercial energy consumed relative to Gross National Product (GNP). There are examples of countries with similar per-capita incomes that consume quite different quantities of commercial energy. Some of these differences result from country-specific physical characteristics, but others are associated with differences in social and economic policies. Policies promoting heavy industry and high rates of urbanization contribute to high energy intensities. Similarly, the energy intensities of countries change over time. In several industrial countries energy intensities declined even before 1973 at a time when oil prices were falling, largely

[15] World Energy Conference, *Global Energy* Perspectives *2000-2020*, Montreal, 1989 (Paris: 1989) projects a threefold increase in consumption of commercial fuels in developing countries between 1985 and 2020. The Marine study projects a rise of 250 percent between 1985 and 2010 (see Alan S. Marine and Leo Schrattenholzer, "International Energy Workshop: Overview of Poll Responses," Stanford University International Energy Project, July 1989).

[16] Rudolfo A. Bulatao, Eduard Bos, Patience W. Stephens, and My T. Vu, *Europe, Middle East, and Africa (EMN) Region Population Projections, 1989-90 Edition* (Washington, DC: World Bank, 1990), table 9.

[17] World Energy Conference, *Global Energy Perspectives 2000-2020, 14th* Congress, Montreal 1989 (Paris: 1989).

Table 1-5-Passenger Fleet Annual Growth in Selected Countries (percent)

Country group	Passenger cars	Commercial vehicles	Two and three wheelers	Total
Developing countries:				
Cameroon	11.8	29.5	9.1	13.1
Kenya	3.2	3.7	4.0	3.3
Bolivia	8.6	24.5	6.9	11.6
Brazil	8.9	7.3	25.6	9.8
Thailand	8.8	4.4	9.5	8.8
India	8.2	11.2	25.4	18.4
China	41.6	14.8	44.9	29.8
Taiwan	16.2	5.4	10.3	11.0
Weighted average	10.0	11.4	19.1	13.9
industrial countries:				
Japan	3.0	4.1	7.0	4.4
United States	2.4	3.5	-5.6	2.3
West Germany	3.3	0.4	-2.2	2.6
Weighted average	2.6	3.6	2.4	2.8

SOURCE: Fleet size and growth from Energy and Environmental Analysis, "Policy Options for Improving Transportation Energy Efficiency in Developing Countries," contractor report prepared for the Office of Technology Assessment, March 1990.

Table 1-6-Electric Appliance Ownership in Urban Areas (percent of households)

Country	Radio	Tv	Fan	Washer	iron	Cooker
China	39	66	45	2	1	
Liberia	76	4	56	1	74	
Guatemala	78	25	—	—	—	—
Manila	80	78	82	—	94	16
Malaysia	70	79	75	16	77	44
Hong Kong	90	91	96	34	87	91
Bangkok	—	96	—	5		84
Taipei	—	92	94	53		89

KEY: — information not available.
SOURCE: Jayant Sathaye and Stephen Meyers, "Energy Use in Cities of the Developing Countries," *Annual Review of Energy, vol.* 10, 1985, pp. 109-133, table 6.

due to improved technologies. After the 1973 and 1979 oil price shocks, the decline in energy intensities was experienced in all industrial countries. While the energy intensities of the developing countries continued to rise after 1973, the rise was less sharp than before. These experiences testify to some flexibility in commercial energy use. The current projections cited above, however, already incorporate assumptions about declining energy intensity in developing countries.

Energy Supply Constraints

The developing countries will face major difficulties in tripling energy supplies over the next 30 years. Significant obstacles include financial constraints, difficulties in increasing biomass fuel supplies, institutional and policy factors, and environmental impacts.

Financial Constraints

Commercial energy consists of both domestically produced and imported supplies. Many developing countries rely on imported oil for virtually all of their commercial energy needs. Further increases in energy imports will impose a heavy burden on limited foreign exchange resources, which may already be under pressure because of debt service payments (see table 1-7).

Funding the development of domestic energy supplies and infrastructure also poses problems. Energy supply facilities such as electricity generating stations and petroleum refineries are highly capital intensive, placing major demands on the scarce supplies of both domestic and foreign resources available for capital investment. Already, investments in the commercial energy supply sector (including electricity, oil and gas, and coal) represented in the 1980s over 30 percent of public

Table 1-7—Energy Imports, Debt Service, and Export Earnings for Selected Developing Countries,[a] 1987

Country	Energy imports as share of merchandise exports (percent)	Debt service as share of exports of goods and services (percent)	Energy imports and debt service as share of total exports 1987 (percent)
Low-income:			
Ethiopia	55	28.4	83.4
Tanzania	56	18.5	74.5
Madagascar	36	35.3	71.3
Rwanda	53	11.3	64.3
Benin	97	15.9	112.9
Kenya	39	28.8	67.8
Pakistan	26	25.9	51.9
Burma	5	59.3	64.3
Lower middle-income:			
Morocco	27	29.9	56.9
Jamaica	31	26.6	57.6
Turkey	31	31.7	62.7
Jordan	53	21.8	74.8
Syrian Arab Republic	40	16.5	56.5
Upper middle-income:			
Argentina	10	45.3	55.3
Algeria	2	49.0	51.0

a Includes all nations in which debt service and oil imports combined *is greater than* 50 percent of total exports.

SOURCE: World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989), pp. 172-173 and 210-211.

investment budgets in a wide range of developing countries (see table 1-8), with the electric utility sector accounting for the lion's share. Despite these already large claims on capital resources, the current level of investment in the electricity sector maybe inadequate. The World Bank estimates that investments of $125 billion annually (twice the current level) will be needed in developing countries to provide adequate supplies of electricity.[18] This figure represents virtually the entire annual increase in the combined GNP of the developing countries.

Finding the domestic and foreign resources needed to finance energy facilities has always posed major difficulties for developing countries. Current levels of domestic resource mobilization, often related to low levels of energy prices, are reported in many countries to fall short of the amounts needed for system expansion.[19] In the past, about one-half of all investments in energy supply have been provided by foreign sources,[20] but high levels of current debt in many developing countries and increasing fiscal difficulties in the industrial countries make it difficult for many developing countries to increase their borrowing from abroad.

Biomass Supply Constraints

It maybe equally difficult to increase supplies of traditional biomass fuels. Despite rapid rates of urbanization in the developing world, almost two-thirds of the total populations in poor nations live in rural areas. These populations largely depend on biomass fuels to produce their energy, with some rural electrification where available, and small but vital quantities of petroleum products (for irrigation, lighting, and transport).

Demand for biomass fuels (largely fuelwood) will continue rising to meet the domestic needs of the urban and rural poor, rural industry, and in some cases, such as Brazil, modern industry. Overuse of biomass resources already contributes to environmental degradation (see below). Moreover, gathering traditional supplies of fuelwood is time-consuming, exhausting work frequently undertaken by women and children, who are thus diverted from other activities (education and farming) that could

[18] U.S. Agency for International Development, *Power Shortages in Developing Countries: Magnitude, Impacts, Solutions, and the Role of the private Sector* (Washington, DC: March 1988), p. 10.

[19] Lawrence J. Hill, *Energy Price Reform in Developing Countries: Issues and Options* (Oak Ridge, TN: Oak Ridge National Laboratory, August 1987).

[20] World Bank, *The Energy Transition in Developing Countries* (Washington DC: 1983).

Table 1-8-Estimated Annual Energy Investment as a Percentage of Annual Total Public Investment During the Early 1980s

Over 40 percent	30-40 percent	20-30 percent	10-20 percent	0-10 percent
Argentina	Ecuador	Botswana	Benin	Ethiopia
Brazil	India	China	Egypt	
Colombia	Pakistan	Costa Rica	Ghana	
Korea	Philippines	Liberia	Jamaica	
Mexico	Turkey	Nepal	Morocco	
			Nigeria	
			Sudan	

SOURCE: Mohan Munasinghe, *Electric Power Economics* (London: Butterworths, 1990), p. 5.

eventually improve their productivity and living conditions. An estimated one-third of the population of developing countries now faces fuelwood deficits, and will increasingly rely on crop wastes and animal dung to meet their energy needs.

Institutional Constraints on Rapid Expansion in Energy Supplies

Over and above the capital constraints discussed above, a wide range of other factors, customarily defined as "institutional," currently impede commercial energy sector development. While definitions of institutional factors differ between observers, they are generally taken to be nontechnological, encompassing a variety of economic, organizational, and policy factors that affect the way technologies perform in operational settings.[21] Some of these factors (the worldwide increase in interest rates, for example) are outside the control of individual countries, but others are related to policies and procedures in the individual country.

The electricity supply system offers an example of the importance of institutional factors. In most countries of the developing world the electricity sector is government owned, reflecting the importance attached to electric power for meeting economic and social objectives, and in some cases, especially in small systems, the advantage of centralization for securing economies of scale and coordination in planning and operations. However, government ownership can lead to interference and loss of autonomy in day-to-day management of utility operations and therefore reduced efficiency. A recent World Bank report on the power sector in developing countries points out that:

> Such interference has adversely affected least cost procurement and investment decisions, hampered attempts to raise prices to efficient levels, mandated low salaries tied to civil service levels, and promoted excessive staffing. This in turn has resulted in inadequate management, the loss of experienced staff due to uncompetitive employment conditions and poor job satisfaction, weak planning and demand forecasting, inefficient operation and maintenance, high losses, and poor financial monitoring, controls and revenue collection.[22]

Manpower problems are exacerbated by the lack of standardization of equipment,[23] which makes the learning process more difficult. Another disadvantage of the multiplicity of equipment is the difficulty of maintaining adequate supplies of spare parts.

Pricing policies are frequently identified as a major institutional problem. Energy pricing policies vary in developing countries, reflecting differences in energy resource endowments and social and developmental policies. However, price controls on energy products, such as kerosene and some electricity prices, are a common feature in many countries. While low prices help to make energy more affordable, they can also result in a level of revenues inadequate to cover costs and finance future supply expansion. Many analysts have characterized this as a common problem in the electricity sectors of a wide range of developing countries.[24]

[21] World Bank, *A Review of World Bank Lending for Electric Power* (Washington, DC: March 1988), p- 74.

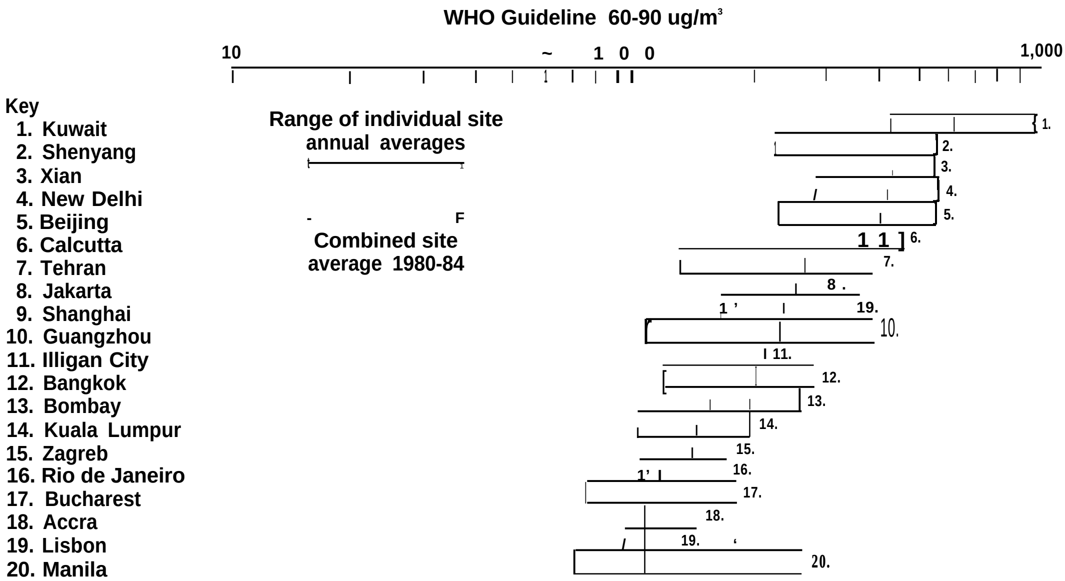
[22] Mohan Munasinghe, *Current Power Sector issues in Developing Countries* (Washington, DC: World Bank, November 1986), P. 14.

[23] In Mali, for example, there are 40 diesel generator sets from 17 different manufacturers (see U.S. Agency for International Development, "Electric Power Utility Efficiency Improvement Study," draft core report, May 15, 1990).

[24] Hill, op. cit., footnote 19; and Donald Hertzmark, "Energy Efficiency and Energy Pricing in Developing Countries," OTA contractor report, June 1990.

Figure 1-5-Suspended Particulate Matter Levels in Selected Cities, 1980-84

Shown is the range of annual values at individual sites and the composite 5-year average for the city.



SOURCE: World Health Organization and United Nations Environment Fund, *Global Pollution and Health* (London: Yale University Press, 1987), figure 3.

Environmental Degradation in Developing Countries

Developing countries are experiencing accelerating rates of environmental degradation and pollution. While many factors contribute to environmental degradation, energy production and use play key roles, especially in urban environmental quality. Even at present levels of energy generation and use, the impacts on environmental quality are severe in many areas. Additional large increases in energy use will exacerbate the situation unless steps are taken to mitigate adverse environmental impacts. At the same time, energy is an essential input to such environmental control systems as sewage treatment.

The combustion of fossil fuels has led to levels of air pollution in cities of developing countries that are among the highest in the world (see figures 1-5 and 1-6). The transportation sector is the largest contributor to air pollution in many cities.[25] The combustion of oil or gas in stationary sources, such as electric generating units, factories, and households, also contributes through emissions of nitrogen oxides, particulate, sulfur dioxide, carbon dioxide, carbon monoxide, and hydrocarbons. The fossil fuel mix has an important impact on emission levels. Coal is the most deleterious of fossil fuels in terms of emissions per unit of useful energy provided, particularly when it is not burned in modern, well-operated plants.

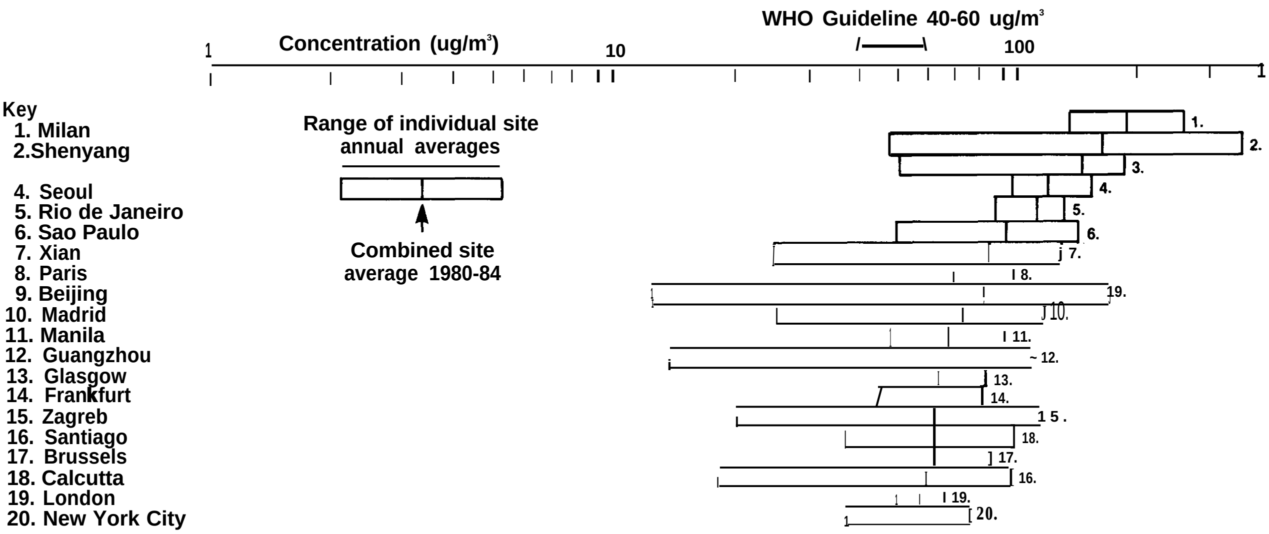
In addition to the environmental damage caused by the combustion of fossil fuels, their production and transportation also impose environmental costs, such as disturbance of lands and aquifers from coal mining, and accidental leaks and spills during oil and gas production and refining. Air quality impacts include, for example, local air pollution from particulate and other emissions during coal mining preparation, and transport and the release of methane, during coal mining and natural gas production and transportation.

Non-fossil energy sources such as hydroelectric development also causes environmental damage. Dam construction often requires the clearing of lands for access routes and removal of construction material, with resulting soil degradation and erosion. Filling the reservoir floods large tracts of land, which usually means loss of agricultural land, human settlements, fish production, forests, wildlife

[25] In Indian cities, for example, gasoline-fueled vehicles—mostly two and three wheelers—ar e responsible for 85 percent of carbon monoxide and 35 to 65 percent of hydrocarbons, while dieselvehicles—buses and trucks-are responsible for over 90 percent noNO_x emissions. Tats Energy Research Institute, *TERI Energy Data Directory and Yearbook 1988 (New* Delhi, India: 1989), p. 250.

Figure 1-6-Sulfur Dioxide Levels in Selected Cities, 1980-84

Shown is the range of annual values at individual sites and the composite 5-year average for the city.



SOURCES: World Health Organization and United Nations Environment Fund, *Global Pollution and Health* (London: Yale University Press, 1987), figure 2.

habitat, and species diversity.[26] The dam and reservoir interrupt the free flow of surface water, affect water tables and groundwater flow, and disrupt downstream flows of water and nutrient-laden sediments. These environmental costs are all the more onerous if the lifespan of hydroelectric projects is reduced through heavier than expected siltation of reservoirs from deforested and/or degraded lands upstream.[27]

Burning biomass, the source of energy used by most of the developing world's population, also causes environmental degradation. Although the use of biomass for fuel is only one, and not the principal, cause of deforestation, it does add additional pressure on forest resources especially in arid or semi-arid regions where forest growth is slow and where there is a high population density or a concentrated urban demand for fuelwood, such as the African Sahel.[28]

When fuelwood is in short supply, rural populations turn to crop residues and dung for their fuel needs. To the extent that these forms of biomass would have been used as fertilizers, their diversion to fuel contributes to lowered soil productivity.[29]

Finally, biomass fuel combustion has a significant impact on air quality. Food is typically cooked over open fries or poorly vented stoves, exposing household members--particularly women and children—to high levels of toxic smoke. Similarly, in colder climates, homes in rural areas are often heated by open fires, with increased exposures to toxic smoke.[30]

[26] For example, the reservoir Akosombo on the Volta in Ghana, with a land requirement of 8,730km², approaches the size of countries such as Lebanon or Cyprus. See R.S. Panday (cd.), *Man-made Lakes and Human Health* (Paramaribo: University of Suriname, 1979).

[27] The Hirakud reservoir in India, for example, was expected to be productive for about 110 years, but now has an estimated productive lifetime of 35 years. U.S. Congress, Office of Technology Assessment, *Technologies To Sustain Tropical Forests,* OTA-F-214 (Washington, DC: U.S. Government Printing Office, March 1984), p. 43.

[28] Douglas F. Barnes, World Bank, "Population Growth, Wood Fuels, and Resource Problems in Sub-Saharan Africa," Industry and Energy Department Working Paper No. 26, March 1990; R.P. Moss and W.B. Morgan, "Fuelwood and Rural Energy Production and Supply in the Humid Tropics," United Nations University, Tycooly International Publishing, Ltd., Dublin, 1981; Daniel Finn, "Land Use and Abuse in the East Africa Region," *AMBIO*, vol. 12, No. 6, 1983, pp. 296-301, Dennis Anderson and Robert Fishwick, World Bank, "Fuelwood Consumption and Deforestation in African Countries," staff working paper No. 704, 19S4.

[29] Organic matter in soils provides most of the nitrogen and sulfur and as much as half the phosphorus needed by plants. It helps the soil bind important minerals such as magnesium, calcium, and potassium that would otherwise be leached away. It buffers the acidity of soils, and it improves water retention and other physical characteristics. See Geoffrey Barnard and Lars Kristoferson, *Agricultural Residues as Fuel in the Third World,* Earthscan, International Institute for Environment and Development, Energy Information Program, technical report No. 4 (Washington DC and London: Earthscan, 1985).

[30] Kirk R. Smith, *Biofuels, Air Pollution, and Health: A Global Review (New* York, NY: Plenum Press, 1987).

Greenhouse Gases and Developing Countries

Energy use in developing countries also contributes to increased emissions of greenhouse gases and associated global climate change. An international panel of scientific experts of the Intergovernmental Panel on Climate Change (IPCC)[31] recently concluded that:

> . . . emissions resulting from human activities are substantially increasing the atmospheric concentrations of the greenhouse gases: carbon dioxide, methane, chlorofluorocarbons (CFCs) and nitrous oxide. These increases will enhance the natural greenhouse effect, resulting on average in an additional warming of the Earth's surface.[32]

Based on current models, the panel predicts that, under a "business as usual" scenario, the global mean temperature will increase at a rate of about 0.3 °C per decade during the next century, a rate at least 10 times higher than any seen over the past 10,000 years.[33]

Atmospheric concentrations of CO_2 have increased by about 25 percent since preindustrial times, largely due to emissions from the burning of fossil fuels and from deforestation. In 1985, according to another IPCC working group, developing countries contributed about one-quarter (26 percent) of annual global energy sector CO_2 emissions.[%] Under the "business as usual" scenario, with expanding populations, rapidly increasing energy use, and assuming the absence of control measures, the developing country share would increase to 44 percent of annual energy sector emissions by 2025.[35]

The magnitude of $C0_2$ emissions from fossil fuel sources is fairly well known, but the contribution from deforestation, which is virtually all from developing countries, cannot be estimated accurately. This makes it difficult to calculate with confidence the developing country share of global annual and cumulative emissions for CO_2 and other gases. Estimates of CO_2 emissions from tropical deforestation differ by a factor of 4.[36] By various estimates, deforestation could be the source of between roughly 7 and 35 percent of total annual CO_2 emissions.

Despite uncertainties, it is safe to conclude that the developing countries already contribute a substantial part of current annual global CO_2 emissions, and that their share will increase in the future. But, because of their large and rapidly growing populations, *per-capita* CO_2 emissions in the developing countries will still remain much lower than in the countries of the industrial world. Developing countries also account for at least half of the global anthropogenic generation of two other important greenhouse gases, methane and nitrous oxide.

Developing and industrial countries would both be damaged by the anticipated impacts of climate change. In addition to increases in mean global temperature, other major effects of global climate change would include increases in sea level1[37] and shifts in regional temperature, wind, rainfall, and

[31]The Intergovernmental Panel on Climate Change (IPCC) is an international task force created by the World Meteorological Organization and the United Nations Environment Program. Initiated in 1987, this body focuses on analyzing current information available on climate change issues and devising strategies to address climate change.

[32]Intergovernmental Panel on Climate Change, "Policymakers Summary of the Scientific Assessment of Climate Change: Report to IPCC from Working Group I," June 1990, p. i.

[33]Id., at p. ii. This would mean an increase over the preindustrial global average temperature of 2 degrees centigrade by 2025 and 4 'C by 2090. This best estimate prediction has an uncertainty range of 0.2 to 0.5'C per decade. This was based on projections derived from another working group that emissions of CO_2 could grow from approximately 7 billion tonnes of carbon (BtC) in 1985 to between 11 and 15 BtC in 2025. Methane emissions were projected to increase from 300 teragrams in 1985 to 500 teragrams by 2025.

[34]Intergovernmental Panel on Climate Change, Working Group III (Response Strategies Working Group), "Policymakers' Summary Of the Formulation of Response Strategies: Report Prepared for IPCC," Executive Summary, p. 10, table 2, June 1990.

[35]OTA calculation based on 2030 ~@ Emissions—Lower Growth Scenario, tables A-21 and A-193 in Intergovernmental Panel on Climate Change, "Emissions Scenarios Prepared by the Response Strategies Working Group of the Intergovernmental Panel on Climate Change," Appendix Report of the Expert Group on Emissions Scenarios (RSWG Steering Committee, Task A), April 1990.

[36]IPCC, "Policymaker's Summary of the Formulation of Response Strategies: Report Prepared for JPCC by Working Group III, " June 1990, p. 5. Estimates of CO_2 emissions from deforestation and land use changes (including woodfuel) were 0.6 to 2.5 PtC in 1980 according to a report prepared for the IPCC Working Group 1. "Scientific Assessment of Climate Change: Peer Reviewed Assessment for WG1 Plenary Meeting, May 1990," Apr. 30, 1990, p. 1-9. More recent evidence from selected countries would indicate deforestation rates now are higher than they were in 1980. Estimates of CO_2 emissions in 1987 were 5.7 +0.5 PtC from fossil fuel burning and total emissions were of 7 +1.1 PtC.

[37]The IPCC working group predicted an average rate of global mean sea level rise of about 6 cm per decade over the next century-20 cm by 2030 and 65 cm by the end of the century (with significant regional variations). This predicted increase is due primarily to thermal expansion of the oceans and melting of some land ice.

storm patterns. These effects in turn would submerge some low-lying coastal areas and wetlands, threaten buildings and other structures in these areas, and increase the salinity of coastal aquifers and estuaries. Such changes would disrupt human communities and aquatic and terrestrial ecosystems, and affect food production and water availability. A number of developing countries would be especially vulnerable to rising sea levels through threats to coastal communities and ecosystems, increased vulnerability to storm damage, and inundation of low-lying arable lands.[38] The adverse effects of climate change would exacerbate the impacts of increased populations in Asia, Africa, and small island nations of the Caribbean, Indian, and Pacific Oceans.[39] The timing, severity, and extent of these potential impacts remain uncertain.

Prospects for Efficiency Improvements in Energy Production and Use

Increasing energy supplies in the "business as usual' mode that underlies the conventional projections thus poses formidable challenges. This unfortunate fact suggests that alternative approaches for providing the vital energy services needed for rapid economic and social development should be investigated, focusing on efficiency improvements.

OTA examined the following energy-related services: cooking, lighting, and appliances in the residential and commercial sectors; process heat and electrical and mechanical drive in industry and agriculture; and transportation (see ch. 3). For the developing countries as a whole, the largest energy end use markets are residential/commercial and industry, which together account for roughly 85 percent of the energy used by final consumers, including traditional energy. Considerable differences exist, however, among developing nations. In Africa, the residential/commercial sector constitutes a particularly high share (mostly in the form of biomass fuels for cooking), while industry's share is quite low. In Latin America, transportation accounts for an exceptionally high share of the total, whereas its share in India and China is quite low.

Industrial process heat and cooking are the largest energy services, each accounting for about one third of all energy consumed (commercial plus biomass) in developing countries. This pattern of energy use contrasts with the United States, where transportation and space conditioning are the highest (although in the United States process heat is a major user as well). Much of the energy used for residential cooking and process heat in the developing countries is consumed in China and India. Together their consumption of energy for cooking and industrial process heat accounts for over 40 percent of all cooking and process heat energy used by developing countries, and for well over one-quarter of all the energy consumed in developing countries.

A wide range of technologies are currently used to provide energy services in developing countries. For example, cooking technologies include stoves using fuelwood, charcoal, kerosene, liquid petroleum gas, natural gas, and electricity, all with different characteristics. These technologies vary widely in their *energy efficiency. In* an open fire, for example, only about 15 percent of the energy contained in fuelwood goes into cooking. In contrast, in a' 'modern" gas stove about 60 percent of the energy contained in the gas is used in cooking. The wide range of efficiencies in the current stock of stoves suggests opportunities for increasing efficiencies of the stock and therefore providing more cooking services with less energy.

There are also differences in efficiencies in providing energy services in the industrial sector—industrial process heat and electric and mechanical drive. The two largest developing country energy consumers, India and China, currently rely on several technologies that are a generation or more behind the state of the art, and are much less energy-efficient than technologies now being used in the United States and other countries. Integrated iron and steel plants in China and India, for example, use twice as much energy per ton of crude steel produced as integrated plants in the United States and Japan. Lower efficiencies are also frequently observed in the transportation sector.

An analysis of the energy supply industry in developing countries similarly indicates much lower

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[38]Intergovernmental Panel on Climate Change, ''Policymalcers'Summary of the Potential Impacts of Climate Change: Report from Working Group II to the IPCC,'' May 1990, p. 8.

[39]J.D. Milliman et al., "Environmental and Economic Implications of Rising Sea Level and Subsiding Deltas: The Nile and Bengal Examples," *AMBIO*, vol. 18, pp. 340-345, 1989.

operating efficiencies than in the industrial countries. In electricity generation, for example, thermal power plants frequently operate far below design capacity and efficiency. Transmission and distribution losses (including unaccounted for losses, unmetered use, etc.) are frequently over 15 percent, substantially higher than losses in industrial country systems.[40] Refineries also operate at much lower efficiencies.

Energy supplies in many developing countries are unreliable, imposing a heavy economic burden. In India, for example, losses sustained by industry due to unreliable electric power supplies in recent years are estimated to represent 2 percent of annual GNP, not including losses in agriculture or losses and inconvenience experienced by residential and commercial users. Similar losses have been estimated for Pakistan. Furthermore, electricity supplies in many countries are of poor quality, discouraging the use of efficient technologies that are critically dependent on high-quality energy supplies.

In characterizing important parts of the energy system as "inefficient, however, it should be realized that in many cases users and producers are acting logically given the framework of resources, incentives, and disincentives within which they make their decisions. One of the reasons that poor households use fuelwood inefficiently is that they lack the financial means to buy more efficient cooking systems. Industrial users must cope with antiquated machinery and erratic fuel supplies of uncertain quality. On the supply side, the record of "poor" performance reflects many factors: poor repair and maintenance, unavailability of spare parts, low fuel quality, older equipment, unsatisfactory management, lack of skilled workers, problems of reaching dispersed populations served by inadequate transport systems, and inappropriate pricing and allocation systems.

The existence of wide differences between operational efficiencies in reasonably standardized operations (e.g., cooking, steelmaking, electricity generation, and petroleum refining), both among developing countries and between the developing and industrial countries, suggests that dramatic improvements in efficiencies are possible. However, the importance of factors other than technology must be recognized for the role they play in improving efficiencies. The policy environment in particular is crucial to the adoption of new technologies.

More efficient ways of providing energy services for development, including both technologies and the institutional and policy mechanisms determining their rate of adoption, will be presented in a later report of this OTA assessment. Attention will also be paid to the energy implications of different development strategies. Some development strategies are associated with high energy use. But developing countries at the beginning of the development process may be able to capitalize on technology to develop toward modern economies without the high energy growth that earlier characterized the path to industrialization.

[40]In the United States, for example, transmission and distribution losses in dense urban service areas are between 6 and 7 percent and in rural service areas nearer 9 to 10 percent.

Appendix 1A—Economic, Social and Energy Indicators for Developing Countries

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	GNP per capita 1987 ($)	GNP per capita ($ppp)	Share of agriculture in total production 1987 (%)	Urban population as share of total 1987 (%)	Life expectancy at birth 1987 (yrs)	Infant mortality 1987 (per 1,000 live births)	Population per physician 1984	Percent of age group in secondary education 1986 (%)	Consumption of traditional fuels per capita 1986 (GJ)	Consumption of commercial fuels per capita 1986 (GJ)	Total energy consumption per capita 1986 (GJ)	Share of traditional fuels in total 1986 (%)	Net energy imports as a share of commercial energy consumption 1986 (%)	Energy imports as a share of merchandise exports 1987 (%)	Debt service as a share of exports of goods and services 1987 (%)
Low-income countries															
Average	280 w	—	[illegible] w	24 w	54 w	103 w	13,550 w	9 w	—	—	—	—	—	16 w	21.9 w
1 Ethiopia	130	304	42	12	47	154	77,360	12	8.19	0.67	8.86	92	100	55	28.4
2 Bhutan	150	—	51	5	48	128	23,310	4	22.31	0.00	22.31	100	100	—	—
3 Chad	150	254	43	30	46	132	38,360	6	5.85	0.57	6.42	91	100	—	3.9
4 Zaire	150	200	32	38	52	98	—	—	8.68	3.01	11.69	74	x	2	12.8
5 Bangladesh	160	646	47	13	51	119	6,730	18	2.46	0.03	2.49	99	40	21	24.2
6 Malawi	160	—	37	13	46	150	11,560	4	7.97	1.77	9.75	82	100	10	23.3
7 Nepal	160	526	57	9	51	128	32,710	25	8.64	0.85	9.49	91	92	31	9.7
8 Lao PDR	170	—	—	17	48	110	1,360	19	10.00	3.42	13.42	75	75	—	—
9 Mozambique	170	528	50	23	48	141	37950	7	9.59	0.89	10.48	92	100		
10 Tanzania	180	291	61	29	53	106	—	3	9.29	1.26	10.54	88	100	56	18.5
11 Burkina Faso	190	359	38	8	47	138	57,180	6	7.83	0.72	8.55	92	100	7	—
12 Madagascar	210	370	43	23	54	120	10,000	36	5.87	1.19	7.06	83	100	36	35.3
13 Mali	210	337	54	19	47	169	25,390	7	6.03	0.64	6.67	90	100	32	9.9
14 Burundi	250	338	59	7	49	112	21,120	4	7.20	0.60	7.80	92	100	8	38.5
15 Zambia	250	579	12	53	53	80	7,100	19	13.19	19.58	32.78	40	33	11	13.5
16 Niger	260	320	34	18	45	135	38,770	6	5.44	1.47	6.91	79	100	9	33.5
17 Uganda	260	319	76	10	48	103	21,900	—	7.01	1.15	8.15	86	100	17	19.5
18 Somalia	290	348	65	36	47	132	16,090	12	7.72	2.63	10.35	75	100	9	8.3
19 Togo	290	489	29	24	53	94	8,720	21	1.88	1.56	3.44	55	100	8	14.2
20 Rwanda	300	388	37	7	49	122	34,680	3	8.59	1.25	9.84	87	100	53	11.3
21 Sierra Leone	300	441	45	26	41	151	13,630	—	20.00	1.84	21.84	92	100	10	—
22 Benin	310	531	46	39	50	116	15,940	16	9.77	1.40	11.16	88	x	97	15.9
23 Central African Rep.	330	436	41	45	50	132	23,070	13	10.74	0.74	11.48	94	100	1	12.1
24 Kenya	330	603	31	22	58	72	10,100	20	14.43	2.94	17.38	83	100	39	28.8
25 Sudan	330	562	37	21	50	108	10,110	20	8.31	2.12	10.43	80	100	38	6.8
26 Pakistan	350	1,165	23	31	55	109	2,900	18	2.19	8.49	10.67	20	39	26	25.9
27 Haiti	360	591	—	29	55	117	7,180	18	9.51	1.80	11.31	84	93	16	7.0
28 Lesotho	370	795	21	19	56	100	18,610	22	0.00	0.00	0.00	—	—	—	4.4
29 Nigeria	370	565	30	33	51	105	7,980	—	8.32	4.82	13.14	63	x	310.0	
30 Ghana	390	361	51	32	54	90	14,890	35	6.10	5.07	11.18	55	100	14	19.2
31 Sri Lanka	400	1,491	27	21	70	33	5,520	66	4.76	4.82	9.57	50	87	25	19.2
32 Yemen, PDR	420	1,038	16	42	51	120	4,340	—	0.00	15.22	15.22	0	70	—	38.2
33 Mauritania	440	539	37	38	46	127	12,110	15	0.00	4.21	4.21	0	100	8	18.2
34 Indonesia	450	1,269	26	27	60	71	9,460	41	7.70	8.47	16.17	48	x	13	27.8
35 Liberia	450	539	37	42	54	87	9,240	—	17.39	4.78	22.17	78	100	11	2.5
37 Burma	—	562	—	24	60	70	3,740	—	4.07	2.65	6.72	61	1	5	59.3
38 Guinea	—	—	—	24	42	147	57,390	9	5.69	2.46	8.15	70	100		
39 Kampuchea, Dem.	—	—			42	—	—	—	—	—	—	87	100	—	—
40 Viet Nam	—	—	—	R	66	46	1,000	43	3.40	3.52	6.92	49	20	—	—
China and India															
Average	300 w	—	30 w	33 w	[illegible] w	62 w	1,640 w	25 w	—	—	—	—	—	5 w	10.7
41 China	290	1,489	31	38	69	32	1,000	42	1.70	21.15	22.00	7	x	2	7.1
42 India	300	775	30	27	58	99	2,520	35	3.01	8.34	11.36	27	14	17	18.9

Lower middle-income countries															
Average	1,200 w	—	—	51 w	64 w	61 w	3,330 w	51 w	—	—	—	—	—	10 w	21.7
43 Senegal	520	754	22	37	48	128	13,450	13	5.71	3.57	9.29	62	100	24	21.4
44 Bolivia	580	1,106	24	50	53	110	1,540	37	2.39	10.90	13.28	18	x	2	22.1
45 Zimbabwe	580	954	11	26	58	72	6,700	46	7.89	21.67	29.56	27	23	6	23.2
46 Philippines	590	1,352	24	41	63	45	6,700	68	5.51	8.41	13.92	40	93	21	23.2
47 Yemem Arab Rep.	590	—	28	23	51	116	6,270	15	0.00	0.00	0.00	—	70	—	24.8
48 Morocco	610	1,284	19	47	61	82	15,610	34	0.56	9.36	9.91	6	100	27	29.9
49 Egypt, Arab Rep.	680	1,080	21	48	61	85	790	66	0.82	21.48	22.30	4	x	5	18.5
50 Papua New Guine	700	1,414	34	15	54	62	6,160	—	15.41	9.19	24.59	63	—	10	13.0
51 Dominican Rep.	730	1,702	17	58	66	65	1,760	47	4.48	13.58	18.06	25	100	37	—
52 Cote d Ivoire	740	941	36	44	52	96	—	20	7.57	6.76	14.32	53	100	11	19.6
53 Honduras	810	915	22	42	64	69	1,510	36	10.85	7.23	18.09	60	92	15	23.0
54 Nicaragua	830	1,857	21	58	63	62	1,500	42	9.43	10.00	19.43	49	97	33	—
55 Thailand	850	1,896	16	21	64	39	6,290	29	10.56	12.95	23.51	45	59	15	13.6
56 El Salvador	860	1,267	14	44	62	59	2,830	24	11.02	8.57	19.59	56	100	14	19.4
57 Congo,People'sR	870	917	12	41	59	73	8,140	—	8.50	12.50	21.00	40	x	5	18.6
58 Jamaica	940	1,733	6	51	74	18	2,060	—	2.08	32.50	34.58	6	100	31	26.6
59 Guatemala	950	1,597	—	33	62	59	2,180	20	9.88	5.95	15.83	62	93	16	24.9
60 Cameroon	970	1,180	24	46	56	94	—	23	8.53	9.91	18.44	46	x	1	15.9
61 Paraguay	990	1,869	27	46	67	42	1,460	30	12.82	11.03	23.85	54	69	10	21.3
62 Ecuador	1,040	2,361	16	55	65	63	830	55	6.87	22.53	29.39	23	x	3	20.7
63 Botswana	1,050	1,987	3	21	59	67	6,910	31	0.00	0.00	0.00	—	—	6	3.7
64 Tunisia	1,180	2,023	18	54	65	59	2,150	39	3.55	19.74	23.29	15	15	15	26.9
65 Turkey	1,210		17	47	64	76	1,380	44	7.91	26.92	34.83	23	—	31	31.7
66 Colombia	1,240	2,612	19	69	66	46	1,190	56	6.00	28.31	34.31	17	x	2	33.4
67 Chile	1,310	3,708	—	85	72	20	1,230	70	4.64	34.16	38.80	12	54	9	21.1
68 Peru	1,470	2,333	11	69	61	88	1,040	65	4.16	19.21	23.37	18	x	1	12.5
69 Mauritius	1,490	1,751	15	42	67	23	1,900	51	19.00	13.00	32.00	59	100	7	6.1
70 Jordan	1,560	2,102	9	66	66	44	1,140	—	0.00	29.21	29.21	0	100	53	21.8
71 Costa Rica	1,610	2,712	18	45	74	18	960	42	21.92	23.08	45.00	49	78	12	12.1
72 Syrian Arab Rep	1,640	2,864	27	51	65	48	1,260	60	0.00	35.98	35.98	0	x	40	16.5
73 Malaysia	1,810	3,204	—	40	70	24	1,930	54	4.79	31.76	36.55	13	100	4	14.3
74 Mexico	1,830	3,987	9	71	69	47	1,240	55	2.94	49.45	52.39	6	x	1	30.1
75 South Africa	1,890	3,948	6	57	60	72	—	—	4.20	95.20	99.40	4	x	0	—
Upper middle-income countries															
Average	2,710 w	[illegible]	—	66 w	67 w	50 w	.170 w	59 w	—	—	—	—	—	12 w	25.8 w
78 Brazil	2,020	[illegible]	11	75	65	63	1,080	36	17.82	32.76	50.58	35	46	17	26.7
79 Uruguay	2,190	[illegible]	13	85	71	27	510	71	10.33	38.00	48.33	21	92	15	24.4
81 Panama	2,240	[illegible]	9	54	72	23	980	59	8.70	26.52	35.22	25	—	29	6.5
82 Argentina	2,390	[illegible]	13	85	71	32	370	74	4.18	57.36	61.54	7	10	10	45.3
84 Algeria	2,680	[illegible]	12	44	63	74	2,330	54	0.74	36.41	37.14	2	x	2	49.0
85 Korea, Rep.	2,690	[illegible]	11	69	69	25	1,170	95	1.47	53.90	55.37	3	88	13	21.9
86 Gabon	2,700	[illegible]	11	43	52	103	2,790	27	22.73	38.18	60.91	37	x	1	5.1
88 Venezuela	3,230	[illegible]	6	83	70	36	700	46	1.26	106.17	107.43	1	x	0	22.6
90 Trinidad and Tobago	4,210	[illegible]	4	67	70	20	960	76	2.50	222.50	225.00	1	x	4	—
91 Libya	5,460	[illegible]	—	67	61	82	690	—	1.22	20.98	22.20	5	x	—	—
92 Oman	5,810	[illegible]	3	10	55	100	1,700	35	0.00	243.08	243.08	0	x	2	—
High-income economies															
Average	14,430 w	—	—	77 w	76 w	10 w	470 w	92	—	—	—	—	—	11 w	1
110 Germany, Fed. Rep.	14,400	9,739	2	86	75	8	380	72	0.6	185.39	186	0	58	7	1
116 Japan	15,760	10,959	3	77	78	6	660	96	0.05	128.94	129	0	96	17	1
119 United States	18,530	12,787	2	74	75	10	470	100	4.88	305.11	310	1	15	19	1

—not available or not applicable.
w = weighted average.
x—exporter.

SOURCE: Columns 1, 3, 4, 5, 6, 7, 8, 13, 14, and 15 from World Bank, *World Development Report 1989* (New York, NY: Oxford University Press, 1989), World Development Indicators, various tables. Column 2 from R. Summers et al., "A New Set of International Comparisons of Real Product and Price Levels Estimates for 130 Countries, 1950-1985," *Review of Income and Wealth*, Series 34, No. 1, March 1988. Columns 9, 10, 11, and 12 from United Nations, *Energy Statistics Yearbook 1986* (New York, NY: United Nations, 1988), table 4, normalized by population from World Development Indicators.