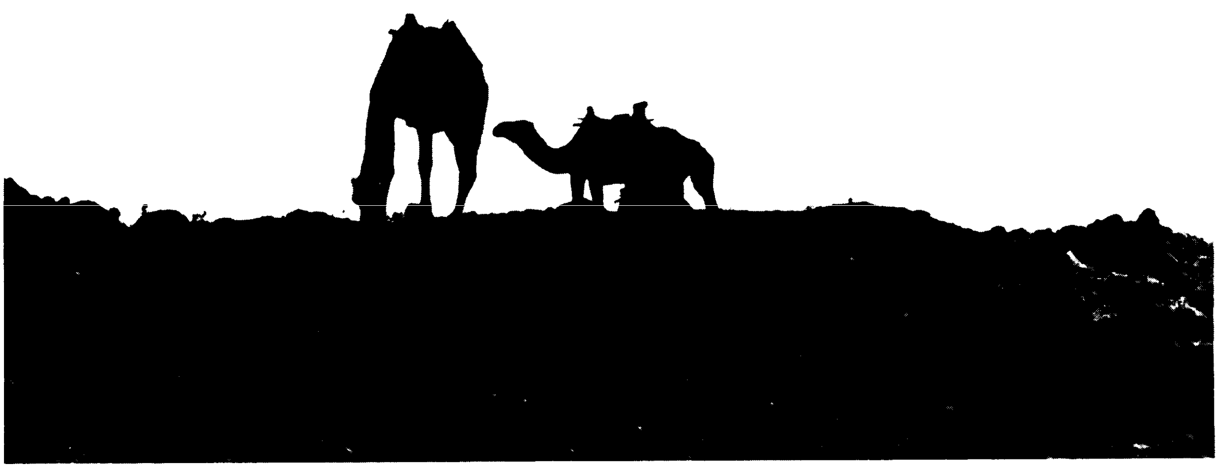
Chapter 2

Energy and the Developing Countries



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INTRODUCTION

Energy use in the 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 rising populations. But the traditional way of meeting these energy service needs-primarily by increasing energy supplies with little attention to the efficiency with which energy is used-could cause serious economic, environmental, and social problems. For many of the developing countries, much of the additional energy needed will be supplied by imported oil, thus further burdening 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 production and use in developing countries contributes to local and regional environmental damage, and, on the global scale, accounts for a substantial and rising share of greenhouse gas emissions.

The way in which developing countries provide their energy services is important to the United States for a number of reasons:

- International Political Stability. Steady broad-based economic growth in the developing countries is a prerequisite for long-term international political stability. The provision of economic and reliable energy services plays a key role in securing such economic growth.
- Humanitarian Concerns. Humanitarian and equity concerns have long been a core element of U.S. foreign relations with developing countries. Assisting developing countries to meet their energy needs can play an important role in helping low income groups.
- Trade and Competitiveness. With the large trade deficits of recent years and the growing internationalization of the economy, the United States has little choice but to pay close attention to export markets. Many of these will be in the developing countries. The developing countries are potential markets for U.S. manufacturers through direct sales, joint ventures, and other arrangements. The electric power sector of developing countries alone is projected by the World Bank to need a capital investment of nearly $750 billion during the 1990s. There will similarly be large markets in consumer products such as automobiles, refrigerators, air conditioners, and many other goods. The United States faces intense competition in the increasingly important markets for energy efficient manufacturing processes and consumer products.
- Global Environmental Issues. Regional and global environmental issues such as acid rain, ozone depletion, and global warming are strongly related to energy production and use. These issues are becoming of increasing concern in developing and industrial countries.
- Global Oil Markets. The World Energy Conference projects that developing countries will account for about 90 percent of the increase in world oil consumption between 1985 and 2020. This will put significant upward pressure on oil markets and could lead to both higher prices and greater volatility, with corresponding impacts on U.S. inflation, balance of trade, and overall economic performance. With business as usual, U.S. demand for imported oil is also likely to increase dramatically over the same time period.
- Global Financial Markets. High levels of developing country indebtedness (a significant portion of which was incurred in building the energy sector) affect global capital markets and the global banking system. This contributes to the instability of the U.S. and international money and banking systems.

This report (see box 2-A) evaluates ways of better providing energy services for development. The analysis examines technologies (hardware, but also the knowledge, skills, spare parts, and other infrastructure) that permit energy to be used and supplied

[1]This chapter draws heavily on the interim report of this project, U.S. Congress, off& of Technology Assessment, *Energy in Developing Countries,* OTA-E-486 (Washington, DC: U.S. Government Printing Office), January 1991.

Box 2-A—The OTA Study In Context

The eight Congressional committees and subcommittees that requested or endorsed this study asked OTA to examine: the potential of new energy technologies to contribute to economic growth while protecting the environment in the developing countries, and the role of U.S. policy in encouraging the rapid adoption of these technologies.

OTA responded to this request in two documents, an interim report, *Energy in Developing Countries* released in January 1991, and the present final report *Fueling Development: Energy Technologies for Developing Countries. The* **interim report 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. A major finding was that despite the low level of energy consumption in developing countries, energy was often produced, converted, and used inefficiently.

The present report, *Fueling Development,* builds on the findings of the interim report by examining the role of technology in improving the efficiency with which energy is supplied and used. This final report incorporates part of the interim report, but readers with more specific interest in patterns of energy demand and supply and its relation to economic growth and environmental quality are referred to the interim report.

The emphasis in the current report is on improving energy efficiencies in using and supplying energy. The emphasis on efficiency should not be taken to minimize the importance of economic structure on energy consumption. Variations in economy wide energy/GDP ratios between countries, and differing experiences over time, suggest that differences in economic structure do have an important role to play in explaining differences in energy consumption. These differences are more often related to economic and social policies, and country specific conditions and endowments, however, than to technology-the focus of this study.

We deliberately take a conservative approach to technology, examining only those that are at present commercially available or are expected to become commercial soon. This is not to discount the remarkable improvements in efficiency now on the drawing board, or the new energy supplies whose commercial development would have revolutionary consequences for all countries of the world. Instead, it recognizes that there is much that can be done here and now in the developing countries using established technologies, and that poor countries cannot be expected to take technological risks, especially when they are not necessary.

Given the immediate pressing needs of the citizens of the developing world for energy services, and the vast potential for improving energy efficiencies with known technologies, it seemed more appropriate to concentrate on relatively near-term responses. Many of the options—improving efficiencies and moving to cleaner energy and renewables-will nevertheless contribute to the solution of longer-term issues such as global warming. The basis for our economic calculations of the cost effectiveness of energy efficient technologies is also conservative, designed to under- rather than over-estimate the cost advantages of energy efficient equipment.

more efficiently, and the institutional and policy mechanisms that determine their rate of adoption. Based on this analysis, the role of the U.S. Government in promoting the transfer and accelerated adoption of improved energy technologies to developing countries is examined.

Developing countries vary widely in their socioeconomic development; their patterns of energy use and supply; and the linkages between their energy use, economic development, and environmental quality. Awareness of these factors is an important first step in developing policies that can effectively respond to the wide range of conditions found in developing countries. For example, 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.

As background to the subsequent analysis, this chapter therefore briefly introduces five sets of issues. First, it describes OTA's analytic approach. Second, it examines who the developing countries are and how they differ from the industrialized countries and from each other. Third, it reviews how energy is used and supplied in these countries. Fourth, it examines the trends in energy use that are leading to the developing countries' growing share in world energy consumption. Finally, it explores how energy is linked with economic growth and with environmental quality. Subsequent chapters examine the extent to which more efficient and cost effective energy use and supply systems can provide

Despite our focussed approach, we were obliged, due to the breadth of the subject and congressional interest in our considering the whole group of vastly disparate developing countries, to be selective in our coverage. As our interim report pointed out, most of the energy used in developing countries today is in the residential sector, for cooking and lighting, and the industrial sector for process heat and electric drive. We therefore emphasize these sectors and services in our energy service analysis. The third major sector, transport, is quantitatively less important than the others, but merits attention because of its reliance on oil, and its contribution to urban air pollution. Perhaps more than the other sectors, however, improvements in the overall efficiency of the transport sector in developing countries depend primarily on transport and urban planning--rather outside the scope of this report-than pure technology, though here again there is major scope for improvement. The services provided by electricity warrant particular attention for a number of reasons; the major share of the electricity sector in development budgets; the current financial and operational problems faced by the sector; the large bilateral and multilateral aid component in electricity development that provides the opportunity for leveraging sectoral change; and the large and costly increases in generation capacity that could be avoided through end-use efficiency improvements.

Oil and gas exploration also are examined in some detail because of the heavy burden imposed by oil imports for many countries, and the major environmental advantages of gas as a fuel. Because most of the population of the developing world live in rural areas, we examine the potential for providing the energy needed for rural and agricultural development-decentralized forms of electricity generation based on locally available renewable resources, and superior forms of fuel based on biomass.

Many of these issues are common to all developing countries. Certain groups of countries, however, command particular attention. India and China receive particular emphasis because of the weight of their total energy consumption, their intensive coal use, and the high energy intensities of their economies. The countries of Africa, though their commercial energy consumption is very small in global and even in developing country terms, need special attention because of their acute poverty and often declining living standards. Latin America receives special mention as well, due to an especially heavy debt burden and strong traditional economic ties to the United States.

Our treatment of policy options is conditioned by three factors. First, it was not possible to cover in consistent detail the content of the many U.S. and Multilateral Development Bank activities affecting the transfer of improved energy technology to developing countries. Second, many of these programs have changed since this project was started, and are continuing to change. Third, Congress has already addressed or is addressing many of the energy issues in connection with its interest in environmental quality. Thus the options identify policy issues rather than providing solutions. Each of the areas identified deserves detailed study before specific options could be justified.

SOURCE: Office of Technology Assessment, 1992.

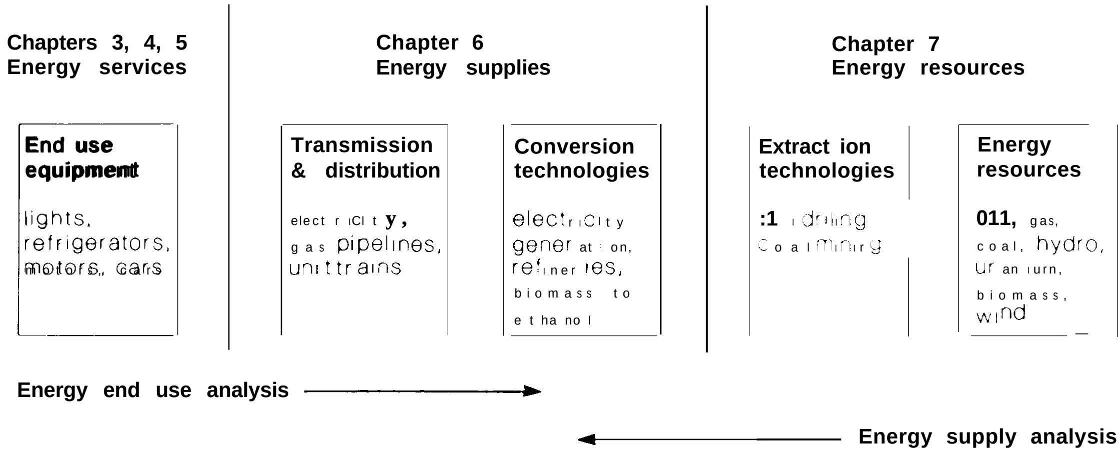
the energy services needed for development, thus moderating increases in energy consumption.

ANALYTICAL FRAMEWORK

The analysis presented in this OTA study has three important features. First, the analysis focuses on the services energy provides, rather than on simply increasing energy supplies. The reason for this approach is simple. Energy is not used for its own sake, but rather for the services it makes possible-cooking, water heating, 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 can be provided in a number of ways—by bicycle, motorcycle, car, bus, light rail, 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. A flow diagram comparing the analytical frameworks for energy services versus energy supplies is shown in figure 2-1.

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

Figure 2-1—The OTA Analytical Framework



SOURCE: Office of Technology Assessment, 1992.

urban captures well 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 might be met by increasing the amount of electricity generated, by increasing the use of more efficient light bulbs and reflectors, or by a combination of the two, perhaps in conjunction with daylighting techniques. A systems approach permits the comparison of efficiency and supply options in achieving the desired end.

The energy services analysis explicitly identifies potential institutional problems by highlighting the gap between what is and what could be. The analysis thereby recognizes 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 from the outside 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.

[2]This report largely follows the definition of "developing' countries-low-and middle-income countries-used by the World Bank, including all of the countries of Africa, Latin America, and Asia, excluding Japan. Saudi Arabia, Kuwait, and the United Arab Emirates are not included 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 OTA report. Where group averages of general economic and social indicators are reported directly from the *World Development* ***Report 1989****, these countries are* **included in the total. In more detailed analysis, they are excluded, While every effort is made to adhere to these definitions, it is not always possible, especially when other sources of data with slightly different definitions are used. See, for example, World Bank,** ***World Development*** *Report 1989 (New* **York, NY: Oxford University Press, 1989), Table 1, World Development Indicators, pp. 164-165.**

Photo credit: Appropriate Technologies, International.

DEVELOPING AND INDUSTRIALIZED COUNTRIES

It is difficult to clearly define the group of "developing nations."[2] If all the countries in the world are ranked by any widely used development index (e.g., GDP per capita), there is no distinct gap in the series that would suggest that those above were ''rich' countries, and those below ''poor. " Further, as is readily observable, some citizens of developing countries have standards of living as high as, or higher than, many citizens of industrial countries. Indeed, the differences between the rich and poor in virtually any developing country are usually more dramatic than the average differences between developing and industrial countries. Most of the citizens of developing countries are poor, however, and it is the weight of their numbers that produces wide differences in average indicators of social and economic wellbeing-infant mortality rates; nutritional intake; access to clean water, sanitation, and health services; educational attainment; per capita income; life expectancy; per capita energy consumption[3]—between the rich and poor countries.

Differences between rich and poor countries also emerge in trends over time. The economies of many developing countries have grown more rapidly than those of industrial countries over the past century, but much of this increase has been absorbed by population growth-leaving per capita Gross Domestic Product (GDP) well below the levels of the industrial countries.[4]

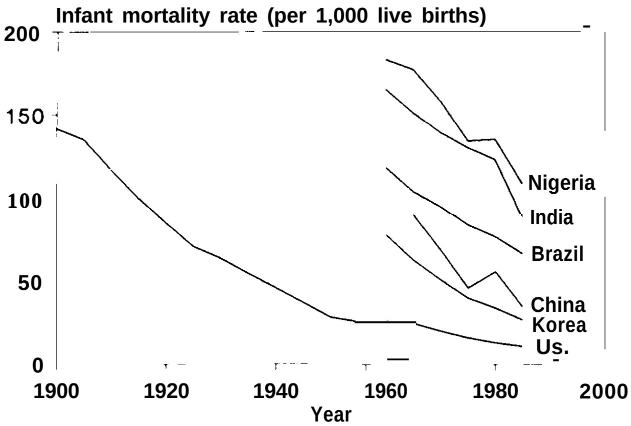
The developing countries have, nonetheless, made rapid progress in improving the quality of life for their citizens, lagging the industrial countries by no more than a generation or two in reducing infant mortality rates (see figure 2-2A) or increasing average life expectancy at birth. Today, only a few countries have lower life expectancies at birth than did the United States in 1900.[5] Substantial gains have also been achieved in providing access to education and in improving other aspects of the quality of life. These improvements have been realized by developing countries at a much earlier point in economic development (as measured by per-capita GDP) than was achieved by today's industrial countries as they developed economically (see figure 2-2B). For example, China and Korea achieved infant mortality rates less than 50 per 1,000 live births at GDPs of about $1,500 per capita (corrected for $1990 Purchasing Power Parity (PPP)). The United States did not achieve these rates of

[3] United Nations Development Program, *Human Development Report 1991* (new York, NY: Oxford University Press, 1991).

[4] For example, a -Pie of six large Latin American and nine Asian countries found overall annual GDP growth rates between 1900 and 1987 of 3.8 percent in Latin America and 3.2 percent in Asia, compared to 2.9 percent for the Organization for Economic Cooperation and Development (OECD) countries. (The Latin American and Asian countries, however, were starting from per capita incomes of between one-fourthand one-half that of the OECD countries.) Population growth rates for the LatinAmerican, Asian, and OECD countries however, were 2,2 percent, 1.8 percent, and 0.9 percent, respectively, leaving per capita GDP growth rates of 1.7 percent, 1.3 percent, and 2.1 percent. The annual difference of 0.4 to 0.8 percent in per capita GDP results in an income differential of 40 to 200 percent over the 87 year time period. See Angus Maddison, *The World Economy in the 20th Century (Paris:* Organization for Economic Cooperation and Development 1987).

[5] The U.S. life expectancy at birth in 1900 was 47.3 years. Today, countries with similar life expectancies include: Mozambique (48), Ethiopia (47), Chad (46), Malawi (47), Somalia (47), Bhutan (48), Burkina Faso (47), Mali (47), Guinea (43), Mauritania (46), Sierra Leone (42), Yemen Arab Republic (47), Senegal (48). The weighted average life expectancy at birth for the low-and middle-income developing countries is 63 years. See World Bank, *World Development Report 1991 (New* York, NY: Oxford University Press, 1991).

Figure 2-2A—infant Mortality Rate Versus Calendar Year for the United States, Brazil, China, India, Korea, and Nigeria



This figure shows that these developing countries lag the United States in reducing infant mortality rates by just 1 to 2 generations or less.

SOURCES: U.S. Department of Commerce, Bureau of the Census, "Historical Statistics of the United States: Colonial Times to 1970" (Washington, DC: U.S. Government Printing Office); Bureau of the Census, "Statistical Abstract of the United States, 1990," (Washington, DC: U.S. Government Printing Off ice); World Bank, "World Development Report" (New York, NY: Oxford University Press), various years.

infant mortality until its per capita GDP was over $7,000.

Pioneering advances in science and technology, agriculture, medicine, sanitation, and other fields have been important contributors to these improvements in the quality of life. Wide differences in these quality of life indicators between countries with similar per capita GDPs, however, also emphasize the important role of social policies and other factors in realizing such gains.[6]

Wide differences in economic and social development also exist both within and among developing countries. A generation of exceptionally fast economic growth in the Newly Industrializing Countries (NICs), principally in Asia, combined with the slow growth or economic stagnation in some other countries, principally in Africa, has widened the gap among developing countries (see figure 2-3). Per-capita incomes in the upper middle-income developing countries (e.g., Brazil, Argentina, Algeria, Venezuela, and Korea) are almost 7 times higher than in the low-income countries.

The income differential reflects important 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 for their relatively low incomes. The share of the total population living in urban areas is much lower in the low-income countries. In several African countries only about 10 percent of the total population are urban dwellers, whereas in countries like Brazil, Argentina, and Venezuela, levels of urbanization (about 80 percent of the population live in towns) are similar to those in the industrial countries.

PATTERNS OF ENERGY USE AND SUPPLY IN DEVELOPING COUNTRIES

Energy Use

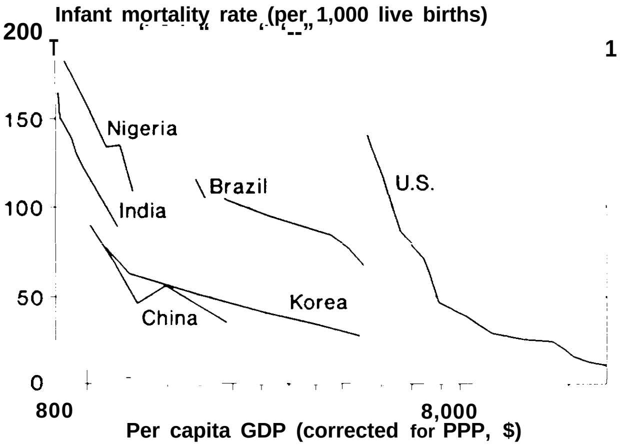
The wide variations in social and economic conditions between developing and industrialized countries are also reflected in their energy use. At the level of final consumption,[7] consumers in developing countries used about 45 exajoules (43 quads) of commercial energy and 16 EJ (15 quads) of traditional fuels, or 61 EJ (58 quads) total in 1985 (see table 2-l). In comparison, consumers in the United States used about 52 EJ (49 quads) of energy (again, not including conversion losses). On a per capita basis, people in the United States used an average of 215 Gigajoules (GJ, or 204 million Btu) each in 1985, compared to 15,20, and 35 GJ per capita (14, 19 and 33 million Btu) in Asia, Africa, and Latin America, respectively (see table 2-2).

These wide variations in energy use are also seen among developing countries. In the upper middle-income developing countries, per capita annual commercial energy consumption is 12 times higher

[6]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).

[7]Note that this does not include conversion losses. Conversion losses are the energy consumed in converting raw energy (such as coal and crude oil) to forms (electricity, gasoline) that can be used by consumers. The largest conversion loss is in the electricity sector. Total conversion losses in the United States account for about 30 percent of total primary energy consumption. Electricity losses account for about 80 percent of that total oone-quarter of total energy consumption.

Figure 2-2B—infant Mortality Rates Versus Per Capita GDP Corrected for Purchasing Power Parity (PPP) for the United States, Brazil, China, India, Korea, and Nigeria



This figure shows that these developing countries have been able to reduce their infant mortality rates at a much earlier point in their economic development as measured by per capita income than did the United States during its economic development. This was made possible by using the scientific, medical, agricultural, public health, and other advances pioneered by the industrial countries. Note that the per capita GDPs have been smoothed-otherwise the curves shown would reverse themselves during serious recessions-so that the curves are monotonic along the GDP axis.

SOURCE: Adapted from figure 2-2A. GDP data corrected by Purchasing Power Parity (PPP) are from: Angus Maddison, "The World Economy in the 20th Century" (Paris, France: Organization for Economic Cooperation and Development, 1989); and from Robert Summers and Alan Heston, "A New Set of International Comparison of Real Product and Price Levels Estimates for 130 Countries, 1950 to 1985," *The Review of* **Income and** ***Wealth,*** **vol. 34, No. 1, March 1988, pp. 1-25.**

than in the low-income countries.[8] China and India differ from the other low-income countries, with per capita consumption of commercial energy more than 3 times higher. Per capita consumption of traditional biomass fuels, on the other hand, is generally higher in the poorest countries, depending on the biomass resources available.[9]

Energy use is typically divided according to end use sector: residential, commercial, industrial, agricultural, and transport. Tables 2-1 and 2-2 list four of these. For commercial fuels only, industry is the largest single end use sector in the developing countries and accounts for about half of the total. In comparison, industry accounts for about one-third of total energy use in the United States. If traditional fuels are included, the residential/commercial sector in developing countries often uses as much or more energy than the industrial sector. Transport accounts for about 10 percent of all energy use in Asia, but for 20 to 30 percent in both Africa and Latin America.

The principal energy services demanded in developing countries today are cooking and industrial process heat (see table 2-3-note that unlike tables 2-1 and 2-2, these values include conversion losses). These services account for 60 percent of total energy use in Brazil, India, and China. Services provided by electricity, such as lighting, appliances, and motor drive, account for about 12 percent of the total, but their share is rising rapidly. The rapid increase in demand for electricity and its high cost explain the emphasis on the electricity sector in this report.

The traditional rural economy relies heavily on biomass—wood, crop residues, animal dung-for cooking or heating; and on human and animal muscle power to grind grain, haul water, plant and harvest crops, transport goods, run cottage industries, and meet other needs for motive power. These forms of energy are extremely limited in output and efficiency. Hauling water from the village well, for example, can take 30 minutes to 3 hours per household each day. The same amount of water could instead be pumped by a motor and piped to the home at a direct cost in electricity of typically less than a penny per day.

As incomes grow and access to improved fuels become more reliable, people are widely observed to shift from traditional biomass fuels to cleaner, more convenient purchased fuels such as charcoal, kerosene, LPG or natural gas, and electricity to meet their energy needs. Modern mechanical drive (electric motors, diesel engines, etc.), in particular, substitutes for human and animal muscle power throughout the economy and allows dramatic increases in the output and the productivity of labor.

A correspondingly 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, among others, all with different cost and performance characteristics. These technologies vary widely

[8] World Bank, op. cit., footnote 2.

[9] Brazil, despite its relatively high income, uses substantial quantities of biomass fuels in modem applications, such as 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.

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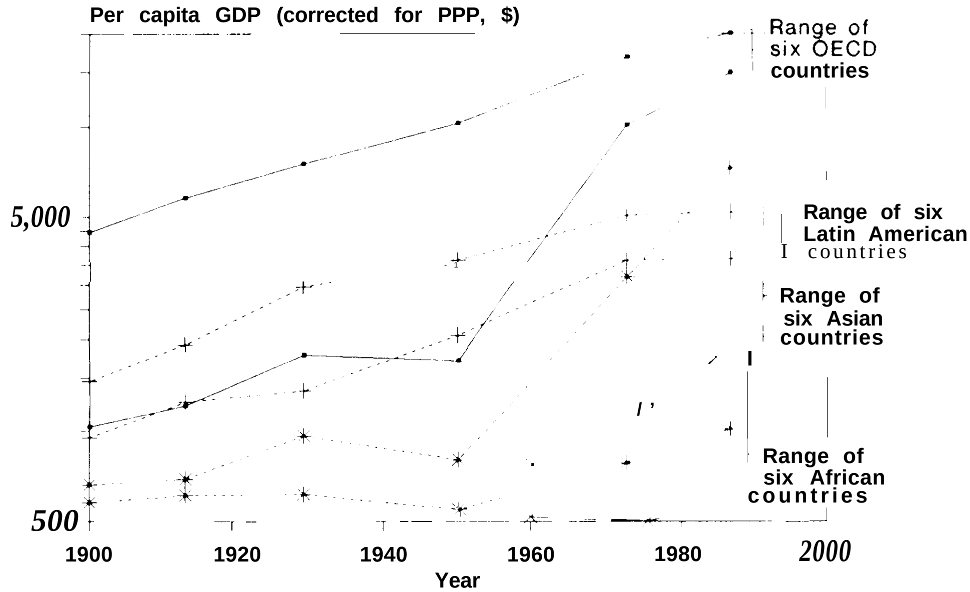
Figure 2-3-Per Capita GDP Corrected for Purchasing Power Parity (PPP) Versus Calendar Year for Eight Industrial and Developing Countries.



This figure shows the change over time in per capita income for the low and high income countries within each of four sets of six countries for Africa, Asia Latin America, and OECD Groups, or 24 countries overall. Note the large overlap in per capita incomes during the early part of this century between some of today's industrial countries and some developing countries. Overtime, today's industrial countries made institutional reforms, invested heavily inhuman and physical capital, and made other changes, resulting in their incomes converging at a high level. The relative success of Latin American, Asian, and African countries in making similarly successful institutional reforms, human and capital investments, controlling population growth, and making other changes is indicated by their per capita GDPs over time.

SOURCE: Adapted from Angus Maddison, "The World Economy in the 20th Century," (Paris, France: Organization for Economic Cooperation and Development, 1989); and Robert Summers and Alan Heston, "A New Set of International Comparisons of Real Product and Price Levels Estimates for 130 Countries, 1950 to 1985," *The Review of Income and Wealth, vol.* **34, No. 1, pp. 1-25, 1988.**

in their energy efficiency. In an open free, for example, only about 17 percent of the energy contained in fuelwood goes into cooking. In contrast, in the "modern" gas stove, about 60 percent of the energy contained in the gas is used in cooking. The preponderance of traditional stoves and fuels in many developing countries suggests opportunities for increasing efficiencies and therefore providing more cooking services from the same amount of energy.

Differences in efficiencies in providing energy services are also observed in the industrial sector—industrial process heat, electric or mechanical drive, and other processes. For example, the two largest developing country energy consumers, India and China, currently use roughly twice as much energy to produce a tonne of steel in their integrated iron and steel plants as is used in integrated plants in the United States and Japan.[10]

Despite these differences in aggregate indicators, there are strong similarities in energy use among developing countries within their rural and urban 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 countries. Energy use by this group in the developing countries is also similar to industrial country energy use 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

[10]Note that there are wide variations between individual plants, with key plants in India and China performing much better than these averages suggest. There are also differences in product mix which modify these estimates. See ch. 4 for details.

Table 2-l—Total Delivered Energy by Sector, in Selected Regions of the World, 1985 (exajoules)[a]

Region	Residential/commmercial Commercial fuels	Residential/commmercial Traditional fuels[b]	Industry Commercial fuels	Industry Traditional fuels[b]	Transport Commercial fuels	Transport Traditional fuels[b]	Total Commercial fuels	Total Traditional fuels[b]	Total energy
Africa	1.0	4.0	2.0	0.2	1.5	NA	4.4	4.1	8.5
Latin America	2.3	2.6	4.1	0.8	3.8	NA	10.1	3.4	13.5
India and China	7.3	4.7	13.0	0.2	2.0	NA	22.2	4.8	27.1
Other Asia	1.9	3.2	4.0	0.4	1.9	NA	7.8	3.6	11.3
Developing countries	12.5	14.5	23.1	1.6	9.2	NA	44.5	15.9	60.4
United States	16.8	NA	16.4	NA	18.6	NA	51.8	NA	51.8

NA = Not available or not applicable.

NOTES: This is delivered energy and does not include conversion losses from fuel to electricity, in refineries, etc. The residential and commercial sector also includes others (e.g., public services, etc.) that do not fit in industry or transport. Traditional fuels such as wood are included under commercial fuels for the United States.

[a]Exajoule (10^{18} Joules) equals 0.9478 Quads. To convert to Quads, multiply the above values by 0.9478.

[b]These estimates of traditional fuels are lower than those generally observed in field studies.

SOURCE: U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries*, OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991) p. 49.

Table 2-2—Delivered Energy Per Capita by Sector in Selected Regions, 1985 (Gigajoules[a]--Includes traditional fuels)

Region	Residential/commercial	Industry	Transport	Total
Africa	11.8	5.2	3.5	20.5
Latin America	12.7	12.5	9.7	34.9
India and China	6.7	7.3	1.1	15.1
Other Asia	7.2	6.2	2.7	16.1
United States	69.8	68.5	77.5	215.8

NOTE: These estimates do not include conversion losses in the energy sector, and underestimate the quantity of traditional fuels used compared to that observed in field studies.

[a]Gigajoule (GJ) is 10^9 Joules and equals 0.9478 million Btu.

SOURCE: U.S. Congress, Office of Technology Assessment, *Energy In Developing Countries*, OTA-E-486 (Washington, DC: Government Printing Office, January 1991) p. 49.

developing countries are then in large part due to the relative share of 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. These 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.

Energy Supply

Biomass fuels are probably[11] the largest single source of energy in developing countries (table 2-4), providing one-third of the total. Coal and oil are the next largest, providing 26 and 28 percent. Primary electricity (mainly hydro) and natural gas account for 7 percent each. Compared with the industrial world, the share of oil and gas is much smaller and the share of biomass fuels larger.

The relative shares of these energy sources in the overall energy supply mix vary significantly across different regions and countries, due in part to unequal endowments of energy resources. Coal supplies about half of the energy requirements for developing countries in Asia, due largely to high levels of coal consumption in China and India, Oil is the major source of commercial primary energy for most countries of the developing world, India and China being the notable exceptions. Natural gas supplies a relatively small fraction of energy in the developing world, despite a more abundant resource base compared with oil.

overall, the developing world produces more energy than it consumes. There are, however, large disparities between countries. 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 2-5).

11 The term "probably" is used because data on biomass fuels are unreliable but tend on the whole to underestimate the amounts used.

Table 2-3-Per Capita Energy Use by Service in Selected Countries (Gigajoules[a])

	Brazil	China	India	Kenya	Taiwan	U.S.A.
Residential	6.2	11.7	5.5	16.9	8.9	64.9
cooking	5.3	8.5	5.0	16.4	4.7	3.5
lighting	0.3	0.4	0.5	0.5	0.7	NA
appliances	0.6	NA	0.05	NA	3.1	13.ob
Commercial	1.5	0.7	0.26	0.4	4.2	45.2
rooking	0.4	NA	0.13	0.24	1.9	NA
lighting	0.5	NA	0.05	0.16	0.8	7.2
appliances	0.6	NA	0.07	NA	1.5	NA
Industrial	19.4	13.8	4.1	4.8	39.2	94.1
process heat	17.5	10.2	2.7	NA	NA	55.8
motor drive	1.6	3.6	1.3	NA	NA	20.4
lighting	0.1	NA	0.05	NA	NA	NA
Transport	13.3	1.2	1.3	2.7	11.5	80.8
road	12.0	0.2	0.8	1.8	10.1	66.7
rail	0.2	0.7	0.4	0.2	0.1	2.0
air	0.7	NA	0.1	0.7	0.7	11.3
Agriculture	2.1	1.8	0.6	0.5	2.6	2.5
Total	43.4	27.0	11.7	25.6	67.7	288.0

NA = Not available or not applicable.
[a]Gigajoule (GJ) is 10^9 Joules and equals 0.9478 million Btu.
[b]This is the combined total for appliances and lighting.

SOURCE: U.S. Congress, Office of Technology Assessment, *Energy In Developing Countries,* OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991) p. 49.

Table 2-4—1987 Primary Energy Supplies (exajoules[a])

	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	63.5	77.0	51.7	26.6	218.7	5.5	224.2
Developing	25.2	27.7	6.5	6.4	65.7	31.3	97.1
Share of Industrial countries	72%	74%	89%	81%	77%	15%	70%
Share of developing countries	28%	26%	11%	19%	23%	85%	30%

NOTE: As in table 2-1, 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.
[a]Exajoule (10^{18} Joules) equals 0.9478 Quads. To convert to Quads, multiply the above values by 0.9478.

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

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.

As noted above, a well established energy transition takes place as development proceeds. Biomass is the primary energy supply for traditional villages and is normally used in its raw form with virtually no processing. When rural populations migrate to urban areas to look for seasonal or full time employment, they continue to use traditional biomass fuels. As incomes increase, however, people are gradually able to purchase processed fuels (when available) that are more convenient, efficient, and cleaner. This shift from traditional biomass fuels to purchased fuels changes the structure of the energy supply industry. As development takes place, an increasing amount of processing takes place, notably in the share of fossil fuels converted into electricity. This means that the conversion sector--electric utilities, refineries, etc.—becomes more important as development proceeds.

Developing Countries in World Energy

The developing countries play an important role in world energy consumption, accounting for about 30 percent of global energy use, including both commercial and traditional energy (table 2-4). Several developing countries-China, India, Mexico,

Table 2-5-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%)	Medium importers (30-70%)	Low importers (0-3070)
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 Includes all countries for which import dependence data are available.

SOURCE: Adapted from World Bank, *World Development Report 7989* (New York, NY: Oxford University Press, 1989).

Brazil, and South Africa-are among the world's top 20 commercial energy consumers, 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. 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 energy. Their share of global commercial energy consumption has risen sharply in recent years (figure 2-4), 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 (figure 2-5), rapid population and economic growth has meant that developing countries accounted for one-half of the total *increase in* global commercial energy consumption since 1973.

The rising 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, and similar results are also found in a large number of other studies.[12] Again, due to rapid population and economic growth, the developing countries are projected to account for almost 60 percent of the global *increase in* commercial energy consumption by 2020. China alone accounts for over one-third of this increase. These rising 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, however, per capita consumption of commercial energy will continue to be far below the levels in industrial countries.

TRENDS IN ENERGY DEMAND IN DEVELOPING COUNTRIES

Factors Increasing Energy Demand

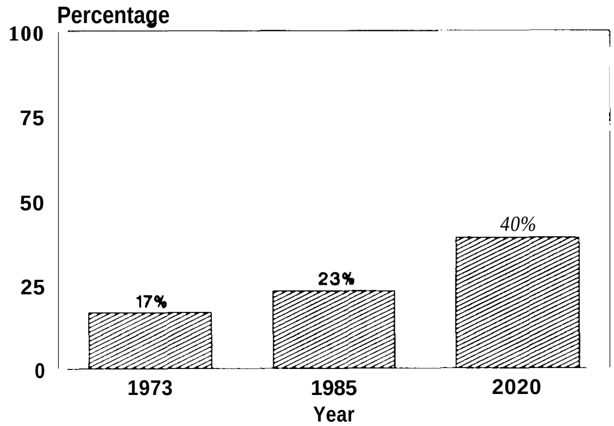
Factors contributing to the rapidly rising energy consumption in developing countries include population growth, economic growth and structural change, and declining real costs of consumer goods.

Population Growth

Over the next three decades the population of the developing world is projected to increase by nearly 3 billion-to almost 7 billion total-while that of

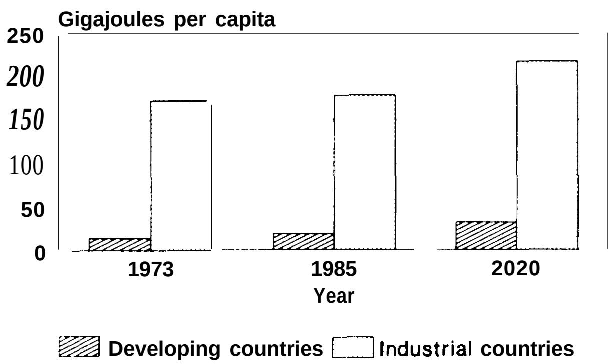
12 An analysis of Projection of global commercial energy consumption over the next 20 years can be found in Allan S. Marine and Leo Schrattenholzer, *International Energy Workshop: Overview of Poll Responses* (Stanford University International Energy Project, July 1989). This analysis reports the results 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 for all regions. The coverage is nonetheless a comprehensive indicator of how energy forecasters view the future. 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, the Environmental Protection Agency's *Emissions Scenarios* document, prepared by the Response Strategies Working Group of the Intergovernmental Panel on Climate Change (IPCC), Appendix Report of the Expert Group on Emissions Scenarios (RSWG Steering Committee, Task A), April 1990, concludes that, over a 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 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 Third World define much of the difference between the low and high growth scenarios.

Figure 2-4-Commercial Energy Consumption, 1973, 1985, and 2020 (developing nation energy consumption as a percentage of world total)



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

Figure 2-5-Per Capita Commercial Energy Consumption, 1973, 1985, and 2020



SOURCE: World Energy Conference, Global Energy Perspective 2000-2020, 14th Cong., Montreal 1989 (Paris,"{ 989).

Organization for Economic Cooperation and Development (OECD) countries[13] will increase by only 100 million-to 850 million total. Even assuming continued decreases in fertility rates (the number of children expected to be born to a woman during the course of her life), the population of these countries[14] could reach 10 billion or more in 2100 (figure 2-6). Developing countries would then account for 88 percent of the 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.[15]

Economic Growth

Securing higher living standards for this rising population requires rapid economic growth, further increasing the demand for energy services. If energy consumption were to increase in proportion to economic growth (ignoring the enormous potential for improvements in the efficiency of both supplying and using energy), then an average annual gross rate of economic expansion of 4.4 percent (including both economic and population growth) in the developing countries-as projected by the World Energy Conference--would represent more than a fourfold increase in economic activity and commercial energy consumption between now and 2020. The demand for energy services could be increased even more by structural changes inherent in the development process, including:

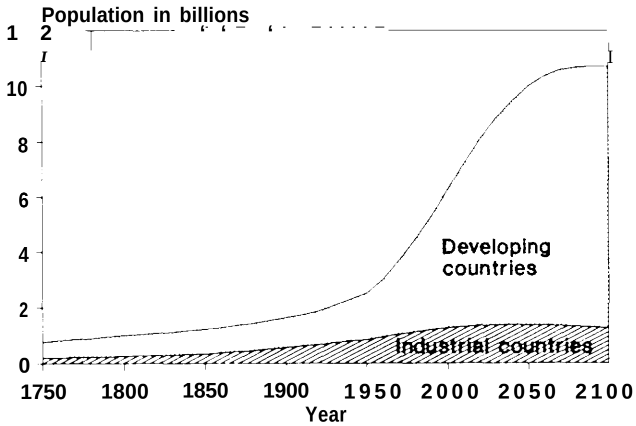
- Urbanization. Urban populations in developing countries are projected to continue rising rapidly, by more than 100 million additional people annually during the 1990s. This rapid growth in urban populations results in rising transportation energy needs as food and raw materials, and finished products are hauled longer distances and as personal transport needs grow.
- Substitution of commercial for traditional fuels. Traditional biomass fuels such as wood, crop residues, and animal dung remain today the primary source of energy for more than 2 billion people, but there is a strong preference for commercial fuels as soon as they become available and affordable;
- Increased use of energy intensive materials. Developing countries have a large demand for energy intensive material such as steel and cement needed to build commercial, industrial, and transportation infrastructures (see figure 2-7).

[13] The OECD countries are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

[14] Rudolfo A. Bulatao, Eduard Bos, patienc, 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.

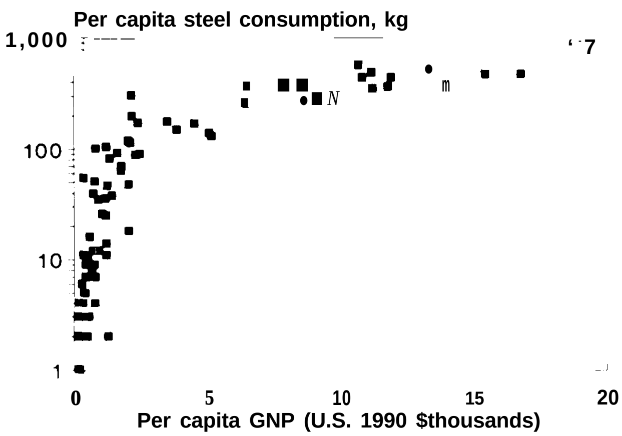
[15] A more detailed analysis of the factors driving population growth is given in, *Us.* Congress, Office of Technology Assessment, *Energy in Developing Countries, OTA-E-486* (Washington, DC: U.S. Government Printing Office, January 1991).

Figure 2-6-World Population Growth 1750-2100 in Industrial and Developing Regions



SOURCE: Thomas Merrick, Population Reference Bureau, "World Population in Transition"' *Population Bulletin, vol.* 41, No. 2, April 1986, update based on United Nations 1989 projections.

Figure 2-7—Per Capita Steel Consumption Versus GNP for Various Countries



The saturation of the steel market at higher income levels as national infrastructures are developed is readily seen in linear or logarithmic plots. It is shown herein a semi-log plot so as to better display both low-end and high-end data. Each data point represents a country.

SOURCE: U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries,* OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991).

Accelerated Consumer Demand

Demand for energy services is further augmented by rapidly rising demand for a wide range of energy-using appliances. Modern manufacturing techniques and improved materials have sharply lowered the real cost of consumer goods—radios, refrigerators, television—in recent years. For example, the real cost of refrigerators in the United States has decreased by a factor of 5 since 1950 (see figure 2-8A). Global distribution systems have also increased the accessibility of these appliances. People in developing countries can thus purchase these goods at a far earlier point in the development cycle (as measured by per capita GDP) than did people in today's industrial countries (see figure 2-8 B). Further, as women in developing countries increasingly enter the formal workforce, the demand for (and the means to purchase) labor- and time-saving household appliances such as refrigerators (to store perishable foods and thus reduce the frequency of grocery shopping) can be expected to grow dramatically. The increase in demand for appliances is further stimulated by frequently subsidized electricity prices.

The increase in consumer appliances is already creating an explosive demand for energy both directly to power these goods and indirectly to manufacture and distribute them. A recent review of 21 of the largest developing countries in Asia, Latin America, and Africa found electricity use to be growing faster in the residential than in other sectors in all but four. Annual growth rates in residential electricity use averaged about 12 percent in Asian countries examined, 10 percent in African countries, and 5 percent in Latin American countries.[16] The rapidly increasing use of these appliances has a strong impact on the electric power infrastructure due to the additional demand placed on systems that are typically already short of capacity. Further, much of the residential demand comes at peak times—the most expensive power to generate.

Difficulties in Meeting Energy Demands

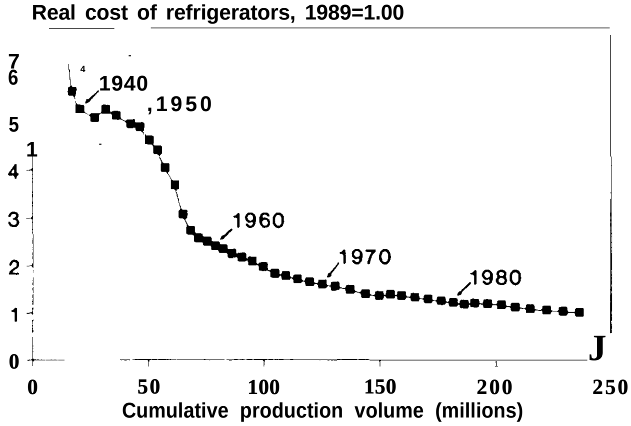
Meeting these rising demands for energy services through the traditional strategy of expanding supplies from large scale conventional energy systems faces large problems—financial, institutional, and environmental.

Financial Constraints

Capital intensive electricity generating stations and petroleum refineries already account for a large part of all public investment budgets in developing countries (see table 2-6). Yet according to the U.S.

[16] Stephen Meyers et al., "Energy Efficiency and Household Electric Appliances in Developing and Newly Industrialized Countries,' Draft Report No. LBL-29678, Lawrence Berkeley Laboratory, October 1990.

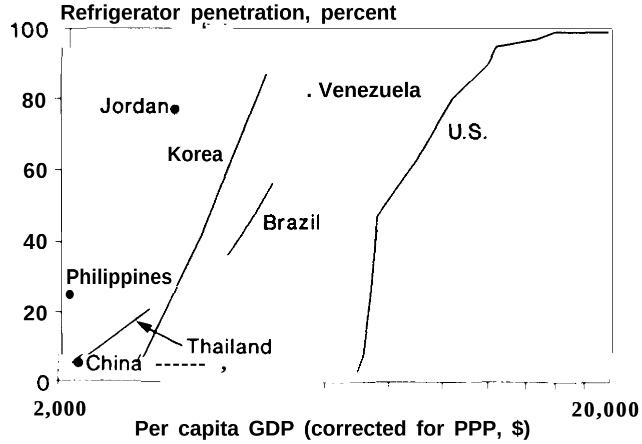
Figure 2-8A—Reduction in the Real Cost of Refrigerators Over Time in the United States



Over the past 40 years, the real price of refrigerators has dropped by almost a factor of 5. For developing countries, such price reductions would allow households to invest in refrigerators at a much earlier point in time than was the case for the United States and other industrialized countries at a similar level of development.

SOURCE: U.S. Congress, Office of Technology Assessment, *Energy in Developing* Countries, OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991).

Figure 2-8 B—Nationwide Refrigerator Penetration Versus Per Capita GDP Corrected for PPP



This figure shows for selected developing countries that a much higher percentage of households own refrigerators than did households in the United States at a similar level of economic development, as measured by purchasing power parity (PPP) corrected per capita incomes in 1990$. Thus, countries like Jordan, Korea and Venezuela have refrigerator penetration rates of around 80 percent with per capita incomes of $3,200 to $5,700, respectively. In comparison, refrigerator penetration rates of 80 percent did not occur in the United States until per capita incomes were $10,000.

SOURCE: GDP data is from: Angus Maddison, "The World Economy in the 20th Century" (Paris, France: Organization for Economic Cooperation and Development, 1989); and Robert Summers and Alan Heston, "A New Set of International Comparisons of Real Product and Price Levels Estimates for 130 Countries, 1950-19S5," The *Review of Income and* Wealth, vol. 34, pp. 1-25, 1966. Refrigerator penetration data for the United States is from: Donald W. Jones, "Energy Use and Fuel Substitution in Economic Development: What Happened in Developed Countries and What Might be Expected in Developing Countries?" Oak Ridge National Laboratory, ORNL-6433, August 1988; Refrigerator penetration data for the various developing countries shown is from: S. Meyers, et al., "Energy Efficiency and Household Electric Appliances in Developing and Newly Industrialized Countries," Lawrence Berkeley Laboratory, LBL-29678, December 1990. Note that the per capita GDPs have been smoothed-otherwise the curves shown would reverse themselves during serious recessions-so that the curves are monotonic along the GDP axis.

Agency for International Development (AID), annual power sector investments would have to double—to $125 billion annually 17-to provide adequate supplies. This would take up a large share of the entire projected annual increase in the combined gross national product (GNP) of the developing countries, leaving little for other pressing development needs.

In the past, about one-half of all investments in energy supply have been in the form of foreign exchange. High levels of debt now make it difficult for many developing countries to increase their borrowing from abroad, and capital is likely to remain tight.[18] A continuing source of difficulty is capital outflow or ''Capital Flight' from many developing countries, particularly the heavily indebted middle income countries.[19] Similarly, there is often a shortage of local currency to pay for energy development due to inadequate revenues from existing operations. Out of concern for the rural and urban poor and to aid development of key sectors such as **agriculture,** energy prices-including that of kerosene, diesel, and electricity-are often kept too low to finance the expansion of new facilities.

Institutional Constraints

The power sectors in developing countries frequently experience a wide range of institutional problems, including excessive staffing, inadequate

[17]This can be compared to the World Bank estimate of $75 billion annually that is being planned for in developing countries.

[18]Marcus W. Brauchli, "Capital-Poor Regions Will Face World of Tighter Credit in the '90s, " *Wall Street Journal,* June 5, 1991, p. A8.

[19]Rigmar Osterkamp, "Is There a Transfer of Resources From Developing to Industrial Countries, *InterEconomics,* Sept./Oct. 1990, p.242-247; Glennon J. Harrison, ' 'Capital Flight and Highly Indebted Countries: An Analytical Survey of the Literature,Congressional Research Service, Library of Congress, March 21, 1991; Glennon J. Harrison, "Capital Flight: Problems Associated with Definitions and Estimates," Congressional Research Service, Library of Congress, March 21, 1991.

Table 2-6—Estimated Annual Energy Investment as a Percentage of Annual Total Public Investment During the Early 1980s

Over 40°/0	40-30%	30-200/.	20-1 o%	1 o-o%
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.

management, weak planning, poor maintenance, deficient financial monitoring, and few incentives to improve efficiency of operation. This raises questions about the ability of this key sector to continue expanding rapidly even if financial resources were available.

Environmental Constraints

On the one hand, modern energy technologies can substitute cleaner modern fuels for smoky traditional biomass fuels; can improve the productivity of traditional agriculture and thus slow the expansion of cultivated lands into tropical forests or other fragile lands; or can power environmental control systems such as sewage treatment. In these cases, modern energy technologies help improve environmental quality. On the other hand, fossil fuel combustion in modern industry, transport, and electricity generation causes air pollution—already often higher in developing country cities than in most industrial country cities—as well as contaminate water supplies and land. Energy production, such as hydro-electric or coal mine development, can cause the loss of agricultural land and displace local populations.

Energy use in developing countries is also of global environmental concern (see below for further discussion). For example, their share of world emissions of carbon dioxide—the most significant greenhouse gas—from the burning of fossil fuel is projected to rise from 25 percent to 44 percent in 2025.[20] If the carbon dioxide impacts of tropical deforestation are included, the developing countries' share of world carbon dioxide emissions rises significantly.

ENERGY, ECONOMIC GROWTH, AND ENVIRONMENTAL QUALITY

Energy and Economic Development

A two-way linkage exists between energy and economic development. The process of economic development strongly influences the amount and type of energy needed. At the same time, developments in the energy sector affect economic growth.

This linkage raises a potential dilemma. On the one hand, the rapid rates of economic growth necessary to provide rising standards of living for growing populations requires sharp increases in energy services. The high cost of providing these services through the conventional route of supply expansion could, however, divert an excessive amount of available investment funds to energy, to the extent of limiting economic growth itself. This possibility is highly undesirable given current low and, in some cases, declining living standards in developing countries.

On the other hand, the inability to supply needed energy services can frustrate economic and social development. In many countries, unreliability and poor quality of energy supplies lead to large costs to the economy through wasted materials, slowdown or stoppage of operations, and investment in standby equipment.

Improving energy efficiencies could help solve this dilemma. The analysis presented here suggests that, on a systems basis, energy efficient equipment can usually provide energy services at lower initial capital costs. Efficiency improvements could therefore increase the capital resources available for

[20] Intergovernmental Panel on Climate Change (IPCC), "Emissions Scenarios," Report of the Expert Group on Emissions Scenarios, April 1990.

investment in social and economic development. The adoption of energy efficient technology could also save foreign exchange, a major constraint in developing countries. On the supply side, improved operating procedures and new technologies may well improve the reliability of energy supplies, and thus reduce the heavy economic losses caused by blackouts and brownouts.

While the major focus of this report is on technologies to improve energy efficiencies in both energy use and supply, the broader issues of the energy implications of different development strategies also need to be considered. A detailed analysis of these issues is beyond the scope of this report, but some general considerations may serve to indicate the importance of the energy sector in broader development goals and strategies.

The traditional route to economic development has been through rapid industrialization, motivated either by ''import substitution' or ''export promotion" considerations. In both cases, the rising share of industry in total output and the associated sharp increase in urban populations has led to a rapid rise in commercial energy consumption.[21] Neither strategy appears to be inherently more energy intensive than the other. Import substitution strategies tend to begin with low energy-intensity assembly type operations, but as they expand to include domestic manufacture of previously imported components—including in some cases metal fabrication-average energy intensities rise.

Conversely, energy intensities associated with export promotion, especially exports based on mining and mineral fuel exploitation, start high, but fall as countries integrate forward to capture the higher value added. The export promotion strategy, however, may have indirect benefits on energy efficiency as the need to compete in foreign markets usually results in the more efficient allocation of resources throughout the economy. Furthermore, export promotion provides the foreign exchange earnings needed to pay for imports of energy efficient technologies. To the extent that export promotion strategies lead to more rapid rates of economic growth, greater opportunities to introduce new, more efficient energy technology are provided.

Changes in the types of products produced within the industrial sector, however, can have a sizable impact on the energy intensity of a country. While the energy content of most industrial products is quite small, a few products--chemicals, plastics, steel, paper, and cement—are conspicuously energy intensive, and a change in the distribution of industrial output between these two categories can impact an economy's overall energy intensity. One-third of the 40 percent decline in the U.S. energy/GDP ratio between 1972 and 1985, for example, is attributed to structural change in the industrial sector, notably the relative decline of steel making; the remainder is due to efficiency improvements. There are similar examples in the developing countries. About half of the post-1979 decline in energy intensity in China (which fell by 30 percent between the late 1970s and the late 1980s) can be ascribed to limits on the expansion of heavy industries and the promotion of light manufactures (e.g., textiles, consumer electronics, processed foodstuffs, and plastics).[22] In the era of cheap oil supplies, countries without domestic energy resources were able to develop energy intensive industries. In recent years, however, countries have been generally reluctant to develop heavy industry based on imported energy.

In adopting industrialization strategies, the developing countries are broadly following the path of the older industrial countries. This raises the possibility of 'leapfrogging'—taking a more efficient route to economic and social improvement than that followed by the industrial countries, whose progress was marked by trial and error and constrained by the need to develop technologies where none existed before. To some extent leapfrogging is already taking place. For example, much steel industry development in the industrial countries took place before the invention of current energy efficient techniques. As demand for steel has been slow, many of these countries have had difficulty modern-

[21] Joy Dunkerley et al., *Energy Strategies for Developing Nations* (Washington, DC: Johns Hopkins University Press, 1981).

[22] See U.S. Congress, Office of Technology Assessment, *Energy Use and the U.S. Economy* (Washington, DC: U.S. Government Printing Off@ June 1990); U.S. Department of Energy, Energy Information Administration, *Monthly Energy Review,* DOE/EIA-0035(91/05 (Washington, DC: May 1991); Ministry of Energy, People's Republic of China, "Energy in China" 1990. The energy intensity went from 13.36 tomes coal equivalent per 10,000 yuan (tee/l@ Y) in 1980 to 9.48 (tee/l@ Y) in 1989 (constant yuan). Total (primary) energy consumption still increased, however, from 603 million tomes coal equivalent (Mtce) in 1980 to 969 Mtce in 1989, but the economy grew at twice that rate. See also Vaclav Srnil, ''China's Energy: A Case Study, " contractor report prepared for the Office of Technology Assessment, April 1990.

izing their industries. In contrast, the more recently developed steel industries in South Korea and Taiwan are based on near state-of-the-art technology and are more energy efficient.

Although rapid industrialization contributed to unprecedented rises in standards of living in the 1950s, 1960s, and 1970s, and for some developing countries even in the 1980s, there is dissatisfaction in many countries with some of the side effects—high unemployment as job creation fails to keep pace with rising populations, unmanageable urbanization, foreign debt, growing dependence on food imports, persistent poverty, environmental degradation. Further, industrialization based on export promotion is threatened by rising protectionism. Together, these factors are leading to consideration of alternative development paths, giving greater emphasis to agriculture[23] or to light, rather than heavy, manufacturing as sources of economic growth.

In such a strategy, it is argued that agricultural development would generate mutually reinforcing linkages with the industrial sector. Thus, increases in farm output would require inputs from the industrial sector in the form of fertilizers, pumps, tractors, and other equipment. The growth of agricultural processing industries would add to these demands from the industrial sector, and also create jobs in rural areas. Higher rural incomes would, in turn, generate additional demand for the products of the industrial sector. This strategy, relying more on raising rural incomes than past approaches, could have favorable impacts on income distribution.

Such a strategy could have important implications for both overall energy intensity and the forms of energy needed. Economies in which agriculture accounts for a large share of total economic activity, tend to have a lower energy intensity .24 Reliable supplies of efficient, modern fuels for agricultural processing, operating pump sets, farm transport, and operating domestic and workshop appliances would be needed in rural areas. The importance of rural electrification to rural development has long been recognized, and major investments have been made

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in **rural** electrification projects, mainly grid extension. Cost and technical improvements in a wide range of small scale, decentralized technologies based on renewable forms of energy (see ch. 6) now offer, in many situations, a more cost effective and sustainable approach to rural electrification. The rising demand for liquid fuels and gases stemming from accelerated rural development could potentially be met through the development of a modern biomass fuels industry (see ch. 6) which simultaneously could increase farm and rural industry employment and income.

The possibilities of alternative strategies for economic and social development, and their energy implications, underline the need to include energy considerations in development planning. Whatever development path is chosen, the energy supply sector is critical for economic development.

Energy and the Traditional Economy

Two-thirds of the developing world's population—some 2.5 billion people—live in rural areas[25] with low standards of living based largely on low-resource farming. This type of farming is characterized by high labor requirements, low productivity

[23] Irma Adelman "Beyond Export-Led Growth,'' *World Development,* vol. 12, No. 9 pp. 937-949, 1984; John P. Lewis and Valeriana Kallab (eds.), Overseas Development Council, "Development Strategies Reconsidered" (New Brunswick, NJ: Transaction Books, 1986).

[24] To cite an admittedly extreme example: the energy intensity of Denmark is one-third that of Luxembourg--despite their very similar levels of income and social development—because Denmark has a large (though highly energy intensive) agricultural sector, while Luxembourg's small manufacturing sector is dominated by the steel industry.

[25] World Bank, *World Development Report 1989,* op. cit., footnote 2.

per hectare and, because of the marginal subsistence, strong risk aversion. Rural populations have little access to commercial fuels and technologies and only limited connection with the modern economy. Biomass fuels satisfy the heating and cooking needs of these populations, and muscle power largely provides for their agricultural, industrial, and transportation energy needs. Although these energy sources provide crucial energy services at little or no direct financial cost, they generally have low efficiencies and limited output and productivity levels.

In many areas, biomass supplies are diminishing due to a host of factors, including population growth and the expansion of agricultural lands, commercial logging, and fuelwood use. The poorest rural peoples often have limited access to even these resources and, therefore, must spend longer periods of time foraging for fuel sources---exacerbating their already difficult economic position.

Traditional villages are complex, highly interconnected systems that are carefully tuned to their environment and the harsh realities of surviving on meager resources.[26] Villages are largely closed systems. The biomass that is used for fuel is part of a system that provides food for humans, fodder for animals, construction materials, fiber for ropes, and even traditional medicines. Similarly, the bullock that pulls a plow also provides milk, meat, leather, and dung for fertilizer or fuel. Changes in any one part thus affect other elements of village life. Changes in agricultural practices, for example, change the amount and type of energy supplies available. In turn, energy sector developments, such as rural electrification, can have major impacts on agricultural practice and income distribution. Making changes in rural systems frequently proves difficult due to the large risks that changes can pose to populations living on the margin of subsistence.

Several factors affect the linkages between energy and the economic and social development of rural economies:

Seasonality

The seasons affect every aspect of rural life: the availability of food, fuel, and employment; the incidence of disease; and even the rates of fertility and mortality .27 Labor requirements for planting are seasonally peaked to take advantage of limited rainfall and other favorable growing conditions.[28] Labor requirements to harvest crops are similarly peaked. Thus, while there may be a large labor surplus during most of the year, labor shortages occur during the critical planting and harvesting seasons. Studies of African agriculture indicate that labor is “the major scarce resource in food production. ’[29] Modern equipment could reduce the high labor demands during planting and harvesting.[30]

Although agriculture demands very high levels of labor during the peak seasons, during the remainder of the year rural areas experience serious underemployment. In turn, this seasonal unemployment in rural areas propels a large amount of both seasonal and permanent migration to urban areas.[31] In Africa and Asia, where the migrants are mostly men,[32] more of the burden for subsistence crop production is shifted to the women who stay behind. Migration to cities increases pressure on forests, because urban dwellers generally *purchase their* wood supplies, which are likely to be derived from cutting whole trees, rather than the gathering of twigs and branches more typical of rural foragers.

[26] See M.B. Coughenour et al, “Energy Extraction and Use in a Nomadic Pastoral Ecosystem,’ *Science, vol.* 230, No. 4726, Nov. 8,1985, pp. 6 19-625; J.S. Singh, Uma Pandey, and A.K. Tiwari, “Man and Forests: A Central Himalayan Case Study, ”*AMBIO*, *vol.* 13, No. 2, 1984, pp. 80-87; Amulya Kumar N. Reddy, “An Indian Village Agricultural Ecosystem—Case Study of Ungra Village. Part II. Discussion, ” *Biomass,* vol. 1, 1981, pp. 77-88.

[27] Robert Chambers, Richard Longhurst, and Arnold Pacey (eds.), *Seasonal* Dimensions *to Rural Poverty* (London: Frances Pinter Publishers, Ltd., and Totowa, New Jersey: Allanheld, Osmun and Co., 1981); Robert Chambers, “Rural Poverty Unperceived: Problems and Remedies,”*World Development, vol. 9, 1981,* pp. 1-19,

[28] Robert Chambers, Richard Longhurst, and Arnold Pacey (eds.), Seasonal *Dimensions to Rural Poverty,* op. cit., footnote 27, pp. 10-11.

[29] Jeanne Koopman Henn, “Feeding the Cities and Feeding the Peasants: What Role for Africa’s Women Farmers?” *World Development, vol.* 11, No. 12, 1983, pp. 1043-1055.

[30] Prabhu Pingali, Yves Bigot, and Hans P. Binswanger, *Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa* (Baltimore, MD: Johns Hopkins University Press for the World Bank, 1987).

[31] Michael P. Todaro, *Economic Development in the Third World* (New York, NY: Longman, Inc., 1977); Gerald M. Meier, *Leading Issues in Economic Development, 4th* ed. (New York, NY: Oxford University Press, 1984); Scott M. Swinton, *Peasant Farming Practices and Off-Farm Employment in Puebla, Mexico* (Ithaca, NY: Cornell University, 1983).

[32] Michael P. Todaro, *Economic Development in the Third World*, op. cit., footnote 31, pp. 192-193. Note that in Latin America more women than men now migrate.

The seasons also affect the availability and usability of renewable energy resources. During the rainy season, wood is less easily obtained and more difficult to burn than during the drier months. In areas heavily dependent on crop residues for fuel, shortages at the end of the dry season can force the use of noxious weeds as substitutes, particularly by the very poor.[33] Correspondingly, in mountainous areas or elsewhere with large seasonal temperature variations, fuel demands can increase significantly during the winter.[34]

Inequities in Resource Distribution and Access

In regions where biomass fuel supplies are limited-particularly those with dry climates and/or high population densities—rural people may travel long distances to collect fuel for domestic use, as much as 20 miles round trip in some areas under special conditions. More generally, when wood is scarce they rely on crop wastes, animal dung, or other materials as substitutes. Estimates of time spent foraging range as high as 200 to 300 person-days per year per household in Nepal.[35] Foraging is also heavy work. In Burkina Faso, typical headloads weigh 27 kg (60 pounds).[36] In many regions, women and children do most of the fuel collection.

Despite these heavy burdens, villagers often prefer to invest their capital and labor in technologies for income-producing activities rather than in fuel-conserving stoves or tree-growing efforts.[37] Reasons for this investment preference include lack of cash income, the ability to minimize wood use or to switch to alternative fuels when wood becomes scarce,[38] conflicts over ownership of land or trees, and easy access to common lands. In addition, villagers often carry out fuelwood collection in conjunction with other tasks, such as walking to and from the fields or herding animals. In this case, collecting biomass resources may prove less burdensome than it appears.[39]

To the village user, the immediate value of these fuels outweighs their potential long-term environmental costs.[40] In India, for example, a ton of cow dung applied to the fields produces an estimated increase in grain production worth $8, but if the dung is burned, it eliminates the need for firewood worth $27 in the market.[41] The diversion of crop residues previously used as soil enhancers to fuel use, however, can over along period of time lead to a loss in soil fertility. Local fuel shortages often have their most serious impacts on the most vulnerable groups. Rural landless and/or marginal farmers may have little access to fuel supplies, especially when the market value of biomass rises,[42]

The Role of Women and Children

Women are particularly affected by biomass fuel availability as they shoulder the burden of most domestic tasks, including foraging for fuelwood and cooking. In many areas they also perform much of

[33] Varun Vidyarthi, "Energy and the Poor in an Indian Village," *World Development,* vol. 12, No. 8, 1984, pp. 821-836.

[34] Majid Hussain, "Fuel Consumption Patterns in High Altitude Zones of Kashmir and Ladakh," *Energy Environment Monitor* (India), vol. 3, No. 2, September 1987, pp. 57-62.

[35] J.S. Singh, Uma Pandey, and A.K. Tiwari, op. cit., footnote 26; Kedar Lal Shrestha, *Energy Strategies in Nepal and Technological Options* @(@: Research Center for Applied Science and Technology, Tribhuvan University, for the End-Use Oriented Global Energy Workshop, Sao Paulo, Brazil, June 1984). The World Bank Energy Sector Assessment for Nepal estimated that 16 percent of all labor went for fuelwood and animal fodder collection.

[36] E. Ernest, ''Fuel Consumption Among Rural Families in Upper Volta, West Africa,' paper presented at Eighth World Forestry conference, J&w@ Indonesia, 1978.

[37] Varun Vidyarthi, "Energy and the Poor in an Indian Village,' op. cit., footnote 33.

[38] Phil O'Keefe and Barry Munslow, "Resolving the Irresolvable: The Fuelwood Problem in Eastern and Southern Africa,' paper presented at the ESMAP Eastern and Southern Africa Household Energy Planning Seminar, Harare, Zimbabwe, Feb. 1-5, 1988.

[39] Irene Tinker, "The Real Rural Energy Crisis: Women's Time," *Energy Journal,* vol. 8, special issue, 1987, pp. 125-146.

'Geoffrey Barnard and Lars Kristoferson, *Agricultural Residues as Fuel in the Third World* (Washington, DC, and London: Earthscan and International Institute for Environment and Development Energy Information Program, Technical Report No. 4, 1985).

[41] G.C. Aggarwal and N.T. Singh, "Energy and Economic Returns From Cattle Dung as Manure and Fuel,'' *Energy,* vol. 9, No. 1, 1984, pp. 87-90; see also G.C. Aggarwal, "Judicious Use of Dung in the Third World," *Energy,* vol. 14, No. 6, 1989, pp. 349-352; Eric Eckholm et al., *Fuelwood: The Energy Crisis That Won't Go Away* (London: Earthscan, 1984), p. 105; Ken Newcombe, World Bank, Energy Department, *An Economic Justification for Rural Afforestation: The Case of Ethiopia* (Washington DC: World Bank, 1984).

[42] Varun Vidyarthi, op. cit., footnote 33.

the subsistence agricultural labor.[43] As women's work often does not produce any cash revenue, they are limited in their ability to introduce improved technologies. Improving labor productivity and energy efficiency in rural areas will thus require special attention to the role of women.

The migration of men to look for urban work leaves women to fulfill traditional male roles as well as their own. In Uttar Pradesh, India, the male to female ratio in villages is 1:1.4 for the working age group of 15 to 50 years.[44] In Kenya, a quarter of rural households are headed by women-in Botswana, 40 percent.[45] Yet the remittances of the migrants can make an important contribution to rural household finances.

Children, too, play an important role in rural labor, freeing adults to perform more difficult tasks.[46] In Bangladesh, for example, children begin performing certain tasks as early as age 4. By age 12, boys become net producers-producing more than they consume--and are nearly as efficient in wage work as men. By age 15, boys have produced more than their cumulative consumption from birth, and by 22 they have compensated for their own and one sibling's cumulative consumption.[47] The important role of children in farming helps explain high fertility rates in rural areas.

The Role of Commercial Biomass in the Rural Economy

While much biomass is used locally, rural areas are also the source of substantial amounts of fuelwood (both firewood and charcoal) used in towns.[48] This trade pumps significant amounts of cash into the rural economy and provides much-needed employment to rural dwellers during non-agricultural seasons. Such marketing networks can be quite extensive and complex.[49]

In many countries, people in the poorest areas, where conditions do not permit expansion of crop or animal production and natural woody vegetation is the only resource, depend heavily on sales of firewood for their income.[50] In India, "headloading" (individuals carrying wood to urban markets on their heads) has become an important source of income for perhaps 2 to 3 million people.[51] Similarly, when crops fail, charcoal production[52] or the cutting of wood from farm hedgerows[53] provides alternatives for earning cash.

The response of rural peoples to fuel shortages varies widely. Some sell wood to urban markets and use the lower quality residues themselves. Others use dung for fuel rather than for fertilizer. In Malawi, to grow sufficient fuel for household use on the typical family farm would displace maize worth perhaps 30 times more; collecting "free" wood

[43] A 1928 survey of 140 Sub-Saharan ethnic groups found that women "carried a major responsibility for food farming" in 85 percent of the cases, and did all but the initial land clearing in 40 percent of the cases. In contrast, the Muslim custom of Purdah, for example, tends to keep women near their homes and away from the fields in Bangladesh. See: Jeanne KoopmanHenn, op. cit., footnote 29; MeadT. Cain, "The Economic Activities of Children in a Village in Bangladesh," *Population and Development Review,* vol. 3, No. 3, September 1977, pp. 201-227; Gloria L. Scott and Marilyn Cam, World Bank, "The Impact of Technology Choice on Rural Women in Bangladesh," Staff Working Paper No. 731, Washington DC, 1985.

[44] J.S. Singh, Uma Pandey, and A.K. Tiwari, "Man and Forests: A Central Himalayan Case Study," op. cit., footnote 26.

[45] World Bank, *Population Growth and Policies in Sub-Saharan Africa* (Washington, DC: World Bank, 1986), p. 39.

[46] Ingrid Palmer has noted: "Children's labor, especially daughters', is usually more significant than husbands' in easing a work bottleneck for women." Ingrid Palmer, "Seasonal Dimensions of Women's Roles," in Robert Chambers, Richard Longhurst, and Arnold Pacey (eds.), *Seasonal Dimensions to Rural Poverty,* op. cit., footnote 27,

[47] Mead T. Cain, op. cit., footnote 43.

[48] The value of commercialized fuelwood and charcoal exceeds 10 percent of the gross domestic product in countries such as Burkina Faso, Ethiopia, and Rwanda and exceeds 5 percent in Liberia, Indonesia, Zaire, Mali, and Haiti. Philip Wardle and Massimo Palmieri, "What Does Fuelwood Really Cost?," *UNASYLVA, vol. 33, No. 131, 1981,* pp. 20-23. George F. Taylor, II, andMoustafa Soumare, "Strategies for Forestry Development in the West African Sahel: An Overview," *Rural Africana, Nos. 23* and 24, fall 1985 and winter 1986.

[49] Alain Bertrand, "Marketing Networks for Forest Fuels to Supply Urban Centers in the Sahel," *Rural Africana,* Nos. 23 and 24, fall 1985 and winter 1986.

[50] J.E.M. Arnold, 'Wood Energy and Rural Communities,' *NaturalResources Forum,* vol. 3,1979, pp. 229-252; Centre for Science and Environment, *The State of India's Environment 1984-85: The Second Citizen's Report (New* Delhi, India: 1985).

[51] Centre For Science and Environment, Ibid., p. 189.

[52] D.O. Hall and P.J. de Groot, "Biomass For Fuel and Food-A Parallel Necessity," draft for *Advances in Solar Energy,* Karl W. Boer (cd.), vol. 3, Jan. 10, 1986; Rafiqul Huda Chaudhury, "The Seasonality of Prices and Wages in Bangladesh," Robert Chambers, Richard Longhurst, and Arnold Pacey (eds.), *Seasonal Dimensions to Rural Poverty,* op. cit., footnote *27.*

[53] Rick J. Van Den Beldt, "Supplying Firewood for Household Energy,' M. Nurul Islam, Richard Morse, and M. Hadi Soesastro (eds.) *Rural Energy to Meet Development Needs* (Boulder, CO: Westview Press, 1984).

proves much easier.[54] In contrast, aerial surveys of Kenya have shown that hedgerow planting increases with population density-demonstrating that villagers respond to the reduced opportunity of collecting free wood from communal lands by growing their own.[55]

These considerations mean that although people in rural areas may appear to use energy-as well as many other resources-in a technically inefficient manner compared with what is possible with modern commercial technologies, they use energy efficiently in the broader context given the difficult constraints of limited resources, technology, and capital that they face.[56] Rather than maximizing production as is done in modern industrial society, traditional peoples focus on minimizing risk in the face of the vagaries of drought and other natural disasters. In so far as traditional peoples are operating rationally within their decision framework, changes are required in that framework through the introduction of external inputs-financial, managerial, material, technical.

Energy and the Environment

Many developing countries are experiencing widespread environmental degradation in both rural and urban areas.[57] Rural areas are experiencing deforestation, desertification, soil erosion (with associated downstream flooding and siltation), and air pollution. In many urban areas of developing countries, levels of air pollution far exceed those in industrialized countries. Water supplies, too, are often heavily polluted.

The role of energy in environmental degradation is complex. On the one hand, energy, used wisely, can potentially provide several important environmental benefits in developing countries. For example, greater energy inputs into agriculture in the form of tractive power, fertilizer, and irrigation, for example, can substantially improve agricultural productivities where soils and climates are appropriate, and help slow the expansion of agricultural lands into tropical forests or environmentally fragile lands that would otherwise be needed to feed a burgeoning population. At the same time, however, modern agriculture can also cause environmental damage: by overuse of pesticides, herbicides, and fertilizers; by waterlogging and salinizing irrigated lands; and by use of these techniques under inappropriate soil and climatic conditions.[58]

In addition to providing environmental benefits, energy production, conversion, and usc also contribute to environmental degradation. Coal mining disturbs surface lands and waters and may also contaminate underground or surface waters if excavated material is not properly managed. Dust and emissions from coal mining and preparation can contribute to local air pollution. Oil and gas production and transport can also lead to land disturbance and water contamination. The combustion of fossil fuels-in refineries, power stations, and by end users-contributes to air pollution through adding sulfur dioxide, particulate, carbon monoxide, nitrogen oxides, and carbon dioxide emissions, leading to acid rain, urban smog, and potentially global warming. The development of hydro resources can flood large tracts of land, uprooting people and leading to loss of forests and wildlife habitat; disrupt the natural flow of rivers; and contribute to the increased incidence of debilitating diseases such as schistosomiasis. Nuclear energy has the potential to release toxic and radioactive materials, and poses problems of weapons proliferation.

[54] D. French, "The Economics of BioEnergy in Developing Countries, " H. Egneus et al. (eds.), *Bioenergy 84. Volume V. Bioenergy in Developing Countries* (Amsterdam: Elsevier, 1985). It is estimated that 90 percent of all rural households collect all their wood; 10 percent purchase some of their wood at $0.50/m^4$ or $0.04/GJ. Urban households buy their wood at a cost of $0.12/GJ. In contrast, plantation-derived fuelwood can cost $1.50 to $2.00/GJ. A farmer could plant trees, but the loss of 0.4 hectare of farmland reduces maize production by a total of $125 and profit by $30. In contrast, trees produced on 0.4 hectare will be worth $6 in 7 years.

[55] P.N. Bradley, N. Chavangi, and A. Van Gelder, "Development Research and Energy Planning in Kenya," *AMBIO*, vol. 14, No. 4-5, 1985, pp. 228-236.

[56] Notable examples of such studies include N.H. Ravindranath et al., An Indian Village Agricultural Ecosystem—Case Study of Ungra Village, Part I: Main observations, *Biomass, vol.* 1, No. 1, September 1981, pp. 61-76; Amulya Kumar N. Reddy, "An Indian Village Agricultural Ecosystem—Case Study of Ungra Village, Part II: Discussion" *Biomass,* vol. 1, No. 1, September 1981, pp. 77-88; M. B. Coughenour et al., op. cit., footnote 26.

[57] The interactions between energy and the environment are analyzed in detail in ch. 5 of the interim report of this project U.S Congress, Office of Technology Assessment, *Energy in Developing Countries OTA-E-486* (Washington DC: U.S. Government Printing Office, January 1991).

[58] U.S. Congress, Office of Technology Assessment, *Enhancing Agriculture in Africa: A Role for U.S. Development Assistance,* OTA-F-356 (Springfield, VA: National Technical Information Service, 1988), Some note, however, that even steep or acid-infertile lands can be productive over long periods as shown by the centuries of terraced rice farming in Asia or continuous sugar-cane cropping in the Dominican Republic. Scc Ricardo Radulovich, "A View on Tropical Deforestation, " *Nature,* vol. 346, No., 6281, July 19, 1990, p. 214.

Table 2-7—Causes and Consequences of Environmental Degradation in Rural Areas

Consequence	Direct cause	Underlying cause
Deforestation Less of biodiversity Soil erosion Flooding	Shifting agriculture Permanent agriculture Permanent pasture	Population growth Poverty Lack of land tenure Low-level agricultural inputs Mechanization of agriculture and/or the consolidation of agricultural lands
	Commercial logging	Destructive logging, lack of forest management and protection, poor reforestation Increased access to forests along logging roads for farmers and ranchers
	Agriculture, ranching, and logging	Production for export markets Fiscal policies and legislation, in part to promote exports of primary products due to need for foreign exchange to service debt. Inappropriate economic valuations of natural resources and biodiversity
	Use of biomass fuels	Inefficient use of fuelwood; overcutting of fuelwood resources
	Use of forest biomass for fodder	Shortages and lack of alternative sources of fodder
Desertification	Agricultural expansion onto fragile lands Overgrazing Burning of grasslands	Population growth Poverty Lack of land tenure Low-level agriculture and/or the consolidation of agricultural lands
	Use of biomass fuels	inefficient use of fuelwood; overcutting of fuelwood sources Lack of access to higher quality fuels and stoves.
	Climate change	Various; not well understood
Air pollution	Slash and burn agriculture Burning of grasslands	Population growth Poverty Lack of land tenure Low-level agricultural inputs
Salinization and water-logging of irrigated lands	Poor @arming and management Inadequate investment in infrastructure	Lack of access to high-quality or alternative sources of fodder Cheap or free water contributing to inefficiency

SOURCE: Office of Technology Assessment, 1992.

Energy efficient technologies can moderate these environmental impacts while providing the energy services needed for development. An increased role for renewable energy technologies and natural gas could also reduce these adverse environmental impacts.

It is important to note, however, that energy is not the sole contributor to environmental degradation in developing countries, especially in rural areas. Others include population growth, inequitable land tenure, unsustainable agricultural and forestry practices, industrialization, and government policy (see table 2-7).

Population pressure is a major cause of environmental degradation in rural areas. As rural populations grow, the demands on the land for food, fuel, and fodder increase accordingly while, in many developing countries, the low agricultural productivities of traditional cultivation techniques have difficulty keeping up. Farmers then face three basic choices: they can ‘mine’ the land—taking more out of it than they put in-until the land is exhausted; they can migrate to new lands--often marginal and ecologically fragile (the best lands are often already in use)--or to poor urban areas; or they can increase the level of (capital-, energy-, and labor-intensive) agricultural inputs--mechanical traction, fertilizer, and irrigation—into the land in order to raise yields.

The latter strategy could also include higher inputs of information and management as might be the case for intercropping, agroforestry, integrated crop-livestock, or other sophisticated agricultural systems.[59]

When farmers migrate to new lands, woodlands are cleared for cropland and pastures. Woodlands are also commercially logged. The use of biomass for fuel or fodder places further demands on woodlands and grasslands, particularly in arid regions with high population densities. Farming, ranching, logging, and the use of biomass fuels are all necessary if the people dependent on these resources are to survive. But these various pressures can also have a variety of negative impacts: destruction of tropical forests and biodiversity; desertification; soil erosion and increased downstream flooding and siltation; and air pollution-local, regional, and global.

Rapid population growth, along with inadequate infrastructure and economic and industrial growth with minimal or inadequately enforced environmental controls, have also led to high levels of pollution in urban areas. Levels of sulfur dioxide, particulate, ground-level ozone, and nitrogen oxides often exceed those in industrialized countries, Major sources include electricity generation, transportation, and industrial production. Greater use of fossil fuels in the modern, primarily urban, sector can also lead to environmental degradation and pollution in the rural areas where fuels are extracted from the ground and transported to the cities, and where hydroelectric facilities are sited.

Many have viewed environmental costs--degradation and pollution of the natural resource base-as the price that must be paid in order to develop economically.[60] Increasingly, however, others argue that environmental protection and economic development are tightly interconnected and mutually supportive.[61] Energy efficiency may allow these polar positions on economic growth and environmental quality to be sidestepped altogether. As detailed in this report, energy efficient technologies usually reduce both initial capital and life cycle operating costs, contributing to economic growth. At the same time, energy efficient technologies, by using less energy to provide a given service, reduce the adverse impacts of energy production and use while still providing the energy services needed for development.

Greenhouse Gases and Global Climate Change

The environmental impacts described above are largely limited to the individual countries concerned. Some activities—notably, the production and use of fossil fuels, deforestation, the use of chlorofluorocarbons (CFCs), and others--can have a wider impact, including impacts on the global climate through the ''enhanced' greenhouse effect. These issues have been explored in depth in several recent publications.[62]

The ''natural' greenhouse effect is a well-established scientific fact. In the absence of the natural greenhouse effect, the average surface temperature of the Earth would be –18 °C instead of the actual +15 °C. This +33 °C increase in average surface temperature is due to the presence of naturally occurring greenhouse gases—principally carbon dioxide, methane, and water vapor. Today, increases in atmospheric concentrations of these and other greenhouse gases due to the burning of fossil fuels, deforestation, the use of CFCs, and other human-induced changes in the biosphere are leading to an enhancement of this naturally occurring greenhouse effect. Table 2-8 lists some of the leading sources of these greenhouse gases. A recent review by over 200 leading scientists from 25

[59] U.S. Congress, Office of Technology Assessment, Ibid.

[60] Clem Tisdell, ''Sustainable Development: Differing Perspectives of Ecologists and Economists, and Relevance to LDCS, ' *World Development*, vol. 16, No. 3, 1988, pp. 373-384.

[61] World Commission on Environment and Development, *Our Common Future* (New York, NY: Oxford University Press, 1987).

[62] U.S. Congress, Office of Technology Assessment, *Changing By Degrees: Steps to Reduce Greenhouse Gases*, OTA-O-482 (Washington, DC: U.S. Government Printing Office, February 1991); Intergovernmental Panel on Climate Change (IPCC), Meteorological Organization/U.N. Environment Program, *Scientific Assessment of Climate Change, Summary and Report* (Cambridge, United Kingdom: Cambridge University Press, 1990); Michael Grubb, *Energy Policies and the Greenhouse Effect, Volume one: Policy Appraisal,* Royal Institute of International Affairs (Aldershot, Hants, UK: Dartmouth Publishing Company, 1990); National Academy of Sciences et. al., *Policy Implications of Greenhouse Warming* (Washington, DC: National Academy Press, 1991); World Resources Institute, *Greenhouse Warming: Negotiating a Global Regime* (Washington, DC: World Resources Institute, January 1991); William A. Nitze, *The Greenhouse Effect: Formulating a Convention* (London: Royal Institute of International Affairs and Washington DC: Environmental Law Institute, 1990); Allen L. Hammond, Eric Rodenburg, and William R. Moomaw, "Calculating National Accountability for Climate Change, ' *Environment*, vol. 33, No. 1, 1991, pp.1 1-15, 33-35; David G. Victor, "How to Slow Global Warming," *Nature*, vol. 349, No. 6309, Feb. 7, 1991, pp.451-456.

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Table 2-8-Sources of Greenhouse Gases

Greenhouse gas	Principal sources
Carbon Dioxide	Fossil fuel combustion Deforestation, land use changes Cement production
Methane	Fossil fuel production (coal mines, oil and gas wells, gas pipelines) Fossil fuel combustion Landfills Rice cultivation Animal husbandry Biomass combustion and decay
Chlorofluorocarbons	Synthetics used in refrigerators and air conditioners Used in manufacturing processes as blowing agent, cleaning agent
Nitrous Oxide	Fertilizers Fossil fuel combustion Biomass combustion Deforestation and land use changes

Adapted from: Michael Grubb, *Royal Institute of International Affairs*,"Energy Policies and the Greenhouse Effect, Volume one: Policy Appraisal," (Aldershot, Hants, England: Dartmouth Publishing Co., 1990); and Dilip R. Ahuja, "Estimating Regional Anthropogenic Emissions of Greenhouse Gases," forthcoming, T.N. Khoshoo and M. Sharma (eds.); "The Indian Geosphere Biosphere" (New Delhi, Indian National Science Academy, Vikas Publishing House, 1991).

countries concluded that this increase in greenhouse gas concentrations will raise the average surface temperature of the Earth (see box 2-B).

Based on current models and under "business-as-Usual' ' scenarios, the Intergovernmental Panel on Climate Change (IPCC) scientists predict that global mean temperature will increase at a rate of about 0.3 °C per decade during the next century, a rate higher than that seen over the past 10,000 years. This would mean a nearly 1 'C increase over present day global average temperatures by 2025 and a 3 'C increase by 2100. In addition to increases in mean global temperature, other effects expected to occur with global Warming include increases in sea level[63] and shifts in regional temperature, wind, rainfall, and storm patterns. These, in turn, are expected to submerge low-lying coastal areas and wetlands, threaten buildings and other structures, and increase the salinity of coastal aquifers and estuaries. Such changes could disrupt human communities and aquatic and terrestrial ecosystems, and affect food production and water availability.[64] Many developing countries will be particularly vulnerable to these effects due to their high degree of dependence on subsistence or low-input agriculture. Some developing countries may also be heavily impacted by flooding of their low lying lands.

In 1985, according to estimates for the IPCC Working Group III, developing countries contributed slightly more than one-quarter (26 percent) of annual global energy sector $C0_2$ emissions; three-fourths came from the industrialized market countries and the centrally planned European countries (including the U.S.S.R.). By 2025, with expanding populations and rapidly increasing energy use, developing countries are projected by the IPCC to produce roughly 44 percent of global energy sector CO_2 emissions. Even so, per capita emissions of CO_2 will continue to be much lower in the developing countries compared with the industrial countries.

While the CO_2 emissions from the commercial energy sector are fairly well known, there are large uncertainties about the contribution of emissions from traditional fuels, and from deforestation and other land use changes. Estimates of the CO_2 emissions from tropical deforestation differ by a

[63] 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 increase is primarily due to thermal expansion of the oceans and melting of some land ice.

[64] Intergovernmental Panel on Climate Change (IPCC), World Meteorological Organization/U.N. Environment Program, ''Policymaker's Summary of the Potential Impacts of Climate Change: Report from Working Group II to the IPCC,'' May 1990, p. 8.

Box 2-B—Highlights of the Intergovernmental Panel on Climate Change 1990 Scientific Assessment

Several hundred scientists from 25 countries prepared and reviewed the scientific data on climate change under the auspices of the World Meteorological Organization and the United Nations Environment Program. This Intergovernmental Panel on Climate Change summarized their findings as follows:

The IPCC is certain that:

- there is a natural greenhouse effect which already keeps the Earth warmer than it would otherw ise be.
- 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 greenhouse effect, resulting on average in an additional warming of the Earth's surface. The main greenhouse gas, water vapor, will increase in response to global warming and further enhance it.

The IPCC calculates with confidence that:

- atmospheric concentrations of the long-lived gases (CO_2, N_2O, and the CFCs) adjust only slowly to changes in emissions. Continued emissions of these gases at present rates would commit us to increased concentrations for centuries ahead. The longer emissions continue to increase at present-day rates, the greater reductions would have to be for concentrations to stabilize at a given level.
- the long-lived gases would require immediate reductions in emissions from human activities of over 60 percent to stabilize their concentrations at today's levels; methane would require a 15 to 20 percent reduction,

Based on current model results, the IPCC predicts that:

- under the IPCC Business-As-Usual Scenario, global mean temperature will increase about 0.3 "C per decade (with an uncertainty range of 0.2 to 0.5 "C per decade); this is greater than that seen over the past 10,000 years. This will result in a likely increase in global mean temperature reaching about 1 "C above the present value by 2025 and 3 "C before the end of the 21st century.
- land surfaces will warm more rapidly than the ocean, and high northern latitudes will warm more than the global mean in winter.
- regional climate changes will differ from the global mean, although confidence in the prediction of the detail of regional changes is low. Temperature increases in Southern Europe and central North America are predicted to be higher than the global mean, accompanied on average by reduced summer precipitation and soil moisture.
- global mean sea level will rise about 6 cm per decade over the next century, rising about 20 cm by 2030 and 65 cm by the end of the 21st century.

All predictions are subject to many uncertainties with regard to the timing, magnitude, and regional patterns of climate change due to incomplete understanding of:

- sources and sinks of greenhouse gases,
- clouds,
- oceans, and
- polar ice sheets.

These processes are already partially understood, and the IPCC is confident that the uncertainties can be reduced by further research. However, the complexity of the system means that surprises cannot be ruled out.

The IPCC judgment is that:

- Global mean surface air temperature has increased by 0.3 to 0.6 "C over the last 100 years, with the 5 global-average warmest years occurring in the 1980s. Over the same period global sea level has increased by 10-20 cm.
- The size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as natural climate variability. Thus, the observed temperature increase could be largely due to natural variability; alternatively, this variability and other human factors could have offset a still larger human-induced greenhouse warming. The unequivocal detection of the enhanced greenhouse effect from observations is not likely for a decade or more.

SOURCE: Intergovernmental Panel on Climate Change, *Scientific Assessment of Climate Change, Summary and Report*, **World** Meteorological Organization/U.N. **Environment Program (Cambridge, United Kingdom: Cambridge University Press, 1990).**

Table 2-9--Parameters for Key Greenhouse Gases

	c o ,	CH_4	CFC-11	CFC-12	N_2O
Atmospheric concentration					
Pre-industrial, 1750-1800	280 ppmv	0.8 ppmv	o pptv	o pptv	288 ppbv
Present day, 1990	353 ppmv	1.72 ppmv	280 ppmv	484 ppmv	310 ppbv
Current annual rate of change	1.8 ppmv (0.5%)	0.015 ppmv (0.9%)	9.5 pptv (4%)	17 pptv (4%)	0.8 ppbv (0.25%)
Atmospheric lifetime (years)	(50-200)[a]	10	65	130	150
Global warming potential relative to carbon dioxide for today's atmospheric composition:					
Instantaneous potential, per molecule	1	21	12,000		
20-year time horizon, per kg	1	63	4,500	7,100	270
100-year time horizon, per kg	1	21	3,500	7,300	290
500-year time horizon, per kg	1	9	1,500	4,500	190
Contribution to radiant forcing,					
1765-1990	61%	2370	2.5%	5.7%	4.1%
1980-1990	55%	15%	5%	129'0	6%
Reduction required to stabilize concentrations at current levels	60-?%	15-20%	70-75%	75-85%	70-8070

KEY: ppm(b,t)v = parts per million (billion, trillion) by volume.

[a]Carbon dioxide absorption by the oceans, atmosphere, soils, and plants can not be described by a single overall atmospheric lifetime.

SOURCE: Adapted from Intergovernmental Panel on Climate Change, *Scientific Assessment of Climate Change, Summary and Report*, World Meteorological Organization/U.N. Environment Program (Cambridge, United Kingdom: Cambridge University Press, 1990).

factor of four.[65] By various estimates, deforestation could be the source of between roughly 7 to 35 percent of total annual CO_2 emissions. overall, the available estimates suggest that developing countries currently contribute somewhere between 30 to 55 percent of total global annual CO_2 emissions. Developing countries also account for at least half of the global anthropogenic generation of two other important greenhouse gases, methane and nitrogen oxides. There similarly remain large uncertainties, however, about the sources and size of these emissions: for example, about the methane emissions from rice paddies and from animal husbandry.

Controlling emissions can slow potential global warming. Emission control strategies that countries could consider today include improved energy efficiency and cleaner energy sources-strategies that also often have economic benefits. The expansion of forested areas, improved livestock waste management, altered use and formulation of fertilizers, improved management of landfills and wastewater treatment, and the elimination of the most greenhouse active CFCs might also reduce or offset emissions. Reducing CO_2 emissions by 60 percent or more (see table 2-9) to stabilize atmospheric concentrations at current levels, however, is a formidable challenge with today's technologies. The United States, for example, would have to reduce per capita consumption of fossil fuels to less than 10 percent of current levels—a more than 90 percent reduction-if such an emissions rate were applied uniformly across today's global population. On the other hand, many developing countries would not currently need to cut fossil fuel use to meet such an emissions target, but might be constrained were they to expand fossil fuel use in the future.

Achieving meaningful reductions in emissions will require unprecedented levels of international cooperation and must include developing countries. In addition to the technological challenges for the energy, agriculture, and industrial sectors, governments of the industrial and developing countries face challenges in improving and expanding institutional mechanisms for transferring technologies that can provide vital energy services while limiting emissions.

[65]Intergovernmental Panel on Climate Change (IPCC), World Meterological Organization/U.N. Environment Program "Policyymaker's Summary of the Formulation of Response Strategies: Report Prepared for IPCC by Working Group III, " June 1990, p. 5. IPCC Working Group 1, "Scientific Assessment of Climate Change: Peer Reviewed Assessment for WG1 Plenary Meeting, May 1990," Apr. 30, 1990, p. 1-9.

CONCLUSION

The magnitude of these problems suggests the need for new approaches to providing the energy services needed for economic development. This report, the final report of this OTA assessment,[66] evaluates the role of technology in better providing energy services for development. By "technology" this assessment includes not only hardware, but also the knowledge, skills, spare parts, and other infrastructure that permit equipment to be used effectively. Further, any discussion of technology must recognize the key role of institutional and policy considerations, as they frequently combine to provide adverse incentives to improved energy technologies on both the demand and supply side. As shown in following chapters, however, there is an historic opportunity to use more efficient energy end use and supply technologies to meet the growing demand for energy services in developing counties while at the same time minimizing financial, environmental, and other costs.

[66] The first report was: U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries*, OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991).