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World Development Report

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Background paper for World Development Report 1992

Commercial Energy Efficiency and the Environment

Robin W. Bates
and
Edwin A. Moore

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This paper — a product of the Office of the Vice President, Development Economics — is one in a series of background papers prepared for the *World Development Report 1992*. The *Report*, on development and the environment, discusses the possible effects of the expected dramatic growth in the world's population, industrial output, use of energy, and demand for food. Copies of this and other *World Development Report* background papers are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact the *World Development Report* office, room T7-101, extension 31393 (September 1992, 59 pages).

The production and use of energy create serious, extensive environmental affects at every level, in every country, argue Bates and Moore. That impact may be more serious in developing than in developed countries as developing countries depend more on natural resources and lack the economic strength to withstand environmental consequences.

At the same time, a reliable energy supply is vital to economic growth and development. Energy consumption and economic growth have been somewhat delinked at high income levels, but increased energy consumption (especially of electricity) is inevitable with higher GDP.

Greater energy efficiency in developing countries and Eastern Europe is a high-priority way to mitigate the harm to the environment of growing energy consumption, say Bates and Moore. They outline four advantages of greater energy efficiency:

- It requires measures that are in the economic self-interest of those regions. Political obstacles make these measures difficult, but there are well-established techniques for addressing concerns about low-income consumers (such as direct income support or "lifeline" rates).
- It will help conserve the world supply of nonrenewable (especially fossil) fuels.
- It will encourage appropriate fuel switching.
- It addresses every level of concern, up to the global effects of global warming.

Any strategy to make energy use and production more efficient must rely more extensively than before on markets that are allowed to function with less government interference. The crucial components of such a strategy (also crucial to economic development generally) are:

- More domestic and external competition.
- The gradual elimination of energy pricing distortions.
- The reduction of macroeconomic and sectoral distortions (for example, in foreign exchange and credit markets).
- The reform of energy supply enterprises — reducing state interference, providing more financial autonomy and a greater role for the private sector.
- Consumer incentives to select more efficient lights, space heating, and so on.

Bates and Moore are not convinced of the need for nonmarket approaches beyond those geared to correct externalities, provide essential information, support basic research and development, and possibly promote pilot projects.

They also conclude that a government is far more likely to take action to reduce an environmental externality if it captures benefits within its own national boundaries that exceed the cost of the action. Reducing the large difference between energy prices and economic costs in developing countries and Eastern Europe is a more immediate issue than carbon taxes.

The developed countries, say Bates and Moore, have an indispensable role to play in improving energy efficiency in the developing countries and Eastern Europe. They can encourage the flow of efficient technology, they can increase conventional aid, and they must accept a greater share of the burden of protecting the global commons.

COMMERCIAL ENERGY EFFICIENCY AND THE ENVIRONMENT

By

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(Background Paper for World Development Report '92)

The World Development Report 1992, "Development and the Environment," discusses the possible effects of the expected dramatic growth in the world's population, industrial output, use of energy, and demand for food. Under current practices, the result could be appalling environmental conditions in both urban and rural areas. The World Development Report presents an alternative, albeit more difficult, path - one that, if taken, would allow future generations to witness improved environmental conditions accompanied by rapid economic development and the virtual eradication of widespread poverty. Choosing this path will require that both industrial and developing countries seize the current moment of opportunity to reform policies, institutions, and aid programs. A two-fold strategy is required.

• First, take advantage of the positive links between economic efficiency, income growth, and protection of the environment. This calls for accelerating programs for reducing poverty, removing distortions that encourage the economically inefficient and environmentally damaging use of natural resources, clarifying property rights, expanding programs for education (especially for girls), family planning services, sanitation and clean water, and agricultural extension, credit and research.

• Second, break the negative links between economic activity and the environment. Certain targeted measures, described in the Report, can bring dramatic improvements in environmental quality at modest cost in investment and economic efficiency. To implement them will require overcoming the power of vested interests, building strong institutions, improving knowledge, encouraging participatory decisionmaking, and building a partnership of cooperation between industrial and developing countries.

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Other (unpublished) papers in the series are available direct from the World Development Report Office, room T7-101, extension 31393. For a complete list of titles, consult pages 182-3 of the World Development Report. The World Development Report was prepared by a team led by Andrew Steer; the background papers were edited by Will Wade-Gery.

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I. INTRODUCTION

1. Economic policies, at the macroeconomic and sectoral level, affect the amount and type of energy used. They have a major impact on the environment, especially on pollution problems. We focus on economic policies in the developing countries and on the role of commercial energy. On a world-wide basis, commercial fuels now represent the predominant form of energy in use, although traditional fuels (notably fuelwood) account for about 12% of world energy supply and are still important in the energy sectors of low-income countries, especially in Africa.[1] An analysis of the current world situation shows that total commercial energy consumption is slightly over 8 billion tons of oil equivalent (btoe), of which almost 90% comes from fossil fuel -- oil, gas and coal. The developed countries (DCs) account for 50% of total energy consumption; the former USSR and Eastern Europe (EE) nearly 25%; and the remaining 25% is consumed in the less-developed countries (LDCs). The prospect of continuing population growth and economic development in the LDCs, combined with high energy intensity, means that their consumption could grow to two-thirds of the world's total by the year 2030. The mainstay of energy supply is likely to continue to be fossil fuels in the near- to medium-term future, which have a life of about 100 years on the basis of existing reserve-to-production ratios.

2. However, most commercial energy forms have adverse environmental impacts, such as local air pollution, global warming or the reduction of biodiversity. While there are technologies, actions and policies to mitigate some of these adverse impacts, as yet there is no ready answer to the problem of carbon dioxide and the associated contribution to global warming. An important challenge facing mankind is, therefore, to find ways of managing economic growth in a way which is sustainable, while recognizing the inevitability of further increases in energy consumption.

3. A crucial element in the management process is the pursuit of policies and the establishment of institutional frameworks conducive to the efficient use and supply of energy. Generally, economically-sound natural resource management policies for a country, which save productive resources and help to extend the overall life of depletable fuels, will also be sound from an environmental point of view. In particular, by acting in their own economic self-interest, LDCs can adopt policies which not only alleviate local and national environmental problems, but also make a significant contribution to attempts to deal with transnational and global environmental problems. Of course, there will be limits to the "self-interest" approach, and instruments such as carbon taxes may need to be implemented in the future, but in the meantime, considerable advances can be made in dealing with energy-related environmental issues through appropriate economic policies which make sense at the national level. With regard to global environmental concerns, there is a strong case for the developed countries to assume a greater share of the burden: the LDCs and EE will need some level of compensatory financial assistance for any action they take on global issues, in addition to existing conventional aid, for example to finance the development and application of renewable energy.

4. This paper reviews recent World Bank experience with regard to the impact of economic policies on commercial energy production and use and on the environment, in the former USSR, EE and the LDCs. We evaluate some of the directions which have been taken to handle externalities, again drawing on recent World Bank experience. At various points, we employ illustrations from China, India, Brazil and Poland, not because they are particularly bad offenders, but because of their

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[1] U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries*, OTA-E-486, Washington, D.C., January 1991, Table 1-3 (p. 8).

significance in terms of world energy consumption and greenhouse gas emissions. Sections II and III identify salient patterns in energy consumption and supply respectively; Section IV discusses the environmental impact of energy production and use; Section V analyzes the effect of economic policy distortions on energy markets, from the demand and supply sides; Section VI discusses the incorporation of externalities in economic policy; and Section VII provides comments on possible future directions for energy policy and the environment.

II. ENERGY CONSUMPTION

5. Total *world commercial energy consumption and its growth rate* for the period 1969-1989 are in Table 1, which distinguishes between the LDCs, EE, the USSR, the DCs, and others. The world average growth rate of 2.1% p.a. for the period 1979-1989 was slightly higher than the world average population growth rate, resulting in a modest increase in world per capita energy use, from 1,541 kgoe to 1,560 kgoe (see Fig. 1). However, these averages conceal striking differences between the DCs and other countries. Not only did total energy consumption during both 1969-1979 and 1979-1989 grow much more slowly in the DCs than elsewhere, it did not even match the much lower population growth in the DCs after 1979; moreover, energy consumption on a per capita basis declined -- from 5,217 kgoe in 1979 to 5,194 kgoe in 1989 -- in contrast to the experience elsewhere (Fig. 1). Growth rates of energy consumption in the USSR and EE were intermediate between those of the LDCs and DCs, but energy consumption per capita increased steadily. Indeed, by 1989, the USSR had almost matched the DCs in terms of per capita energy consumption. Finally, energy consumption grew most rapidly in the LDCs throughout the period 1979-1989, although, given steady population growth, energy consumption per capita was still less than 10% that of the DCs in 1989.

6. The *regional breakdown of world commercial energy consumption* is in Table 2. The DCs, with only 15% of the world's population of 5.2 billion, still account for around half the total energy consumption of 8.1 billion toe; the USSR and EE consume nearly 25%; and the remaining 25% is consumed in the LDCs. It is also worth noting (Table 3) that nearly half of total commercial energy consumption in the LDCs and EE occurs in just four countries (China, India, Brazil and Poland), while nine hold nearly a two thirds share.

7. The *cross-sectional data* for 1989 in Fig. 2 show clearly, on a double-logarithmic scale, the link between commercial energy consumption and GDP. Nevertheless, while energy use increases with GDP. it is notable (Table 4) that energy intensities, as measured by energy consumption (in kgoe per US$ of GDP), decrease as economies make the transition from the low- to the middle-income and from the middle- to the high-income categories. Low-income countries, as a group, consume more than three times as much energy per US$ of GDP than the high-income countries. As Table 4 indicates, another factor is at work in Fig. 2, namely the effect of socialist, mixed and market economies. The high materials-intensity of the socialist economies is well known and energy is no exception. China and EE exhibit by far the highest energy intensities, in excess of 1 kgoe/US$ of GDP. China and Poland are the most energy-intensive economies in the world; while Japan is the least, consuming little more than one-twelfth of China's energy per US$ of GDP. If the socialist economies are excluded from the comparison, the low- and middle-income countries (mostly with mixed economies) have energy intensities of about 0.4 kgoe/US$ of GDP and 0.6 kgoe/US$ of GDP respectively, suggesting that energy-intensity initially increases, as economies grow, before declining at high-income levels. Finally, the high-income market economies have the lowest energy intensities, typically about 0.4 kgoe/US$ of GDP, or less.

8. The *trends in energy-intensity* in the LDCs are not reassuring, despite the two oil price shocks. Of the five largest consuming countries in Table 3 (with more than half the total LDC and EE commercial energy consumption), three increased their energy intensity over 1971-1989 (Brazil, India and Mexico), although China and (from 1982) Poland decreased theirs (see Table 5). In sharp contrast, five of the major industrialized countries (France, Germany, Japan, UK and USA), achieved substantial reductions in energy intensity over the same period (see Table 6).

9. The wide *variation in energy intensity between the countries* in Tables 5 and 6 suggests that there is considerable potential for improving end-use energy efficiency, above all in USSR/EE, and a substantial body of technical evidence bears this out. Numerous engineering studies show a significant difference between actual consumption and the energy consumption that could theoretically be achieved from more efficient (and known) technologies, notable examples being in electric lighting, motor vehicles, cooking stoves, building construction, electric motors, refrigeration, space heating and cooling, etc.[2/] This theoretical difference amounts typically to at least 20-25% of total energy consumption in most countries: an even higher figure is sometimes quoted. For example, in the USA, a 1978 study estimated the hypothetical savings from a "least-cost" energy strategy to be 25% of total energy actually consumed in that year,[3/] and in 1987 it was again suggested that the USA could have reduced its total energy bill by 25%, simply by adopting available technologies which are economically justified.[4/] For Brazil, a 1987 study estimated that the additional electricity savings available from implementing technologies in six major end-use areas "that are technically and economically feasible and, in many cases, already available in Brazil" could amount to 20% by 2000 and that "additional savings may be possible in other areas such as water heating and air conditioning."[5/] A follow-up study in 1990 reached similar conclusions, with savings of 24% from a "rapid shift to more efficient end-use technologies," most of which would be available today and others which "could be made available if so desired"[6/] (a discussion of energy efficiency programs in Brazil is in Box 1). World Bank staff estimates also point to significant energy conservation potential in a wide range of LDCs. For example: (i) *in India*, it was concluded that the potential savings, simply from implementing 26 "feasible" and "economic" end-use technologies, might be in the order of 20%; (ii) *in Hungary*, it was calculated that potential energy savings in a cross-section of industries could be about 20%, with up to 40% possible in key sectors, such as cement, fertilizers and steel; and (iii) *in China*, 1988 data showed that 82% of industrial boilers had efficiencies below 60%, compared with 80% achieved in DCs, implying a fuel loss of 90 million tons of coal p.a. (i.e., 10% of China's annual energy consumption at that time). A more comprehensive review of energy savings potential

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2/ See, for example, World Resources Institute, *World Resources 1990-91*, Oxford University Press 1990, pp. 25-26; M. Munasinghe and S. Munasinghe, "Energy Policy, Technology Cooperation and Capital Transfers to Address Global Climate Change Issues in Developing Countries," *A Comprehensive Approach to Climate Change*, Report from a Workshop, Oslo, July 1-3, 1991, T. Hanisch (ed.), Center for International Climate and Energy Research, Oslo, 1991; and Barakat & Chamberlin, Inc., *Efficient Electricity Use: Estimates of Maximum Energy Savings*, Electric Power Research Institute, 1990.

3/ E. Hirst *et al.*, "Improving Energy Efficiency: the Effectiveness of Government Action," *Energy Policy*, June 1982.

4/ See H. Geller, *et al.* "The Role of Federal Research and Development in Advancing Energy Efficiency: A $50 Billion Contribution to the U.S. Economy," *Annual Review of Energy*, Vol. 12, 1987.

5/ H.S. Geller *et al.*, "Electricity Conservation in Brazil: Potential and Progress," *Energy*, Vol. 13, No. 6, 1988.

6/ H.S. Geller, *Electricity Conservation in Brazil: Status Report and Analysis*, American Council for an Energy-Efficient Economy, August 1990.

BRAZIL **BOX 1**

Contradictions in Policy

Energy Sector

1. From 1971, Brazil's energy consumption grew at more than 6% p.a., significantly above the average for middle income developing countries (4.4% p.a.); and, in 1989, Brazil was the third-largest consumer of energy among the LDCs and F (Table 3). While energy intensity in Brazil is substantially below that of middle-income countries on average (Table 4), energy intensity in general and electricity intensity in particular have climbed noticeably since before the first oil price shock. Brazil is reasonably well endowed with energy resources, which permit it a diversified energy supply base: petroleum and hydroelectricity each accounted for 33% of primary energy consumption in 1990; firewood 15%; alcohol from sugar cane 10%; coal 5% and gas 2%. The country is able to meet roughly half of its own petroleum requirements; and almost the entire electricity supply is generated from domestic hydroelectric power.

2. Brazil has made efforts to increase energy efficiency; tackle the environmental and resettlement problems associated with hydro generation, especially in the Amazon; and address the pollution caused by fossil-fuel consumption, notably in the State of São Paulo. However, policies were pursued which contradicted those efforts, by discouraging efficient inter-fuel substitution, the optimal location of energy intensive activities and energy efficiency. They also weakened public-sector management; stimulated public investment; and seriously exacerbated the macroeconomic problems of external debt, the public sector deficit and inflation.

Energy Efficiency and Environmental Measures

3. One of the more successful *energy efficiency programs* pursued by the Government is the National Program of Electric Energy Conservation (PROCEL), initiated in 1985 and supported in part by the World Bank, through its electric power lending program. PROCEL aims to save up to 10% of annual electricity consumption by 2000 and 15% by 2010. An umbrella energy "rationalization" program (PRONRE) was also started, in 1989, to integrate electricity with other fuel conservation efforts. The implementation of technical loss reduction programs in the *power sector*, partly financed by the World Bank, has shifted the emphasis of the investment program away from generation, towards transmission and distribution: the generation share of total investment fell from 65% in the late 1970s and early 1980s to a projected 55% in 1991-1995. The economic rates of return on these programs have been shown to be high. Given that over 95% of power supply is from hydroelectricity, the reduction in capacity requirements will have a beneficial impact on the environment, by postponing the need to construct some hydroelectric facilities. Brazil also made progress in dealing directly with the environmental and resettlement issues associated with the construction of hydroelectric generation schemes. An Environmental Master Plan, agreed under a World Bank Power Sector Loan in 1986, lays down guidelines for the treatment of environmental, resettlement and Indian matters, and proposals for Amazonian hydro development have now been postponed, scaled down or even dropped (see Box 6).

4. In the *oil and gas subsector*, natural gas is being used as a substitute for petroleum products, which are environmentally more harmful. While overall penetration of the energy market has been small (2%), flaring was reduced (from 35% in 1983 to 16% in 1989); and gas supply extended to major industrial consumers and population centers in the Rio de Janeiro and São Paulo areas. A gas project to supply São Paulo with natural gas, supported by the World Bank, has an estimated economic rate of return of 33%; and will reduce air pollution in the city of São Paulo, mainly by replacing high-sulphur fuel oil. Investments are occurring in the refining and transport of petroleum products, to increase energy efficiency, also with a high rate of return and important environmental benefits. For example, a recently-approved World Bank loan will help PETROBRAS replace the transport of products by road and sea with pipeline transport, and avoid port expansion and other investments. The estimated economic rate of return is 22%; vehicular emissions and leaks from tankers will be cut; and risks associated with road traffic accidents and spillage of hazardous and environmentally-damaging materials eliminated. The project includes a hydro treatment unit at the Cubatão refinery, to produce diesel in place of lower-value fuel oil, yielding a 23% rate of return and reducing sulphur emissions by 70 tons per day.

5. Brazil's direct initiatives regarding *air pollution* include the industrial city of Cubatão, in the State of São Paulo. Cubatão has been widely regarded as one of the most polluted regions in the world: aside from water and solid hazardous waste pollution, fossil-fuel use created a major air pollution problem, with serious effects on health and vegetation. Following the passage of legislation in 1976, the strengthening of the State's environmental agency (CETESB) and the creation of a revolving environmental fund (supported by the World Bank), a vigorous program of pollution abatement was implemented, with dramatic results. By 1987, air pollution had improved substantially and tests of school children revealed a drop in respiratory ailments.

BOX

Brazil also succeeded in introducing ethanol as a substitute for gasoline, following the establishment of its national alcohol program (PROALCOOL) in 1975, thereby reducing carbon and lead emissions in the major cities.

Economic Policy Distortions

6. On the other hand, Brazil has pursued a variety of macroeconomic and sectoral policies which undermined or even negated the efforts described above. Crucially, the energy efficiency programs have at best a limited chance of success, so long as the Government fails to maintain *the level and structure of energy prices* in line with economic costs. Progress was made in the electric power sector, aided by the World Bank, in formulating a tariff structure based on long-run marginal costs (LRMC), which resulted in displacing more than 2,000 MW of load from peak to off-peak hours, reducing investment requirements by about US$3 billion; and a further displacement of 1500 MW is expected by the end of the 1990s, equivalent to US$2 billion. However, since 1980, the average electricity tariff has been too low, destroying the power sector's financial base, discouraging energy efficiency and over-stimulating demand and investment, although specific promotional electricity rates for industry were withdrawn after 1985. Also, the tariff has been nationally uniform, causing excessive consumption in high-cost areas and eliminating regional incentives to use local energy-supply options. A full move to LRMC pricing could cut electricity consumption by 10-15% by 2000 and save a further 6,500 MW of capacity, worth over US$10 billion.

7. The situation was the opposite in hydrocarbons: the average price of *oil products* was maintained at or above the economic cost but the price structure was seriously distorted, with gasoline cross-subsidizing naphtha, fuel oil, kerosene and LPG. While diesel was priced close to its economic cost, it was under-priced relative to gasoline, causing some undesirable inter-fuel substitution. LPG was subsidized primarily to assist low-income families; however, the low price may also have encouraged its clandestine substitution for gasoline as a vehicle fuel. Adjustment in the structure of petroleum products' prices could cut overall consumption by 5%; while abandoning uniform national prices would facilitate exploitation of regional comparative advantage and encourage energy efficiency where costs are high.

8. Efficient inter-fuel substitution is hindered by the lack of adequate transmission and distribution infrastructure for *natural gas*, which could have cut further the consumption of fuel oil and air pollution. The limited penetration of natural gas in Brazil's energy sector was caused by a complex set of circumstances, including conflicting or unclear priorities, deficient pricing policy for gas and its substitutes, and (more recently) the tight financial position of PETROBRAS. It can also be argued that the development of natural gas was limited by the institutional and legal framework, which gives PETROBRAS the monopoly of natural gas production, transmission and import. The lack of competition prevented São Paulo, for example, from seeking alternative foreign supplies, e.g., through imported LNG.; while gas utilization was impeded by the lack of a clear definition of the relative roles of PETROBRAS and the State gas companies in the lucrative industrial market, notwithstanding the provisions of the new Constitution.

9. In the past, Brazilian energy strategy deliberately promoted the substitution of *coal* for fuel oil in cement and steel, despite its high ash and sulphur content, with pricing and administrative incentives. Annual coal investments jumped from less than US$10 million in 1976-80 to over US$80 million in 1981-1985; annual production increased from about 2 million toe to over 3 million toe. While the promotion of *ethanol* reduced fossil-fuel related air pollution, the economic cost was extremely high, with subsidies amounting to nearly US$2 billion in 1988; alcohol combustion has contributed other emissions, e.g., acetaldehyde, which is linked to respiratory problems and suspected of causing cancer.

10. The consequences of Brazil's failure to deal adequately with energy pricing issues were reinforced by *policies and institutional arrangements* which shielded producers from domestic and international competition: barriers to competition and structural change have muted the price and other incentives to Brazilian managers to introduce cost-reducing measures. A more competitive environment would have made it harder for Brazilian companies to set prices on a "cost-plus" basis and pass on to consumers the consequences of inefficient energy management practices.

Sources: World Bank information and staff estimates.
World Bank, "The Urban Edge", Vol. 14, No. 8, October 1990.

in a sample of 25 LDCs by the Joint UNDP/World Bank/Bilateral Aid Energy Sector Management Assistance Program (ESMAP) suggested that an average of 20% of total end-use energy could be saved from the existing capital stock.[7]

10. Looking to the future, the developing countries can be expected to account for an ever-growing portion of world energy consumption, due to their lower per-capita consumption base, higher population growth rate, higher energy intensity, and continuing switch from traditional fuels to commercial energy (due to a diminishing stock of traditional fuels and rising living standards). Quantification of the impact of these factors is difficult, particularly because the future economic conditions in the LDCs (as elsewhere) are uncertain, but the growth rate of developing country energy use will remain above that of the developed countries. One *scenario for the period 1990-2030* is shown in Fig. 3, which assumes that, while the effects of a larger population, lower energy base, and higher population growth rates prevail in the developing countries, energy efficiency measures are applied. Over the 40-year period, the world energy consumption growth rate would average 2% p.a., driven by a developing country energy consumption growth rate of almost 4-1/2% p.a. The developing country share (including USSR/EE) of total world energy consumption would increase from about one-third in 1990 to two-thirds by 2030.

III. <u>ENERGY SUPPLY</u>

11. The *sources of world commercial energy supply* in 1990 are given in Fig. 4, which shows a fossil-fuel share of 88%. (This is calculated by basing nuclear and hydro contributions on the oil equivalent of thermal plants producing the same electricity output; if only the heat equivalent of electricity is considered, then fossil-fuel share increases to 95%.)

12. The world *fossil fuel reserve position* in 1990 is given in Fig. 5. While supply is evidently limited, each year further exploration work results in an increase in the known stock of proven reserves; in the case of oil, for example, from 95.2 btoe in 1986 to 136.5 btoe at the end of 1990. Nonetheless, we can expect that the economic reserves will be fully consumed unless a major switch away from fossil fuels occurs.

13. In the near- to medium-term future, the *alternatives to fossil fuel* seem unlikely to make a major impact on the supply situation. *Nuclear power* growth slowed dramatically in the 1980s, due to environmental concerns about the Three Mile Island (USA) and Chernobyl (USSR) nuclear accidents, rising capital costs and long schedules for licensing approval and construction. It may be 20 years before environmentally-acceptable nuclear reactor designs can be developed and proven, so that nuclear power can expand significantly (Box 2). Similarly, *hydroelectric power* does not have the potential to alter significantly the world's fossil fuel use. The world's developed hydro capacity is

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[7] World Bank, *Energy Efficiency Strategy for Developing Countries: the Role of ESMAP*, Background Paper for Discussion at ESMAP's Annual Meeting, World Bank, 1989.

BOX 2

THE STATUS OF NUCLEAR POWER

1. Over the past 40 years, nuclear power has developed rapidly as an emerging technology, so that by 1988 there were 429 power reactors totalling 311 GW of capacity in operation in 31 countries, including 11 developing countries. Another 70 reactors were under construction. In 1988 nuclear power contributed 18% of the world's electricity supply, and the large nuclear programs in France and Belgium resulted in the nuclear share of electricity production reaching 70% and 66%, respectively, in those two countries.

2. The nuclear program has been largely based on six types of nuclear reactor:

(i) About 55% of the operating reactors are pressurized water reactors (PWR) with light water under high pressure to prevent boiling, transferring the heat of uranium fission to heat exchangers developing steam to drive turbo-alternators producing electricity.

(ii) About 20% of the reactors are boiling water reactors (BWR), wherein the light water moderator and coolant is allowed to boil so the steam drives a turbine directly.

(iii) In the pressurized heavy water reactor (PHWR), heavy water is used as the moderator and coolant so natural uranium can be used as the fuel, the heat of fission being transferred through steam generators supplying a turbine.

(iv) The early reactors in the UK were gas cooled reactors (GCR), with graphite as the moderator and gas (carbon dioxide) as the coolant.

(v) Some Russian reactors are light-water-cooled, graphite-moderated reactors (LWGR), including the Chernobyl reactor that suffered a major accident.

(vi) The fast breeder reactors (FBR) are an alternative to all the above "thermal" reactors.

3. During the 1980s, the nuclear programs in most countries slowed considerably, due to rising costs, lengthened schedules, environmental concerns over nuclear waste disposal, and safety and environmental uncertainties following the U.S. Three Mile Island accident in 1979 and the U.S.S.R. Chernobyl accident in 1986. The latter resulted in many deaths, widespread land contamination, and radioactive fall-out over a large part of Europe. The large nuclear programs in France, Japan, and Korea are continuing but the nuclear programs have slowed in most other countries and all nuclear reactor builders are cautiously reviewing their designs.

4. Manufacturers are studying and developing new types of reactors that are expected to be more inherently fail-safe. These designs will have to be fully developed, tested, and proven through several years of operation of prototypes before there can be a general worldwide acceptance of nuclear power. Therefore it may be 20 or more years before nuclear power can play an increased role in displacing fossil fuels for electricity production. Nuclear power will have to be shown to be safe and to be economically superior to fossil fuel power alternatives to win favor again as a power source.

5. A major disadvantage of nuclear power is the significant cost ($200 million or more for a 1000 MW plant) of decommissioning the facility at the end of its useful life. After the fuel and radioactive waste have been removed for reprocessing or storage, the nuclear reactor must be either: (i) left intact and continuously surveyed; (ii) entombed; or (iii) dismantled, using special remote handling techniques. All three alternatives are costly. It is estimated that the provision of funds for future decommissioning by any of these alternatives may require an electricity cost increment of about US4 mills/kWh or roughly 10% of the cost of nuclear power generation.

Sources: S. Traiforos, A. Adamantiades, and E. Moore, "The Status of Nuclear Power Technology - An Update," *Industry and Energy Department Working Paper, Energy Series Paper No. 27*, April 1990.
J. Gaunt, N. Numark, and A. Adamantiades, "Decommissioning of Nuclear Power Facilities," *Industry and Energy Department Working Paper, Energy Series Paper No. 28*, April 1990.

about 600 GW or barely 25% of potential (Box 3). Even if an optimistic 50% of the potential were to be developed, the energy heat equivalent would be only 0.4 btoe annually, compared to the 1990 fossil fuel production of 8 btoe. While the potential of *small hydro* -- estimated at 100 GW, or roughly 5% of the major hydro potential -- should not be overlooked, the relatively high capital costs, the variable outputs, and the large number of sites required limit its impact.

14. There are many technologies for *renewable energy*, with some future potential for reducing the use of fossil fuels, e.g., using *tidal* and *wave energy*, *ocean thermal energy* conversion and *salt gradient energy*, but capital costs are high and as yet no major installations are expected. *Windpower*, of course, is an ancient technology, and has been used since the 1920s for electric power generation. Tax benefits provided the incentive for wind power development in the USA during the 1980s and some 7,500 wind turbines totalling about 1,500 MW were installed. Wind power has the disadvantage of varying output as winds change, and high wind locations must be selected. Furthermore, capital cost is high, and small unit sizes create aesthetically disturbing results, because of the need for hundreds of windmill towers across the countryside to produce any significant amount of power. For these reasons wind power is also not expected to make any major reduction in fossil fuel use. The site-specific nature of *geothermal energy* also does not permit its general use to displace fossil fuels.

15. Over the last 20 years, *solar photovoltaic* technology has developed considerably, as the cost of photovoltaic arrays declined, through mass production and new developments in silicon cells; but costs are still too high to permit widespread application. *Solar thermal* technology, notably in the USA and Israel, has focused on using solar energy, collected by parabolic mirrors, to develop steam to drive a conventional turbo-alternator that produces electricity. Capital costs are about US$2,500/kW but reductions are expected with larger unit sizes and further developments, including the use of pressurized water as the heat gathering fluid instead of oil. Solar thermal probably has the greatest potential among the more recent renewable energy sources for effecting some reduction in fossil fuel use.

IV. ENVIRONMENTAL IMPACT OF ENERGY PRODUCTION AND USE

16. Energy's impact on the environment can be distinguished at four levels.[8] First, *local impacts* are associated with specific activities: slag heaps from coal mines, re-settlement problems at a hydro-electric dam, or the loss of wildlife habitat for a reservoir. Here, the pressures for mitigation of the adverse environmental effects are generally driven by local concerns, such as over resettlement and public health impacts at major hydro projects in Africa (Aswan in Egypt, Akosombo in Ghana, Kossou in the Ivory Coast), or the environmentalist opposition to the development of the Bombay High offshore field in India. Total suspended particulate (TSP) emissions from fossil fuels, notably from coal combustion, is a particular problem, since large quantities of flyash may be contained in the emissions which are released to the atmosphere, even from a tall stack. These constitute a health risk, especially the ultra fine particles, which collect in the linings of the lungs.

17. Second are *national and regional issues*, which are often at the river basin scale, such as those involving the Amazon Basin in Brazil or the Mahaweli Basin in Sri Lanka. River basin development is generally for multiple purposes, bringing energy planners and electric utilities concerned with

[8] For details of this multilevel integrated conceptual framework for analysis of the energy-environmental issue, see M. Munasinghe, *Energy and Analysis and Policy*, Butterworth Press, London 1990, Chapter 1.

BOX 3

THE STATUS OF HYDRO POWER

1. Renewable hydro power is based on heat from the sun evaporating water from the world's oceans to fall as rain and snow and run off to the ocean. The flowing water provides potential for hydro power at locations where heads can be developed to permit the installation of hydro turbines with generators. It is estimated that about 400,000 km^3 of water are evaporated annually from the oceans; 100,000 km^3 fall on land; of this quantity 63,000 km^3 are lost by re-evaporation; leaving 37,000 km^3 flowing down rivers to the sea.

2. The hydro power potential of the world that is technically capable of development is about 2,300 GW, as shown below, of which roughly one-third is in the developed countries and two-thirds in the developing countries. This estimated hydro potential is based on average flow conditions at those sites technically capable of development, without considering the relative economics of hydro power and other power alternatives or environmental factors, such as population resettlement and agricultural land flooding.

3. The hydro power developed to date throughout the world is slightly over 600 GW or barely one-quarter of the technical capability (see below). Hydro development is becoming less attractive as costs increase, construction schedules lengthen, and environmental factors (heightened by public pressure and increasing population) prevent construction at otherwise favorable sites. Large hydro projects with huge reservoirs are particularly disadvantaged, because these typically flood fertile valleys, requiring massive population relocation, and also disturb the cyclical river flows, which carry nutrient-laden silt to downstream agricultural areas, as the Nile River did before the Aswan Dam was constructed. In Europe, continuing hydro development is typically in run-of-river projects, which provide hydro energy to displace thermal fuels and some generating capacity, with minimum disruption of natural river flow patterns.

4. To put hydro power potential in perspective, even if an optimistic 50% of the world's technical hydro potential can be ultimately developed, the annual energy output would be only about 5000 TWh. The heat equivalent of this amount of electricity is roughly 0.4 btoe, compared to the world's fossil fuel proved reserves of about 800 btoe, or the 1989 fossil fuel production of 8 btoe. Since hydro capability is therefore only 5% of present fossil fuel use, hydro does not have any significant potential to permit a major shift away from fossil fuels, and thereby improve the world's environment.

World Technical Hydro Power Potential

Region/Country	Technical Potential	
	Generating Capacity GW	Average Flow Annual Energy Twh
Africa (less S.A.)	427	1,194
South Africa	10	26
Asia (less Japan)	634	2,508
Japan	50	130
Europe (less E.E.)	194	659
Eastern Europe	21	63
U.S.S.R.	269	1,095
U.S.A. and Canada	290	1,273
Mexico and Central America	38	203
Caribbean	2	12
South America	288	1,637
Oceania	36	202
World Total	2,261	9,802
Developed Countries	871	3,449
Developing Countries	1,390	6,353

Source: World Energy Conference, "Survey of Energy Resources 1974," Table VI-5.
United Nations, *1988 Energy Statistics Yearbook.*

hydroelectric development into contact (and often conflict) with agencies involved with irrigation and regional development. TSPs also frequently represent a national and regional hazard.

18. Third, *trans-national issues* include acid rain or radioactive fallout from one country to another. These are generally subcontinental in scale, and typically require intergovernmental agreement for their resolution. The sulphur in any fossil fuel is converted by combustion to sulphur dioxide (SO_2). High-sulphur coals, residuals and refinery residues produce large amounts of SO_2 in stack emissions, which combine with water vapor to produce acid rain. The latter can travel long distances before falling to the earth, and result in health hazards to populations, environmental damage to buildings, harm to forests, and destruction of wildlife. Natural gas and light oils have only small amounts of sulphur, so do not present a major problem. However, coal may have a sulphur content of 5% or more and can be a severe pollutant. Nitrogen oxide (NO_x) emissions, produced in large amounts by motor vehicles during the combustion of fossil fuels, also result in acid rain deposits.

19. Finally, there are *global impacts*, such as the potential worldwide warming due to the increasing accumulation of greenhouse gases, e.g., carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and carbon monoxide (CO), as well as chlorofluorocarbons (CFCs); or pollution of the marine environment by oil spills and other wastes. If we accept the estimates in Table 7 of the relative effects of different greenhouse gases on global warming, by economic activity, we can conclude that the energy sector contributes about one-half of the greenhouse gases, mostly in the form of CO_2. Given that fossil fuels comprise nearly 90% of the world's commercial energy supply, then fossil fuels would also account for almost one-half of the global warming effect.

20. While environmental and natural resource problems of any kind are a matter for serious concern, those that fall within national boundaries are inherently easier to deal with from the standpoint of policy implementation, and are those that will generally be of immediate concern to energy planners, to be addressed in a national energy strategy. Even in cases where national energy strategies will have global consequences -- particularly in the case of India and China, whose economies depend heavily on coal (Boxes 4 and 5) -- the reality is that the most immediate pressures will come from local and national considerations.

21. Several important technical measures are available to mitigate *the environmental effects of fossil fuels*, which contribute to environmental hazards at all four levels of impact, notably through emissions of carbon, sulphur, nitrogen and TSPs. Coal-fired conventional steam power plants are among the worst offenders, along with the burning of coal in households and small industry in a number of countries (for examples, see Boxes 5 and 7, on China and Poland respectively). During combustion, the carbon in coal combines with oxygen in the air to form CO_2 and CO. When the fuel is a hydrocarbon, as with gas or oil, the combustion of the hydrogen results in harmless water vapor, so that the CO_2 per unit of electricity output is only about one half that of coal. Additionally, coal can have substantial amounts of sulphur, ranging from 0.5% to 5%. However, unlike carbon emissions, there are ways to remove sulphur from the plant effluent, through a combination of: coal washing, to remove pyrite sulphur in particle form; scrubbing, using slurries of lime or limestone as the sorbent; and sulphur flue gas desulphurization (FGD). However, FGD has large space requirements, large volumes of by-products, and high cost, while removing only 90% of the SO_2 from the stack emissions; as of 1988, only about 140 GW of FGD equipment were installed in OECD countries. Finally, the sulphur problem can be addressed through: fluidized bed coal technology,

BOX 4

INDIA

PROBLEMS IN COORDINATION

Energy Overview

1. India has significant but not substantial energy resources, given its requirements. Coal accounts for 57% of primary energy consumption, nearly all of it mined domestically (64% using open-pit methods); some 55% of coal supply is consumed in thermal power plants. Oil meets 33% of primary consumption (63% imported); natural gas 7%; and hydroelectric power the balance (3%). Energy demand growth is high (at about 6% p.a.) and partly driven by a significant energy intensity of 0.637 kgoe/US$GDP at 1987 prices (Table 4).

Environmental Aspects of Energy

2. India is the second largest coal consumer in the developing world, relying virtually entirely on indigenous production, which leads to extensive environmental impacts. *In production*, opencast mining requires large amounts of land and consequently a need to resettle and rehabilitate displaced populations. Also, waste heaps and dust are created. The rapid run-off of rain water leads to surface drainage problems, due to topsoil deprivation, a lowering of the ground-water table, and depletion of aquifers. At two locations, serious mine fires create open flames and pollution, through smoke and noxious gases. Deep mining is environmentally less harmful, but causes subsidence, affects the water table, and poses problems of acid drainage along with other chemicals.

3. *In use*, emissions result because Indian coal has a high ash content and much higher SO_2, NO_x, and CO_2 emissions than oil or natural gas. Most Indian power plants have electrostatic precipitators but only one (the TATA plant at Bombay) has flue gas desulphurization equipment (FGD), and there are no firm plans to install FGD or SCR equipment. Studies indicate that, between 1990 and 2000, annual emissions will double to 2.1, 1.9 and 334 million tons for SO_2, NO_x and CO_2, respectively. By 2000, ash disposal requirements will be 75 million tons annually and flyash will be 0.7 million tons. It is hoped that the total emissions per kWh will decrease somewhat, through use of more efficient plants and greater use of gas, but the total emission volumes will still be roughly double those of 1990. Only one-third of the power plants presently comply with the emission regulations.

Energy Institutions

4. Complex institutional arrangements have handicapped the efficient operation of the energy sector, where numerous entities have been given responsibilities, which sometimes overlap. In electric power especially, least-cost operation is difficult in the face of dual control by the State and Federal governments. There exist five bodies at the Federal level (the Central Electricity Authority, National Thermal, National Hydro, National Transmission and National Rural Electrification entities); and 18 State Electrification Boards (SEBs), overlaid with five Regional Electrification Boards, at the State level. In oil and gas, there are the Indian Oil Corporation, Oil and National Gas Commission, Gas Authority and Oil India Ltd; while coal is under the control of Coal India. Not surprisingly, the sector faces difficult coordination problems and also political interference in decisions which normally should be the responsibility of the operating organizations.

5. First, *in electric power*, the administrative planning arrangements discourage integrated system operation, producing a bias towards generation and away from transmission and distribution, which in turn increases system losses. In generation, thermal power plants sometimes receive bonuses for high plant factors, while hydro plants spill water; and in transmission, planners propose to install capacitors to correct low voltages, while there are large blocks of unswitched reactors consuming reactive power at the load-center substations. Furthermore, the commercial incentives for SEBs were reduced by political interference from State governments in day-to-day operations, again making coordination more difficult to achieve and reducing operational efficiency.

BOX 4 (Continued)

6. Second, *in the natural gas subsector*, weak institutional arrangements, combined with the lack of clearly defined organizational responsibility for marketing, impeded coordination between producers and consumers; furthermore, there was no institutional mechanism to adapt evolving gas availability and match it to changing demand. Additionally, at least in the earlier stages of gas development, the natural gas sector suffered from an unclear policy on the part of Government, which initially allocated priority to fertilizer plants and led to under-utilization of pipeline capacity. Taken in conjunction with low producer prices in the past, often below average incremental cost, the overall result has been gas flaring, amounting to one-third of gross production. Meanwhile, the Bombay Suburban Electric Supply Company is constructing a 500 MW coal-fired power plant, with higher cost and emissions compared with gas (at least initially, there is no FGD equipment); and using coal transported 1,400 km. Fortunately, provision is being made for possible future gas firing at the plant: after switching, there will be a significant reduction in emissions.

7. Third, *in the coal subsector*, mining targets established by Coal India are on a weight basis. Thus, rocks and waste are loaded on unit trains for delivery to SEB plants, where fuel cleaning and sorting aggravates the already difficult plant operations.

Sources: Consultants reports by London Economics, Montan-Consulting GMBH, and D. Butcher, produced for the World Bank; and World Bank staff information and estimates.

which captures the sulphur during combustion in a "bed" within the furnace and is developing rapidly; coal beneficiation, in which the coal is crushed and separated; coal gasification, which also removes nitrogen compounds and ash; and coal liquefaction.[9]

22. The nitrogen which is oxidized during combustion (to yield NO_x) can be reduced with combustion control (CC), using modern electronics, while selective catalytic reduction (SCR) has recently been developed to remove NO_x from stack emissions. The SCR system does not produce a by-product and it is 90% effective in NO_x reduction. Most SCR applications to date are in Japan and Germany. Finally, TSPs appear in stack emissions but can be removed using either electrostatic precipitators or baghouse fabric filters. There is an energy requirement, however, ranging between 0.25% and 1% of plant output. Typically 60-80% of the ash content of the coal goes to the stack as flyash. The remaining 20-40% collects in hoppers and in the bottom ash pit as slag. Bearing in mind that some poor quality fuels have up to 40% ash, the quantities of ash (and flyash) can be considerable.

23. Some representative capital costs for adding FGD and SCR equipment in Germany, Japan and the USA, are:

Capital Costs (US$/kW)

	FGD	SCR
Germany	81	37
Japan	155	39
USA	170	83

[9] For additional (and generally optimistic) discussion of advances in coal technology, see D. Anderson, *Energy and the Environment - An Economic Perspective on Recent Technical Developments and Policies*, The Wealth of Nations Foundations, Special Briefing Paper No. 1, May 1991.

BOX 5

CHINA

Towards a More Efficient Coal Use

Coal Use

1. China has the highest ratio of commercial energy consumption to GDP in the world, although energy intensity has declined substantially since 1978 (Table 5). Further reductions will depend overwhelmingly on using coal more efficiently, which is the dominant energy source in China, accounting for about 75% of the commercial energy supply. Only Poland and South Africa had higher shares (80% for Poland, see Box 7); with India (57%) (Box 4), South Korea (35%), the U.K. (31%) and the USA far behind (30%). Non-commercial energy sources, including firewood and agricultural residues, are used by the rural population, but even in the rural areas the use of coal in households is increasing and amounts to 80-100 million tons annually. Total coal use in China is approaching 1,000 million tons annually, or roughly one-quarter of the world total, which has had serious harmful environmental effects.

2. China's 1988 coal consumption and growth rates by sector were:

Use	1988 Consumption (Million tons)	Share (%)	1980-1988 Growth (% p.a.)
Industry boilers and kilns	424	43	5.5
Power generation	252	26	9.4
Residential/Commercial	212	22	6.7
Cooking (steel)	71	7	4.0
Transport	24	2	
	----	----	----
TOTAL	983	100	6.2

3. Two-thirds of the coal is destined for small industrial boilers and for residential/commercial use. There are 300,000 small boilers in industries, largely burning coal, and the average efficiency is only 55-60% compared to 80% in OECD countries. The low boiler efficiencies are due to: poor quality coal as delivered; small boiler sizes; poor operation and maintenance; varying qualities of boilers; low quality of boiler auxiliaries; lack of special boiler manufacturing equipment and tools; short boiler lives (compared with OECD countries) of 10-15 years or less; and lack of combustion control equipment and instrumentation. The mismatch of coal quality and application in China is a further cause of low energy efficiency. Much of coal mining and distribution is centrally controlled at fixed prices. Typically, the end user has no choice of coal source and quality. Boiler operators must accept the coal as delivered, pick out the rocks, spray the coal with water to reduce the fines in the flue gas, and handle the large volumes of bottom and fly ash collected from the boilers. Small industrial boilers use stoker grates that require lump coal, and the fines may end up in the ash pit. On the other hand, utility boilers with pulverizers use fines and lump coal must be pulverized. A grading and washing system at the mines would remove stones and dirt, some ash, some sulphur and would permit selecting fuels for each application. It is estimated that the poor quality coal supply, small boiler sizes of inefficient design, low quality of boiler auxiliaries, and the lack of boiler standardization result in extra coal consumption amounting to 80 million tons annually. Urban coal use for cooking and heating amounts to almost 100 million tons annually. Stove efficiencies are low, averaging 25% or less. Honeycomb briquettes, usually from anthracite, are promoted in major cities to minimize pollution and are subsidized. Government policy to reduce pollution is aimed at briquette promotion, increased use of gas for cooking, and district heating.

Fuel Substitution Possibilities

4. *Oil* is the second largest commercial energy source (19% of the total). Of the 1989 production of 137 million tons, 20% was exported, but the ratio is likely to fall, as domestic demands grow, mainly for use in transportation and the petrochemical industry. China's limited oil reserves offer little scope for reducing coal's dominant energy share. Known *gas* reserves (1 trillion cubic meters) are modest by world standards and relative to population and gas accounts for only 2% of total commercial energy, although there is some minor scope for piping flared gas into distribution systems. Only 5% of the country's large *hydro* potential has been developed, partly limited by the capital requirements and the long construction schedules. Hydro accounts for about 25% of total electricity production; the share may increase slightly but will not change coal's dominant position.

BOX 5 (continued)

Energy Efficiency Measures

5. There are several technical measures which could be taken to improve energy efficiency, which are both economically sound and environmentally beneficial. Increasing *coal screening* from 21% to 100% would cost US$1.60/ton, US$1.5 billion in total, but the recovery of fines would return all costs and earn a 20% return. The cost of increased *coal washing* would be significant, but ash and sulphur content could be reduced by at least 15% and 25-35% respectively. The savings in transport costs, ash disposal by the user, and boiler maintenance and availability could again yield a 20% return. The payback period to *boiler replacement*, from higher efficiency and coal savings, is 2-12 years. Larger unit sizes for utility boilers (phasing out units of 10-25 MW or even less and replacing with 300-600 MW units) would save about 70 million tons of coal annually or US$2 billion in fuel costs. Further areas for energy efficiency improvements which have been shown to be economic relate to *building insulation, cogeneration* of process heat and power in industry and the *dispatching* of coal-fired generating plant. Coal price and enterprise reform are keys to the implementation of those and other energy efficiency measures and to reducing energy intensity. Moving towards economically-efficient coal pricing in China could cut coal use by at least 10% and yield substantial economic gains, simply from making the above measures attractive and shrinking demand through a price-elasticity effect.

Air Pollution and Controls

6. The wide use of coal in China results in solid waste, water and substantial air pollution. Concerning air pollution, the readings obtained in nine cities for TSP and SO_2 (710-1546 and 238-700 micrograms/m^3 respectively) greatly exceed WHO standards for short-term exposure (150-230 and 100-150 respectively). Of major concern are the fine and extra fine particles, including toxic or carcinogenic elements associated with coal combustion, which are absorbed in the linings of the lungs. It is estimated that China contributes 10% of the world's CO_2 pollution. Total emissions in China in 1988 (in million tons) were estimated as: TSPs (20); sulphur oxides (20); and CO_2 (597).

7. At present there are no sulfur dioxide or nitrogen oxide control measures in China. Nitrogen oxide will be an increasing problem as the vehicle fleet expands. Small boilers can be a significant source of nitrogen oxide, because high temperatures have to be used to stabilize the flame if the available coals differ from the boiler fuel specifications.

8. Considerable effort is being directed in China at environmental improvement measures, including appropriate legislation. The existing legislative controls include a pollution levy system by municipalities and government to persuade industries to apply pollution control systems. China is also aware of its impact on global warming. It has continued to promote a wide range of energy conservation activities and recognized that fuel diversification, particularly towards gas and hydro, is necessary but will require major capital expenditures which are not readily available.

Source: World Bank information and staff estimates.
B.P. Statistical Review of World Energy, June 1991.

In addition, emission control technologies should include CC; typical costs for these three items in a coal-fired plant, compared with oil and gas, are shown in Table 8. At 70% capacity factor and 10% discount rate, emission control costs amount to US mills 9.1/kWh, US mills 6.7/kWh and US mills 1.3/kWh for coal, oil and natural gas steam power plants respectively. Since steam plant generation costs are typically US cents 4/kWh or higher, the emission control cost is roughly 25% of the total generation cost for coal steam. The low emission control cost for gas steam of US mills 1.3/kWh is only one-seventh of the emission cost of coal steam.

24. While the installation of FGD and SCR equipment can clean up the stack gaseous emissions from a coal-fired conventional steam plant, *fuel switching* may be more effective; natural gas, for example, has almost no sulphur and produces less CO_2. Fig. 6 compares emissions for a typical coal-fired plant (equipped with FGD and SCR) with a gas-fired steam plant. Note that, with gas as the fuel, CO_2 is reduced by about one-half, NO_x is reduced to one-third, and SO_2 is eliminated.

25. *Gas turbine technology,* which uses the high exhaust temperature to add a waste heat boiler

to develop steam for a steam turbine, has made great strides in the last 45 years. Thermal efficiencies of over 50% are possible and 60% may be achieved by the year 2000, when metallurgy advances permit higher firing temperatures. The best fuel for gas turbines is natural gas, because of the low contaminants; but distillate is a traditional fuel, and heavy oil is occasionally used, although special treatment is required to minimize damage due to contaminants.[10] Nitrogen oxide emissions can be reduced with the steam injected gas turbine (STIG) or the intercooled steam-injected gas turbine (ISTIG).

26. Table 9 summarizes the capital cost, emissions of SO_2, NO_x, and CO_2 and thermal efficiencies of the various alternative thermal power sources. The *striking advantage of gas over coal* is clearly shown for each type of plant, even if the coal power plant uses emission control equipment. Gas capital costs are substantially lower, at one-third to one-half of the coal capital costs; there is virtually no SO_2 pollution, compared with 90-99% reduction for coal-based plants; and NO_x and CO_2 emissions are roughly 50% of coal-based plants. Furthermore, gas power plant efficiencies are higher than coal power plants. Of course, the availability of an adequate gas supply will often be an issue; and losses from natural gas pipeline systems (which are high in the USSR and EE) contribute to global warming, through methane emissions. The efficiency of steam power plant generally can be raised beyond the figure of around 35% shown in Table 9, through cogeneration, which uses some of the waste power plant heat for process steam, useful in district heating.

27. Another major contributor to the fossil-fuel problem is the *transport sector*, since about half the world's oil or one-fifth of all commercial energy is consumed by a world fleet of 500 million vehicles, which is growing at about 5% per year. Vehicle exhaust emissions contribute particularly to local environmental problems and include: carbon monoxide; nitrogen oxides; hydrocarbons; SO_2; particulate matter; and various toxic substances, such as benzene, asbestos, aldehydes and ketones. However, they also contribute to global warming, through CO_2 production and CFCs. Exhaust emission control measures typically include: recirculating a portion of the exhaust gases to reduce peak temperatures and therefore NO_x formation; improved combustion, through electronic control of ignition timing and air/fuel ratios; and exhaust treatment, using catalytic converters.

28. Unfortunately, the main existing alternatives to fossil fuels -- hydroelectric and nuclear power -- also have environmental drawbacks at various levels of impact. *Hydroelectric power* is an excellent source of renewable energy. It does not present global environmental disadvantages, and often has multipurpose benefits from irrigation, better navigation, flood control, fishing and tourism. On the other hand, hydro plants may suffer from local, regional, national and sometimes trans-national environmental problems (Box 6). For example, they may inundate fertile valleys and population centers, requiring resettlement of the local population; alter the river flow and affect the downstream population, particularly those involved in agriculture and fishing; change the river quality, especially the silt content; disrupt navigation; affect the reservoir area ecosystem; and flood historic sites.

29. *Nuclear power* stations are normally able to satisfy adequate environmental standards, if properly designed and operated. Yet catastrophic nuclear accidents can occur under unforseen conditions; radioactive fallout will then affect the local, regional, national and trans-national environments. A further environmental consideration is the radioactive waste disposal problem. The world's nuclear power capacity will soon total 500 GW: about 75% will be in the form of light water

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[10] Even then, the economic life and availability are lower, while maintenance is higher.

BOX 6

ENVIRONMENTAL ASPECTS OF HYDRO POWER

1. In 1990, the Bank conducted an environmental review of Bank-financed power projects, including 59 hydro projects completed in the period 1978-1989 with Bank financing of $7.7 billion, which provide 24 GW of generating capacity. The average Bank hydro project has a reservoir area of about 211 km^2, with a range for the projects of 1,800 km^2 (Nangbeto in Togo) to 0.4 km^2 (Kerala in India). The typical hydro project required the resettlement of about 2,000 families, usually employed in agriculture or fishing, from the reservoir area to higher ground. Compensation arrangements normally included the value of each family's land and home. Nevertheless, the Bank's review points out that there have been many cases of lives being disrupted through inequitable compensation, including a case where 16,000 people lost access to agricultural land. The damming of a river also disrupts established patterns of wildlife, agriculture, fishing, navigation and sometimes forestry.

2. An example of the possible disruption to human life is the prospective *Three Gorges Project* on the Yangtze River in China. This 13,000 MW project would require resettling 330,000 people to establish a 572 km^2 reservoir. The average river flow of 14,300 m^3/sec. carries a high silt load of about 1.17 kg/m^3. Damming the river will result in collecting of silt and reservoir sedimentation in the order of 500 million tons over the project lifetime. The project would change both downstream river flow and the nutrient content of the water.

3. *Brazil's dependence on hydroelectric generation* -- over 90% in terms of capacity -- has made it especially vulnerable to criticism regarding its handling of environmental issues, above all in Amazonia. It has faced two particularly acute problems: involuntary resettlement of human populations; and the loss of biodiversity. The choice of non-forested or non-agricultural sites for reservoirs helps to minimize the impacts on humans and wildlife; conservation of other areas in perpetuity may offset, at least partially, inundated forest and land; and compensation can improve the quality of life for some people. Unfortunately, there is an important exception: jungle dwellers, for whom successful relocation may be impossible.

4. Probably the most harmful of Brazil's hydro projects, from an environmental viewpoint, was the 250 MW *Balbina* scheme, constructed in the vicinity of Manaus, after the two oil price shocks. The huge 2,360 km^2 reservoir is shallow, so that trees protrude from the water. A considerable area of rainforest was lost and the decaying trees generate greenhouse gas. Water quality below the dam is extremely poor, jeopardizing river dwellers and fishlife. The Waimiri-Atroari Indians were harmed and adequate measures were not put in place to provide for their needs.

5. Certainly Brazil has made major strides forward in recognizing and dealing with these concerns, since the construction of *Balbina*, notably through implementation of the Environmental Master Plan (see Box 1). The widely-criticized Babaquara hydro project was wisely canceled, as it would have flooded more than the combined areas of the Itaipu and Tucurui plants (3,890 km^2) for only 6,000 MW of capacity, compared with over 20,000 MW. To a considerable extent, Brazil has succeeded in internalizing the environmental costs of hydroelectric development, which may well be the most benign source of energy supply for Brazil, as well as the least-cost. Certainly the nuclear power program, which produced virtually no electricity, has been the subject of controversy, over its safety as well as its economics.

<u>Source</u>: World Bank, "A Review of the Treatment of Environmental Aspects of Bank Energy Projects," *Industry and Energy Department Working Paper, Energy Series Paper No. 24*, March 1990.
P.M. Fearnside, "Brazil's Balbina Dam: Environment versus the Legacy of the Pharaohs in Amazonia," *Environmental Management*, Vol. 13, No. 4, July/August, 1989.
L. Pinguelli Rosa and R. Schaeffer, "Risks and Environmental Impacts of Hydroelectricity in Brazil," *Paper presented to Joint IAEA, ILO/UNEP/WHO Workshop on Assessing and Managing Health and Environmental Risks From Energy and Other Complex Industrial Systems*, Paris, 13-17 October 1986.

reactors, requiring enriched uranium (20 tons/GW annually); and the remainder will be heavy water reactors, using natural uranium (160 tons/GW annually). The annual irradiated fuel total will be about 20,000 tons, which must be stored (or reprocessed) in a special facility. Selection of long-term radioactive material storage sites has met with strenuous public opposition so far, and most materials are being stored at nuclear plants. Finally, the decommissioning of nuclear reactors at the end of their operational lives represents a potential environmental problem (Box 2).

V. ECONOMIC POLICY DISTORTIONS AND ENERGY MARKETS

30. The preceding discussion and analysis lead to several important conclusions regarding energy and the environment, and the role of energy efficiency. *First*, the growth in total world energy consumption will continue, as more countries move along the curve in Fig. 2. *Second*, while promising developments in renewables technology are taking place, there is unlikely to be any major shift in the main sources of energy in the foreseeable future, and fossil fuels, hydroelectricity and nuclear power will continue to provide the world's energy base. *Third*, all of the main energy sources have adverse environmental consequences: although there are available measures to mitigate the impact of these sources, the developing world has so far taken only limited advantage of them (para. 72). For some time to come, the world will face difficult trade-offs between the environmental costs and benefits of the main energy sources, on the one hand; and the economic costs and benefits on the other. *Fourth*, it is therefore crucial for governments to establish policies and institutional frameworks which will support the efficient supply and use of energy. It can be argued that these policies and frameworks will generally be in the self-interest of countries, as they will promote economically-sound development at the macroeconomic and energy sector levels. In contrast, as we shall now discuss, governments in practice pursue policies which are detrimental to economic growth and the environment, including governments in developing countries (see Boxes 1, 4, 5 and 7 on Brazil, India, China and Poland).

31. We emphasize that *energy efficiency is not an objective* in itself. The demand for energy is a derived demand, not a final demand, both in the end-use and intermediate markets. For producers, energy is combined with other inputs, notably raw materials, capital and labor, in the production of goods and services. For consumers, energy is an input in the utility maximization process, yielding comfort, light, cold and hot food, etc. The most efficient use of energy is simply the consumption which results from combining all scarce resources in the economy to maximize net social welfare, taking into account, *inter alia*, environmental impacts. Hence, *at the technical level*, energy efficiency requires maximizing net benefits for any given total energy input, or (equivalently), minimizing energy use to obtain a given net benefit. This "waste avoidance principle" corresponds to the minimization of energy intensity only if the value of output and non-energy inputs is specified. *In economic terms*, it is more usual to deal with trade-offs of two broad types: (i) the substitution of energy for non-energy inputs (i.e., using more energy to reduce the amount of capital, labor etc.) and *vice versa*; and (ii) choosing the mix between different types of energy, sometimes requiring additional or fewer non-energy inputs (inter-fuel substitution). Technical efficiency depends mainly on institutional and organizational factors, "know-how" and available technologies. The trade-offs in the economic approach, on the other hand, are made to secure the least-cost solution and depend critically on relative prices.

32. In a *properly functioning energy market*, profit maximization provides the motive for producers to use a given supply of energy and other inputs in a way which maximizes output value; and to seek new technologies or use existing technologies, such that a given output can be produced at the lowest cost, given the prices of alternative energy and non-energy sources and the investment costs of the feasible technical solutions. Similarly, consumers in a competitive energy market will allocate their given budgets between alternative energy sources and appliances and invest in energy conservation to maximize their welfare; or to minimize their purchases of energy and other goods and services to attain a given level of welfare. Hence, the price of energy relative to non-energy and the relative prices of different forms of energy play crucial roles in helping the energy market to function properly. However, government policies frequently distort the relationship between these prices and

erect other barriers to the proper operation of the energy market.[11] These policies are detrimental both to economic growth and the environment. Reducing policy distortions will promote economically-sound development at the macroeconomic and energy sector levels; and, at the same time, help to control pollution in the developing countries. Being in the self-interest of those countries, they may be termed "no regrets" policies. The problem of externalities, i.e., benefits and costs which are not captured by market forces alone, is a separate issue, which we discuss in Section VI.

A. Demand-Side Distortions

33. The variety of market imperfections and distortions which impede optimal end-use choices can usefully be categorized in terms of: (i) those which distort price signals or else place constraints on the consumer's ability to respond, even if price signals are correct; and (ii) those which stem from deficiencies in the basic process underlying decisions on energy use. Concerning *the first category*, price signals will be distorted if energy prices are held below the full economic costs, including environmental externalities. There may also be distortions between energy production costs and prices, compared with the cost of increasing energy efficiency, for example due to subsidies on certain forms of energy production and macroeconomic distortions, e.g., taxes and duties on the import of energy-efficient equipment. Furthermore, even if the pricing signals in the energy market are correct, there could be constraints limiting the extent to which consumers are able to respond efficiently to those signals. Imperfections in the capital market (along with inadequate internal cash generation in firms) may hinder the availability of finance; currency restrictions may curtail the supply of foreign exchange to implement energy efficiency measures; and there may be quotas or an outright ban on the import of certain energy-efficient equipment or devices to measure energy efficiency, which are not produced locally.

34. Concerning the *second group* of imperfections and distortions, various deficiencies can be identified in the way that energy consumers take decisions, leading to inertia or under-investment in energy efficiency. Consumers could be slow in responding to changes in energy prices, especially where energy represents a small proportion of total costs; they may face imperfect information about the benefits and costs of energy efficiency (partly because the private sector may be unable to capture fully the benefits of research and development on generic energy conservation technologies and therefore be unwilling to carry it out); they may lack the methodology to evaluate that information (i.e., to handle the inter-temporal comparisons or trade-offs which must be made between additional capital costs and reductions in energy costs); they may not know how to design, initiate and implement energy conservation programs (notably due to a specific lack of expertise in energy management at the plant level); and they may be ignorant about the sources of energy conservation finance and the procedures for securing it.

35. Institutional and regulatory barriers to efficient decision-making are frequently encountered in the energy market. Firms which consume energy may not be motivated by profit maximization; managers may not pursue energy efficiency aggressively or may attach a low priority to it, due to weak

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[11] For an elaboration of the points in this paragraph, and paras. 33-36, see R.W. Bates "Energy Conservation Policy, Energy Markets and the Environment in Developing Countries," *Environment Department Working Paper No. 45*, The World Bank, Sector Policy and Research Staff, May 1991.

competitive pressures and the role of non-profit incentives in managerial decision-making;[12] and there could be a widespread use of "cost-plus" pricing, particularly in the public sector but also in a highly-protected private sector, under which companies routinely try to pass higher energy costs on to consumers.

36. Direct empirical evidence of the impact of these market imperfections is unsatisfactory, especially in the second category; similarly, their relative importance and the actions best suited to overcome them are not always evident.[13] Nevertheless, there is ample experience to suggest that many of the imperfections and distortions described above are directly attributable to the policies and institutional models widely favored by governments in LDCs and EE. We consider, first, energy pricing distortions; and, second, macroeconomic and sectoral distortions.

1. Energy Pricing Distortions

37. The general *failure of LDCs and EE to establish output prices for energy which reflect economic costs*, even excluding environmental costs, is well-documented. Some examples are provided in Figs. 7 and 8. The situation is especially apparent for the level of prices in electricity, coal, natural gas and (among oil-exporters) petroleum products. Price structures are also distorted, particularly regarding different supply voltages or consumer categories in electricity; petroleum products, for oil-importing, as well as oil-exporting countries; coal qualities; and geographical location (for all energy forms). The reasons for these pricing distortions are probably more political than economic[14] and need not concern us here, although we should note that concerns over personal or regional income distribution effects are not always well-founded (Box 1) or that there may be more efficient ways to handle them than through general subsidies to energy.

38. The prevalence of economic subsidies has *direct effects* on the environment, through resource allocation, which are considered in detail in this Section. By encouraging the substitution of energy for non-energy products, the overall level of energy consumption is raised; the structure of consumption within the group of energy products or between classes of consumer may also be altered. Moreover, the spatial distribution of energy consumption can be environmentally significant. Subsidizing high-cost locations not only has the obvious result of encouraging the excessive use of energy within those areas, but also, because such locations are often relatively remote, may entail the transport of more energy over longer distances. Furthermore, they can be environmentally fragile, as in the Amazon region, and therefore adversely affected by the type of development which often accompanies subsidized energy prices.

39. In addition, subsidized energy prices are likely to have financial implications, creating *indirect effects* on the environment. The reluctance of Governments to grant tariff increases in response to

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[12] For example, there may be more prestige attached to the implementation of large-scale investment projects, rather than more mundane and low-prestige energy conservation measures; or managers may be more preoccupied with short-term problems.

[13] This position was taken by C. Blumstein, B. Krieg, L. Schipper and C. York, in "Overcoming Social and Institutional Barriers to Energy Conservation," *Energy*, Vol. 5, No. 4, April 1980; and more recently, nearly a decade later, by R.S. Carlsmith, W.U. Chandler, J.E. McMahon and D.J. Santini, *Energy-Efficiency: How Far Can We Go*, ORNL Report T-11441, January 1990.

[14] See, for example, T. Sterner, "Oil Products in Latin America: the Policies of energy Pricing," *Energy Journal*, Vol. 10, No. 2, April 1989; and M. Kosmo, "Commercial Energy Subsidies in Developing Countries," *Energy Policy*, June 1989.

changing conditions has seriously undermined the financial performance of many State-run energy suppliers in the LDCs. Companies which are unable to cover their financial costs are much less likely to engage in environmental expenditures, which can increase capital costs by 10-20% and operating costs by 5-10%, if the latter have no obvious and immediate financial remuneration. We return to these effects in our discussion on supply-side efficiency.

(i) Electricity Prices

40. Empirical information is particularly good on electricity prices in the LDCs. A 1990 World Bank report demonstrates that average electricity tariffs in 60 LDCs fell, in real terms, by 3.5% p.a. over 1979-1988, compared with an average real price increase of 1.4% p.a. in the OECD countries.[15] The absolute average price of electricity in the LDCs, in US$ of 1986, fell from US cents 5.2/kWh to US cents 3.8/kWh, while it increased from US cents 6.1/kWh to US cents 6.9/kWh in the OECD countries. The same survey reveals that, in 1987, 60% of the LDCs had tariffs that did not cover average incremental costs (AIC);[16] and the (weighted) average ratio of the retail tariff to cost was 62%. A more recent (1991) study of 20 countries in the Latin America and Caribbean Region (LAC), by staff from the World Bank and the Latin American Energy Organization (OLADE), contains similar results: 17 countries (85%) with tariffs below AIC; and an average ratio (weighted) of 72% between price and AIC.[17] Taking the countries with the three largest power systems in the developing world -- accounting for over half of LDC electricity consumption -- continues the pattern. The ratio of price to AIC is found to be (Figs. 7 and 8): 50-80% in China (1987); 66% in Brazil (1989); and 30-50% in India (1990). In Poland and Mexico, two other major electricity consumers, the ratio is around one-third (1987) and two-thirds (1988) respectively (Fig. 7).

41. The 1990 World Bank report[18] further examines the structure of electricity tariffs, concluding that tariffs in the countries surveyed do not reflect the costs of supply at different voltage levels and that there are major cross-subsidies between industrial and residential consumers. OECD countries on average charge high-voltage consumers 60% of the average low-voltage tariff; in the LDCs, the ratio is 78%. In Mexico, Brazil and Argentina, residential consumers pay about 40% of AIC; while industry pays 80-107% (Fig. 7). Such cross-subsidies are an important disincentive for residential consumers to implement energy conservation measures of the type routinely identified in the literature.[19] In India, agriculture is the most favored group of all, receiving supply at around 10% of AIC (Fig. 8): the number of electric pumpsets and agricultural electricity demand has grown rapidly. A recent World Bank analysis of the implications of uniform national electricity tariffs in

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[15] "Review of Electricity Tariffs in Developing Countries during the 1980s," *Energy Series Paper No. 32*, November 1990.

[16] AIC is generally recognized as an appropriate approximation for the long-run marginal cost of electricity supply. It is typically measured as: the present economic value of the stream of investment costs (generation, transmission and distribution) to deliver an increment of electricity demand over a given planning horizon; divided by the present value of the incremental demand which can be attributed to that investment. M. Munasinghe, *Electric Power Economics: Selected Works*, Butterworths, London, 1990, p. 112.

[17] Infrastructure and Energy Division and Latin American Energy Organization (OLADE), *The Evolution, Situation and Prospects of the Electric Power Sector in the Latin American and Caribbean Countries*, Latin America and the Caribbean Technical Department, Regional Studies Program, Report No. 7, Vol. 1, Regional Report, World Bank, Washington, D.C., August 1991.

[18] *Energy Series Paper No. 32, op. cit.*

[19] See para. 9.

Brazil concluded that the regional cross-subsidies range from 20-40% of AIC in the North and South respectively; and that they were an important source of inefficient energy supply and use, while not providing an appropriate vehicle to implement the Government's broader concerns for regional economic and social development.

(ii) Petroleum Product Prices

42. While not as comprehensively documented, the situation in the market for petroleum products in the oil-importing LDCs provides an interesting contrast to electricity. Those countries have generally maintained average petroleum product prices at or above the level of the average economic cost (or average border price); but this result is usually reached by taxing gasoline, which masks extensive cross-subsidizes to other petroleum products. A recent World Bank study, referring to the January 1988 situation in 25 selected countries worldwide (including EE), shows 24 of them charging above the border price for gasoline, and 13 subsidizing kerosene.[20] Data provided by Kosmo, for 1983 and 1985, show that 9 out of 10 oil importers had average retail prices in excess of the average border price, but that 5 of the 10 subsidized key individual products.[21] Similarly, all 13 oil importers in LAC analyzed by Sterner in 1989 had domestic prices above the border prices on average.[22] World Bank staff estimates for particular countries (Figs. 7 and 8) suggest that: Brazil (1989) established a price for gasoline which was almost double the border value, while all other products, except diesel, were subsidized, notably naphtha (one-third the border price); in India (1991), gasoline was nearly four times the border value, while other products (except for fuel oil in the non-fertilizer market) enjoyed substantial subsidies, especially kerosene (40% of the border price) and naphtha; and in Argentina (1989), gasoline was sold at more than twice the border price, with many other products again being subsidized. Finally, Poland even subsidized gasoline in 1987, at an estimated 91% of the true economic value.

43. An analysis by World Bank staff of the issue of uniform *regional pricing of petroleum products* in Brazil concludes, as in the case of electricity, that it would distort patterns of development away from activities which would exploit regional comparative advantage, e.g., reducing the incentives to exploit local energy sources in high-cost areas. In particular, regional cross-subsidies would favor uneconomic development in remote frontier locations, and aggravate the effects of other economic policies, further jeopardizing Indian settlements, rainforest and wildlife. In the Center-West and North, which contain Amazonia, subsidies on fuel oil amount to 40-60% of the economic cost.

(iii) Coal Prices

44. Coal prices are widely subsidized, in developed as well as developing countries. A 1985 World Bank study of coal pricing in 16 countries reported distorted policies, at the beginning of the 1980s, in Germany, France and the UK; as well as Argentina, Brazil, India, Morocco and (to some degree)

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[20] I.G. Heggie, *Selecting Appropriate Instruments for Charging Road Users*, Infrastructure and Urban Development Department, INU Report No. 95, World Bank, Washington, D.C., Feb. 1992.

[21] "Commercial Energy Subsidies in Developing Countries," *op. cit.*

[22] *Op. cit.*

Turkey and Yugoslavia.[23] China, India and Poland now account for 75% of coal consumption in the LDCs and EE: their policies merit particular attention. All three have under-priced coal supplies, sometimes seriously (Figs. 7 and 8). In Poland and India, the level of coal prices was set at 31% and 86% of AIC in 1987 and 1990 respectively. China operates a dual market system, with roughly 40% of coal sales taking place at controlled prices, and the remainder traded in a free market. The delivered price in the former was approximately 60% of AIC in 1989; although in the latter, it may have been at or above the economic cost of supply.[24] Inefficient coal use is a major source of air pollution in all three countries.

45. China, India and Poland have further suffered from serious distortions in the structure of their coal prices. In China, regional price differentials do not reflect transport costs; and the structure of prices in both China and Poland does not adequately mirror differences in quality (heat value and ash content). There is consequently an unsatisfied demand for higher-grade coals, associated with an excess supply of poor quality coals, and a potential for misallocation among competing uses. For India, a 1991 consultants' study commissioned by the World Bank found that under-pricing rose to 40-50% for the best-grade coal.

(iv) Gas Prices

46. The use of gas, unlike other fuels, is often supply constrained and, despite underpricing at the retail level, consumption is consequently not over-stimulated. We shall return to this issue later, in our discussion of supply-side efficiency. In Argentina, the second largest consumer of gas among LDCs in 1989, where gas is a major element in the energy matrix (30% of total energy consumption), residential consumers paid only 15% of AIC in 1989 (Fig. 7). Poland has limited supplies of natural gas which, with imports from the (then) USSR, meet 9% of energy needs; retail prices were 50% of the border equivalent in 1987 (Fig. 7). China severely restricts natural gas availability, which represents only 2% of commercial energy consumption, to fertilizer and petrochemical production, selling it at a controlled price which is less than production cost and, in 1986, 40% of the "free market" value. World Bank staff estimated that coal-based town gas retailed at 30% of the production cost of coke oven gas, the cheapest form of coal gas, even without providing for distribution costs.

(v) Demand Elasticities and Cross-Elasticities

47. There is a large gap between energy prices and costs in the LDCs and EE. Thus, the scope for energy pricing reform is clear, on grounds of financial need and environmental protection, as well as economic efficiency. A final question, therefore, relates to the extent to which energy consumption would fall if prices were increased fully to the level of economic cost.

48. The elasticity of demand for the main energy products has been studied, for a selection of OECD countries and LDCs. Tables 10 and 11 give a representative sample of some of the results. The numerical values vary, but broad patterns emerge.

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[23] "Domestic Coal Pricing: Suggested Principles and Present Policies in Selected Countries," *Energy Department Paper No. 23*, September 1985.

[24] In a large country like China, transport costs are important. These averages are therefore rough guides only.

49. For *electricity supply*, results in LAC for Costa Rica, Paraguay and Dominican Republic indicate long-run price elasticities in the order of -0.5; Mexico and Argentina fall in a range of roughly -0.2 to -0.5; while Brazil is closer to -0.8. For Asia, the Indian numbers are compatible with Mexico and Argentina; the other countries (Pakistan, Thailand, Philippines) are short-run elasticities, and therefore yield very low figures (-0.2 or less). In all LDCs, industrial price elasticities are almost invariably higher than residential. OECD results are similar, although the elasticities tend to be distinctly higher: typically close to unity for residential consumers and slightly above for industrial. In a survey of US econometric studies of energy demand, Bohi and Zimmerman concluded that the "residential demand for electricity appears to have a price elasticity near -0.2 in the short run and near -0.7 in the long run."[25]

50. Less information is available on *natural gas* and *coal*, but long-run studies of the former in OECD, Argentina and Brazil suggest figures in the range -0.2 to -0.7; while short-run price elasticity estimates for both gas and coal in a group of Asian countries are around -0.1 to -0.2. Studies of the industrial coal market in the USA and Canada, and of the overall market in Ireland, suggest figures of -1.29 and -1.39 respectively in the long run.

51. Price elasticity estimates for *petroleum products* are more difficult to interpret, given the range of products involved, although overall averages of -0.5 for OECD, -0.1 for India and -0.8 for Brazil have been calculated. In OECD, Argentina and Brazil, elastic demands were found for gasoline (-1.0 to -2.12); and fuel oil also was relatively responsive to price changes (-0.8 to 1.31). The short-run estimates from Asian studies again are low (-0.1 to -0.3).

52. Although energy demands by fuel type appear to be relatively price inelastic, the substantial gap which exists between price and economic cost across a broad spectrum of developing countries strongly suggests that *large energy efficiency gains are available through efficient pricing policies*, aside from the beneficial financial and fiscal effects which would accrue. To the extent that the production and use of most commercial energy forms has adverse environmental impacts, significant environmental gains can also be anticipated. Of course, extrapolation of elasticity values to large price increases is risky: increases in the order of 50-100% would be needed for electricity and coal; and perhaps 20-50% for key petroleum products, such as fuel oil and naphtha. On the other hand, gradual price adjustments, to achieve closer alignment between prices and costs in the medium term, should be regarded as more realistic. The case of natural gas is peculiar, in that it is normally supply constrained, and price increases are not likely to reduce consumption. A further complication concerns cross-elasticities of demand, because a general movement towards efficiency pricing entails a realignment of relative energy prices as well as increases in the general energy price level. The paucity of reliable econometric data on cross-elasticities and the complex relative price adjustments involved make it impossible to explore here with any rigor the net effect of relative price adjustments on energy consumption. A 1986 study of seven OECD countries found "no comprehensive evidence available on interfuel substitution in general";[26] and a 1990 Irish research paper concluded that

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[25] D.R. Bohi and M.B. Zimmerman, "An Update on Econometric Studies of Energy Demand Behavior," *Annual Review of Energy*, Vol. 9, 1984.

[26] V.B. Hall, "Major OECD Country Industrial Sector Interfuel Substitution Estimates, 1960-79," *Energy Economics*, April 1986.

"most cross-price elasticities were not found to be statistically significant."[27] However, Table 12 summarizes some of the limited econometric findings for OECD countries.

53. Price increases for *electricity and coal* are the highest priority, given the present large subsidies for both and the especially severe harmful environmental effects of the latter. The former is also a heavy user of coal (45% of LDC electricity supply in 1989 was based on coal);[28] and hydroelectric generation has become a highly sensitive environmental issue in many parts of the world, with Thailand's Pak Mun dam being a good recent example. Furthermore, electricity consumption has grown faster than energy as a whole in the LDCs. Overall LDC energy consumption grew at about 8% and 5% p.a. in the 1970s and 1980s respectively (Table 1): the corresponding figures were 10% and 7% for electricity consumption.[29] If we accept -0.5 as a reasonably conservative point estimate of the own-price elasticity of demand for these two fuels, real price increases of 10% p.a. for both electricity and coal could substantially dampen their future consumption growth rates. Electricity consumption is expected to increase at an average annual rate of 6-7% during the 1990s:[30] the rate could drop to 2% p.a. Some of the demand for electricity and coal could be expected to shift to petroleum products and gas. The cost of emission control technologies for oil and gas is lower than coal in steam-electric power generation (Table 8), and the environmental advantages of natural gas in particular over coal, in both intermediate and final energy use, are significant. In the case of *petroleum products*, we would anticipate that price increases would have a limited or perhaps no impact on aggregate consumption, given that most of the own-price impact would come through the structure of consumption and that the evidence on cross-elasticities against coal and electricity prices is mixed.[31] Subject to supply constraints, *gas demand* could be expected to increase substantially, given the prevalence of suppressed demand in many countries with gas reserves (e.g., India, Brazil, China and Poland); and the high (positive) cross-elasticities from coal and electricity prices. Recognizing the difficulty in assessing the net effect of the complex realignment of price levels and structures which we envisage, in adjusting to efficient pricing policies, and in view of the uncertainties inherent in the type of analysis we have attempted above, it may be instructive to provide two concrete illustrations from recent World Bank staff estimates for Brazil and Argentina: in both cases, it was calculated, as a rough order of magnitude, that price increases based on economic costs would reduce overall energy consumption by approximately 9%. In Brazil, the impact of efficient pricing was calculated separately for electricity and petroleum products, at 20% and 5%

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[27] D. Conniffe and S. Scott, *Energy Elasticities: Responsiveness of Demands for Fuels to Income and Price Changes*, The Economic and Social Research Institute, Dublin, 1990.

[28] E. Moore and G. Smith, "Capital Expenditures for Electric Power in the Developing Countries in the 1990s," *Industry and Energy Department Working Paper, Energy Series Paper No. 21*, February 1990.

[29] *Ibid.*

[30] *Ibid.*

[31] Table 12 implies that the demand for petroleum products would decrease in response to a coal price increase; and increase following an electricity price increase.

of consumption respectively (Box 1). The consumption of natural gas more than doubled, although it remained supply-constrained.[32] In Argentina, the combined effect was estimated to be 9-12%, not broken down into components.

2. Macroeconomic and Sectoral Distortions

54. Government policies have frequently led to distortions extending beyond the prices of energy itself, and placed obstacles in the way of energy users responding efficiently to energy pricing signals. At an even more fundamental level, the basic institutional mechanisms and incentives at the level of the final consumer often run counter to efficient behavior. Examples from all these areas have been documented as major obstacles to energy efficiency in the four countries which account for half the energy consumption in LDCs and EE (Boxes 1, 4, 5 and 7).

55. India, China and Poland have faced *trade systems* which biased the decisions of energy consumers towards energy as opposed to non-energy inputs. The import of energy-efficient equipment and technologies was made difficult or expensive, through physical controls, import duties and foreign exchange limitations, thus rendering them commercially unattractive. At the same time, the domestic manufacturers and suppliers of energy-using equipment were protected by high import tariffs and direct controls, giving them little incentive to introduce innovations or energy-efficient products. In Poland, domestic manufacturers of boilers continued to focus on coal, since that is where there expertise lies. In China, it was noticed that the lack of domestic competition among contractors delayed the dissemination of available technology and practices used in other parts of China, including building materials.

56. Despite basic differences in their economic structures, energy consumers in both India and China face serious *capital rationing* problems. The result is a bias against investment in energy efficiency and pollution abatement, even though the rate of return is high, in order to channel limited funds into manufacturing. In China, the situation is aggravated by an overstructured and inflexible *system of foreign exchange allocation*, which hampers the import of intermediate or final technologies which could stimulate faster modernization of equipment in a number of industries. In Poland and Brazil, *credit markets were segmented*, with interest rates artificially lower or subsidized in some sectors (e.g., alcohol production). In Poland, consumer choice was further limited by a variety of *administrative devices*. Regulations prohibited the use of specific fuels for particular purposes, e.g., gas as a boiler fuel (Box 7).

57. There are *deficiencies in the decision-taking mechanisms* regarding energy and non-energy inputs in China, Poland, India and Brazil. High materials intensity and a concentration on quantity throughput is a feature of centrally-planned economies: high use of energy per unit of output is no exception.[33] In China and Poland, the administrative nature of the planning and investment allocation processes, at the plant and industry level, emphasizes *production targets* rather than efficiency, innovation and profitability. There is a bias towards *minimizing investment outlays* without considering operating savings, which distorts the trade-off between energy and non-energy inputs and

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[32] With overall weights of one-third each for electricity and petroleum products in total energy consumption, this implied a combined price effect of about 9%.

[33] For some interesting insights into this phenomenon, see M. Jänicke, H. Mönch, T. Ranneberg and U.E. Simonis, "Economic Structure and Environmental Impacts: East-West Comparisons," *The Environmentalist*, Vol. 9, No. 3, Autumn 1989.

POLAND **BOX 7**

A Need for Freer Markets

The Energy Sector

1. Poland was the fourth-largest consumer of energy among the LDCs in 1989 (Table 3) and has one of the most *energy-intensive* economies in the world, with energy use approaching 1.9 kgoe per $ of GNP: only China has a comparable ratio, with slightly more than 1.9 kgoe (Table 4). The Polish economy is also very *coal-intensive*. Based on 1987 data, coal accounted for some 80% of the energy market; while imported oil and natural gas represented only 13% and 8% of primary energy consumption respectively. Only South Africa had a higher share of coal in primary energy use. Coal consumption is particularly concentrated in specific sectors, one of which is electricity, which depended on coal for 93% of its generation, and accounted for 58% of total coal consumption. The commercial and residential sectors also depended heavily on coal, for 80% of their energy needs. The high level of energy intensity and coal usage in Poland is not readily explained in terms of comparative advantage and low production costs. Rather, it is much more *clearly linked to serious policy distortions in the economy as a whole and the energy market in particular*.

Environmental Effects of Coal

2. A combination of energy-intensive GDP and overwhelming dependence on coal has created major environmental problems, in terms of air pollution, water quality and solid waste disposal. Upper Silesia, the center of the mining industry, is one of the most polluted regions in Europe.

3. The high emissions of dust, sulphur dioxide and other pollutants affecting *air quality*, which create serious health hazards, are associated mainly with coal consumption. Whereas the ambient concentration of particulates and sulphur dioxide has fallen significantly in many major Western European cities, since the mid-1970s, urban air quality in Poland has hardly improved over the same period. Domestic coal-fired heating systems and district heating plants, which have inadequate emission control, along with individual coal fires used for heating apartments and houses, are among the main pollution culprits. The coal industry has had a major impact on *water quality*, through the daily discharge of over 9,000 tons of salt, making many parts of the two main rivers, the Vistula and the Odra, too corrosive for even industrial consumption. High salinity necessitated heavy investments by industries and local authorities in water transport and treatment. Finally, coal contributes to the problem of *solid wastes*. The mining of coal, lignite and metals accounted for 66% of the flow of wastes in 1986; with electricity generation and district heating systems contributing a further 19%. Otherwise valuable land was thereby preempted from use in areas where significant levels of urbanization and industrialization had already created growing demands. Sulphur compounds in the coal waste heaps contaminated ground- and surface-water; and coal in slag heaps was subject to dangerous spontaneous combustion.

4. A minimum estimate of *income losses due to air and water pollution* in Poland is put at 2.5-3.0% of GDP, of which approximately 1-1.5% is due to the health effects of air pollution (i.e. in the form of lost working time and productivity), and another 0.5-0.8% to high levels of water salinity (due to discharges from coal mines) and BOD in major rivers. These costs are two to three times the levels estimated for various OECD countries.

Economic Policy Distortions and Energy Efficiency

5. A close examination of Poland's economic policies highlights a range of distortions which have promoted energy intensity, the emphasis on coal, and the consequent serious environmental degradation. First, energy prices do not reflect economic costs, thus depriving energy consumers of the correct signals. Second, the absence of inter-fuel competition limits the ability of consumers to respond to price signals, even if they were correct. Third, the entire calculus of decision-taking has been rendered deficient.

6. In 1987, *average fuel prices* in Poland were only about one-third of their opportunity cost, causing too much overall energy consumption. Furthermore, *relative fuel prices* were out of line with relative costs, preventing economically-efficient inter-fuel substitution, which would also have been environmentally beneficial. Solid fuels and electricity were priced at around one-third of their cost, while the ratio for petroleum products and natural gas was two-thirds to one-half. Finally, *the price differential between grades of coal* did not adequately recognize quality: it was based on heat content, leading to excess demand for the higher quality coals and excess supply for low-grade (high ash) coals. These price distortions discouraged the emergence of a coal cleaning industry, and provided no incentive to improve mining techniques.

BOX 7 (Continued)

7. In addition to price distortions, *consumer choice has been limited* by a variety of administrative devices. Regulations prohibited the use of specific fuels for particular purposes (e.g. gas as a boiler fuel) and coal is centrally allocated, which forces some large coal consumers, mainly power stations, to use lower grades of coal than they would choose to purchase at the present structure of coal prices. Network and supply restrictions, aggravated by below-cost pricing for gas, limit the coverage of the gas network and the distribution of certain petroleum products; while foreign exchange shortages and protection from foreign competition steer consumers towards domestic manufacturers of boilers and other energy conversion equipment, who focus on coal as the primary fuel.

8. *Deficiencies in the basic process underlying the calculus of major energy consumers* were as important as the policy distortions described above. Firms were more interested in meeting production targets than in financial performance. The absence of realistic budget constraints and effective domestic and international competition muted or eliminated the incentives for Polish managers to introduce cost-reducing measures. A survey of the attitudes of industrial energy consumers to energy price increases revealed the prevalence of "cost-plus pricing" and the expectation that enterprises can simply pass on increases in energy costs to final consumers. In contrast, enterprises indicated that they would devote more scarce management time to easing constraints on the availability of non-fuel inputs and to increasing output.

Policy Measures to Promote Energy Efficiency

9. *Macroeconomic reforms* are a key part of the necessary policy package to improve energy efficiency in the Polish economy. The main ingredients of the package are: the introduction of a unified market foreign exchange rate; the lifting of subsidies on lending rates; limiting Government involvement in decisions on the allocation of credit; the strict enforcement of hard budget constraints, including (where necessary) bankruptcy; the promotion of competition; and giving managers unrestricted access to complementary supplies of capital, labor and materials.

10. *Sectoral reforms* constitute the other key component, including: the dismantlement of the coal monopoly; full economic pricing and inter-fuel competition; competitive coal marketing; and investment in electricity metering. At the start of Poland's move towards a market economy, the average price of energy relative to other inputs needed to increase to three times the then-existing level, forcing energy consumers to accord much higher priority to energy conservation. The prices of coal and electricity needed to double relative to petroleum products and gas, inducing the substitution of fuel oil and gas, which are less polluting than coal and coal-based electricity production. At the same time, the relative prices of different coal grades needed to be adjusted to reflect market conditions. Moreover, if the environmental costs of different coal grades were internalized, e.g., through tradeable permits and pollution and effluent charges, or if regulations on ash and sulphur were enforced, the premium value of high-quality coals would increase further, thereby encouraging coal beneficiation and the improvement of average coal quality.

Source: World Bank information and staff estimates.

discourages energy efficiency measures, including the introduction of new technologies. Although Brazil and India are more market-oriented, there is widespread use of *"cost plus" pricing*. In the case of Brazil, it is encouraged by the fact that producers have been shielded from domestic and international competition: barriers to entry and structural change have muted the price and other incentives to introduce cost-reducing measures. In India, public sector enterprises routinely apply "cost-plus" pricing formulae; and the use of protective import tariffs raises the prices of final products overall, making energy a smaller proportion of total financial rather than the true economic costs. In Poland, a study initiated by World Bank staff, which surveyed the attitudes of industrial energy consumers to energy price increases, revealed the prevalence of "cost-plus" pricing. In the absence of effective domestic and international competition, enterprises expected to be able to pass on increases in energy costs to final consumers. Recent World Bank studies of China, Poland and India all underlined the need for "hard" budget constraints, to increase cost consciousness, including awareness to energy costs and a willingness to reduce them in the pursuit of efficiency. Obviously, State enterprises in China and Poland have not normally gone out of business; in India, the Government has been willing to provide financial support to inefficient enterprises, to prevent closure and job losses.

B. Supply-Side Distortions

58. A complex set of financial, institutional and managerial considerations affect the operating efficiency of energy suppliers, due partly to the fact that the traditional model in the LDCs and EE has almost invariably been the State-owned and controlled public enterprise, with little or no private-sector participation or influence. Varying degrees of privatization are being proposed or implemented in, *inter alia*, Argentina, Turkey, Philippines, Côte d'Ivoire, Chile, Pakistan, Thailand and Malaysia; but, until recently, private sector initiatives were relatively uncommon in relation to total energy supply in the LDCs and EE. Even cofinancing obtained by World Bank borrowers from commercial sources has been minimal, averaging only US$200 million p.a. over the decade 1979-88 in the power sector.[34]

59. Given the *powerful influence of government* in the traditional energy supply model for LDCs and EE, and the usual *lack of private sector participation* in the energy sector, state monopolies are often hampered in their pursuit of efficient practices, including least-cost energy supply and commercially-sound pricing policies. Frequently, absent the profit motive and the need to deal vigorously with competitive forces, they may not themselves seek and achieve the full scope for efficiency in energy supply available to them. Indirectly, adverse environmental effects often ensue. We consider the main sources of supply-side inefficiency below, in terms of: controlled producer prices; weakened finances; and institutional and managerial factors.

1. Producer Price Controls

60. A crucial element in the ability of a company to act as a commercial entity is reasonable autonomy in setting prices. Low coal prices and incorrect price differentials between coal grades has led to a lack of beneficiation and incentives to improve mining techniques, for example in China and Poland. Coal with high ash content is shipped over long distances and increased coal-handling costs and lower boiler efficiencies are imposed on coal users, who lack alternative suppliers (Boxes 5 and 7). More coal washing and coal screening would be economically justified and take place in the face of efficient coal prices. The supply of natural gas, a joint product of national oil companies, is frequently constrained, despite its clear environmental advantages over other fossil fuels, because it is usually a new energy source, requiring substantial infrastructure investments to develop its market potential; and its price is low relative to petroleum products. Poland, China, India, Argentina and Brazil all failed to expand natural gas utilization as much as would be economically and environmentally justified, partly due to low producer prices. Where supply is constrained, an appropriate policy is to price natural gas on the basis of the cost of the fuels which it could replace: such a policy would often generate sufficient revenue to attract investment in natural gas exploration and development. In China, town gas also was discouraged, because suppliers were not able to generate the funds for necessary investments, although town gas is less polluting than the direct burning of coal for household use.

2. Weakened Finances

61. A 1988 survey of 123 power projects financed by the World Bank and completed between 1967 and 1982, concluded that the financial performance of the *electricity sector* in LDCs had

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[34] World Bank staff estimate.

deteriorated markedly in the 1980s, as measured by several key financial indicators; and that inadequate increases in tariff levels had played a significant role in the deterioration.[35] Real tariffs fell by 3.5% p.a. over 1979-1988 (see para. 40); and average rates of return on assets fell from levels averaging over 9% in 1966-1973 to 6% in the 1980s.[36] The maintenance of a closer relationship between the average economic cost and retail price of petroleum products (see para. 42) has helped State-run *oil companies* avoid the worst financial consequences suffered by electricity companies as a result of Government energy pricing policies. Nevertheless, low prices received by producers, or (equivalently) high taxation and royalty payments, sometimes undermine profitability. In Argentina, the national oil company had a substantial positive net operating income turned into large losses, even before depreciation provisions, after the deduction of multiple surcharges, taxes, royalties etc. The financial position of the national oil companies in Brazil and India, while still sound, declined after 1986, as producer prices were held down. Finally, the financial condition of the *coal enterprises* in the major coal-producing countries in the developing world was universally poor. In China, they lost 18% of revenues in 1986 and required financial subsidies. Coal India's poor financial performance also was linked to insufficient coal price increases: its accounts were closed with a loss in all but four years since its nationalization in the early 1970s. Subsidies were also necessary for the Hard Coal Board in Poland. It is significant that pricing reforms based on economic principles would not only improve resource allocation in the energy sectors of the LDCs and EE, but would generally be financially beneficial. World Bank staff have estimated that price increases to 63% of AIC in the Indian power sector, and 80% of AIC in the Brazilian power and Chinese coal sectors, would have been sufficient to meet financial criteria. Clearly, full attention to cost reducing measures is also a prerequisite of improved financial performance.

62. *The consequences of a weak financial situation* in energy supply enterprises are wide-spread. Facing financial constraints, state monopolies concentrate their limited resources on production. Lacking a profit orientation and not facing competition, they are more responsive to political pressures and public opinion; after all, government is for the most part the source of the financial constraints and public opinion can influence government, even in non-democratic systems. Hence, resources are more likely to be devoted to expanding supply than to improving efficiency, reducing costs or, at least until recently, mitigating the harmful environmental impacts of production. The nature of incentives in the public sector is such that expenditures on items such as maintenance, power system loss reduction and refinery upgrading receive lower priority than increased production.

63. *Improved maintenance* reduces the fuel requirements of thermal systems.[37] Furthermore, as plant availability rises, loadings on existing plants increase, and thermal efficiencies improve, as do heat rates. The fossil fuel requirements for thermal power plants in developing countries total about 300 mtoe: an increase of two percentage points on the average thermal efficiency (say from 32% to 34%) would reduce fossil fuel consumption by about 20 mtoe annually. Regrettably, power companies often neglect maintenance in times of financial shortages.

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[35] "A Review of World Bank Lending for Electric Power," *Energy Series Paper No. 2*, March 1988.

[36] World Bank, "A Review of Bank Lending for Electric Power," *op. cit.*

[37] It also reduces the investment needs, as reserve margins fall.

64. Investments in transmission and distribution can *reduce power system losses* and hence total production requirements. In a thermal system, emissions will decline. However, losses include both technical and non-technical losses, the former being due to resistance losses in conductors, transformers and equipment, and the latter to uncollected revenues. Reductions in non-technical losses do not affect consumption directly, but they do improve the financial situation of the power company; and non-collection of revenues is equivalent to a zero price for electricity. In India, investments in transmission and distribution were retarded by low tariffs and a weak financial position; and farmers frequently do not pay already low electricity tariffs for irrigation pumping loads. On well-designed, operated and managed power systems, losses should not exceed 10%. The statistics for 100 LDCs show that, in 1987, system losses in 30 countries were over 20%; and over 30% in nine countries.[38] If overall technical losses could be reduced by 5%, fuel savings could amount to 15 mtoe p.a.

65. *Maintenance and upgrading of oil refineries* suffers from constrained finances. The throughput losses of refineries in LDCs often exceed 2% or even 4%, compared with 1% or less in a well-run refinery in a developed country.[39] The higher losses are due to leakage, evaporation, poor maintenance, spills and high own-consumption of energy. Such refineries also tend to produce low-quality petroleum products, especially fuel oil, which are much more polluting.[40] The refinery upgrading taking place in Cubatão, Brazil, is a good example of the way in which refinery upgrading investments can yield a high economic rate of return and significant environmental benefits (Box 1).

3. Institutional and Managerial Factors

66. In many countries, the State's monopoly in power supply imposes no obligation to coordinate operations with steel industries, refineries and others to combine electricity with steam production. Along with low producer and consumer prices, this has left largely untapped the potential for private sector participation through *cogeneration*. In China, higher prices for electricity and coal, and the right institutional arrangements, would encourage cogeneration from the numerous manufacturers with industrial boilers, which produce high-pressure steam. The national power company in Nigeria (NEPA) and the Government-owned petroleum company (NNPC) operate separate gas-fuelled power and process steam facilities, which could be combined at a common location, to increase the joint thermal efficiency from 35% to 70%. It can be noted that, with more use of natural gas for electricity generation, the potential for cogeneration increases, because it permits greater independence in operation of the power and steam facilities. Based on a survey in Canada, cogeneration might be possible on about 5% of the capacity of a typical utility: a rough estimate of the potential for saving fossil fuels in LDCs is correspondingly 15 mtoe.

67. In India, complex administrative and institutional arrangements discourage integrated power system operation, causing a *bias towards generation and way from transmission and distribution investments*: system losses, gross production and pollution increase. At the Federal level, there are

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[38] World Bank, "Summary Data Sheets of 1987 Power and Commercial Energy Statistics for 100 Developing Countries," *Industry and Energy Department Working Paper, Energy Series Paper No. 23*, March 1990.

[39] U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries*, OTA-E-486, Washington, D.C., January 1991.

[40] K. McKeough, A Study of the Transfer of Petroleum Fuels Pollution, *Industry and Energy Department Working Paper, Energy Series Paper No. 37*, July 1991.

the Central Electricity Authority, National Thermal, National Hydro, National Transmission and National Rural Electrification entities. At the State level, 18 State Electrification Boards are overlaid with five Regional Electrification Boards. It is not surprising that coordination and political interference are basic problems in the sector, affecting the efficiency of energy supply and use. More generally, *over-reliance on physical production targets* also seems to be part of the institutional problem in India, affecting both electricity and coal supply (Box 4).

68. Political and institutional factors also contributed to the *slow development of gas supply infrastructure* in LDCs, in addition to the pricing effects discussed earlier. Over half the world's natural gas reserves are in the LDCs and the AIC of gas is usually lower than that of coal or oil. The role of the Federal Government and the monopoly position of the national oil company undoubtedly played a part in delaying gas expansion in Brazil. Initially, government policy gave priority for gas utilization to a limited number of industries, mainly fertilizers, and gas prices were kept low. Furthermore, natural gas was part of the monopoly of the national oil company, which implied that greater gas penetration would have been at the expense of its own petroleum products, notably fuel oil. While a constitutional change transferred the right to distribute natural gas to the states, obstacles remain to the expansion of gas infrastructure, as the states are not permitted to obtain bulk supplies from other sources (e.g., imports); and there is a lack of a clear definition of the relative roles of the national oil and the State gas companies in the lucrative industrial market (Box 1).

69. Weak institutional arrangements, combined with an early emphasis on utilization for fertilizer production and low producer prices (as in Brazil), help to explain the slow penetration of gas in the Indian energy sector. The result has been the flaring of one-third of gross production in 1990, while the Bombay Suburban Electric Supply Company is constructing a 500 MW coal-fired plant at extra cost, with higher emissions and using coal transported 1,400 km (Box 4). Fortunately, provision is being made for possible future gas firing at the plant.

70. State involvement in the energy sector has led to *political interference in investment decisions*, as well as in pricing. The Government of Nigeria is encouraging NEPA to develop the 950 MW Zungeru hydro plant, although large amounts of natural gas are being flared. In Brazil, the Government proceeded with the development of nuclear power, although it was not part of the least-cost solution for the power sector: the plant has produced virtually no electricity, despite an investment equivalent to several billion US dollars; and there has been controversy over its environmental impact (Box 6). The development of international electric power interconnections has been slowed by political factors as much as by economic, financial and technical considerations and there remains tremendous scope for such interconnections to reduce fossil fuel consumption. Significant possibilities are in West Africa (e.g., from Nigeria to Côte d'Ivoire) and South America (e.g., between Brazil and Argentina). Political considerations also led to the proliferation of inefficient refineries, notably in Africa, with relatively high losses and low-quality products.

VI. EXTERNALITIES

71. Section V emphasized the need to reduce economic policy distortions. Nevertheless, even if a Government implements the policies necessary to foster properly-functioning energy markets, we must recognize that there are external environmental costs which are not reflected in market prices. Numerous policy instruments are available to governments to handle these externalities, a common distinction being made between "command-and-control" measures (C&C), public expenditures and

market-based instruments (MBIs)[41]. While limited use has been made of MBIs, in Europe and the USA, most countries (including EE and the LDCs) have relied overwhelmingly on C&C and direct public expenditures, to reduce the environmental consequences of energy production and use.

A. Command and Control (C&C)

72. *Energy production decisions* in LDCs and EE are usually mainly within the public sector and (at least in principle) readily subject to C&C or can be handled as direct public expenditures. Certainly in the near term, expenditures on emission control equipment are an attractive way to mitigate the national environmental effects of fossil fuel production, although there may also be transnational benefits. As we have shown in para. 26, "clean" technologies can reduce pollution by more than 90%. Most coal-fired plants in the LDCs have electrostatic precipitators or some form of particulate emission control, but little has been achieved in FGD or SCR, for nitrogen oxide removal. In the developed countries, FGD and SCR installations in operation or under construction totalled about 140 GW and 36 MW respectively, in 1988. In India, the Trombay plant has FGD installations totalling about 2 GW, but it is not believed that there are, as yet, any other significant developing country FGD or SCR installations, because the costs associated with such measures are considerable. In the decade 1990-2000, electricity supply in the LDCs is expected almost to double, to a total requirement of about 4,000 TWh. A review of the utility expansion plans indicates that the capacity of coal-fired thermal plant would also roughly double, to about 340 MW[42]. The capital costs of installing FGD and SCR on all the new coal-fired plant, and, say, one-quarter of the existing plant, would be in the order of US$37 billion, which would be in addition to nearly US$1 trillion expected to be required for normal capital investment. Of course, the type and amount of emissions control equipment installed should be commensurate with the benefits available locally (e.g., the reduction of particulates may be more cost-effective than controlling sulphur emissions, or the local ambient levels of SO_2 may not warrant installation of FGD, as perhaps in Hungary and Yugoslavia). On the other hand, there are substantial efficiency gains available through the elimination of pricing distortions in electricity supply: the ensuing reduction in investment requirements, through a lower growth rate of electricity consumption, and of subsidies should more than offset the costs of emission control.

73. The powerful influence of governments over energy production decisions in the LDCs and EE also lends itself to the internalization of environmental costs and benefits in the investment decisions of energy companies. Thus, the construction and production of nuclear power plants is regulated in those countries with nuclear facilities, covering nuclear waste disposal, safety and other environmental concerns. Whether such regulation is satisfactory or not is a separate issue, not addressed here. Similarly, state-owned power companies can be required to take full account of the adverse environmental consequences of hydroelectric plants (para. 28). Brazil is an example of a country which has made significant strides forward in incorporating environmental concerns within the energy sector: environmental issues in the power sector are handled through implementation of an Environmental Master Plan, agreed under a World Bank loan in 1986 (Box 1); while the national oil company has built up a strong capability to deal with environmental matters, through a special

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[41] G.S. Eskeland and E. Jimenez, "Choosing Policy Instruments for Pollution Control - A Review," *Country Economics Department, WPS 624*, World Bank, Washington, D.C., March 1991; and D. Anderson, "An Economic Perspective on Management in the Public Sector," *Environmental Management in Developing Countries*, D. Erŏcal (ed.), OECD, Paris, 1991.

[42] E.A. Moore and G. Smith, *op. cit.*

superintendency.

74. *On the consumption side*, major sectors subject to direct C&C in the DCs are transport and industry. Transportation accounts for more than 25% of total commercial energy consumption in most LDCs; and over one-third of their oil consumption[43]. While the transport sector in the LDCs contributes far less to global emissions of CO_2 and pollutants, such as CO, NO_x and SO_x, than in the DCs, the situation is likely to change, as urbanization and vehicle ownership continue to increase rapidly[44]. Already, vehicles in large cities, such as São Paulo, Mexico City and Santiago, are major sources of local air pollution[45]. Yet, unlike the DCs, LDCs have made little effort to regulate directly the consumption of transport fuels. Exhaust emission standards for gasoline-powered automobiles are usually non-existent; where they exist, as in Brazil and Mexico, they are far less stringent than in the USA and Japan[46]. However, probably due to the gravity of the situation, Mexico (unlike most other LDCs) is resorting to direct controls over energy consumption, such as the banning of cars from being driven in Mexico City on specific days, under a license plate number system; the introduction of unleaded gasoline; and the promotion of catalytic converters.

75. As much as 40%-50% of total commercial energy consumption in the LDCs occurs in the industrial sector[47]. To the extent that the resulting emissions have been controlled at all, direct regulations have normally been used, by requiring the application of abatement technologies similar to those used in power generation, and described in paras. 21-26. Some LDCs, such as Mexico and Brazil, have also made efforts to reduce the sulphur content of automotive and industrial fuels.

B. Market-Based Instruments (MBIs)

76. Among the possible *indirect MBIs*, gasoline taxes are widespread in the LDCs and EE (para. 42). While the motivation is typically fiscal, there are beneficial environmental effects, through reduced total gasoline consumption. In many LDCs and EE some of this is offset by favorable price differentials for diesel, LPG and kerosene; and little or no price advantage has been given to unleaded or leaded gasoline. However, Brazil has sold hydrous fuel alcohol at 75% of the gasoline price, resulting in a substantial switch to ethanol use and an absolute decline in gasoline consumption. Renewables in general, of course, will be stimulated in the face of differential taxes penalizing fossil

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[43] U.S. Congress, Office of Technology Assessment, *op. cit.*, p 76.

[44] J.J. MacKenzie and M.P. Walsh, *Driving Forces*, World Resources Institute, Washington, D.C., 1990, pp 17-20; and A. Faiz, K. Sinha, M. Walsh et al., "Automotive Air Pollution: Issues and Options for Developing Countries," *Infrastructure and Urban Development Department, WPS 492*, World Bank, Washington D.C., 1990, p vii.

[45] A. Faiz, K. Sinha, M. Walsh *et al.*, p viii.

[46] *Ibid.*, pp 52-54.

[47] U.S. Congress, Office of Technology Assessment, *op. cit.*, p 62.

fuels. Another indirect MBI, which has been applied in only one instance in an LDC, is congestion pricing; but the signal success of the Singapore Area Licensing Scheme may be attributed to special, even unique features[48].

77. Taxes on specific emissions or on carbon content are the most obvious examples of *direct MBIs*. These instruments may, *inter alia*, induce abatement measures, e.g., the technologies described earlier; reduce overall energy use; or encourage inter-fuel substitution. While carbon taxes may have good revenue-raising potential in a relatively non-distortionary way[49], the global rationale for carbon taxes is unlikely to appeal to the LDCs or EE. Emissions taxes, however, in the form of fees levied on air pollutants, are used in Bulgaria, Hungary, Czechoslovakia and Poland[50]. The recently promulgated list of fees for Poland contains 51 substances, including lead, mercury, SO_2, NO_x, and PM. In the past, the level of the fees was too low, relative to marginal pollution or abatement costs, enforcement was inadequate and firms did not operate with hard budgets. The level of fees has recently been increased substantially in real terms and there are signs that fees are making an impact on polluters. A particularly interesting direct MBI, namely emissions trading, has been little used, even in OECD countries: the USA has been the main center of practical interest, notably with lead and SO_2. No examples exist in the LDCs or EE, although the U.S. Environmental Defense Fund is supporting work in the highly-polluted Katowice region of Poland, which shows that net economic benefits could stem from emissions trading, i.e., both air pollution and abatement costs could be reduced, compared with alternative approaches.

C. C&C or MBIs?

78. *The relative merits of MBIs and C&C* have been thoroughly discussed in the theoretical literature; and some important lessons have been drawn from the limited practical experience to date in the DCs[51]. The evidence so far suggests that MBIs can help societies to achieve given environmental objectives at lower total cost than C&C alone, by permitting energy producers and users more flexibility in their responses and providing economic incentives for technological change. Furthermore, MBIs may generate revenues in a way which involves fewer economic distortions than conventional taxes. Nevertheless, as far as the LDCs and EE are concerned, there is a critical need for more empirical work and implementation experience, in order to derive more reliable conclusions on the role of MBIs. The World Bank is attempting to meet some of that need, through its operational work and research. Case studies are being developed, for example, in Poland, Mexico, Brazil and Indonesia. While it is already probably safe to predict that these case studies will suggest that MBIs have a greater role to play than at present in the LDCs and EE, the most likely conclusion will be that a mixture of policy instruments is generally desirable, depending on their cost-

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[48] I.G. Heggie, "Improving Management and Charging Policies for Roads: An Agenda for Reform" *Infrastructure and Urban Development Department*, INU Report No. 92, World Bank, Washington, D.C., December 1991.

[49] A. Shah and B. Larsen, "Global Warming, Carbon Taxes and Developing Countries," *Paper Presented at the American Economic Association Annual Conference*, New Orleans, January 3, 1992.

[50] G. Hughes, "Are the Costs of Cleaning up Eastern Europe Exaggerated? Economic Reform and the Environment," *Oxford Review of Economic Policy*, Vol. 7, No. 4, 1991; and P. Wilczynski, "Environmental Management in Centrally-Planned Non-Market Economies of Eastern Europe," *Environment Working Paper No. 35*, Environment Department, World Bank, Washington, D.C., July 1990.

[51] T.H. Tietenberg, *Environmental and Natural Resource Economics*, 2nd ed., Scott, Foresman and Co., Glenview, Ill., 1988; and W. Baumol and W. Oates, *Economics, Environmental Policy and the Quality of Life*, Prentice Hall, Englewood Cliffs, N.J., 1979.

effectiveness in particular circumstances. Monitoring and enforcement costs and capability will be among the crucial considerations, as well as the nature of decision-taking mechanisms in the country concerned (notably the responsiveness of energy producers and consumers to economic incentives). Work by the World Bank already concluded in Mexico City indicates that, by applying a gasoline tax in combination with other policy instruments (including C&C instruments), the total costs of meeting given emissions standards could be reduced by nearly 20%[52]. On the other hand, where public health and safety or rapid results are involved, C&C instruments will almost inevitably assume greater importance than MBIs.

VII. FUTURE DIRECTIONS

79. We have argued that *energy production and use create extensive and serious environmental effects*, at the local, national, regional, trans-national and global levels. These effects concern all countries, although it is arguable that the impact on developing countries may be more serious than on developed countries, since the former depend more on natural resources and lack the economic strength to withstand the environmental consequences. At the same time, a reliable energy supply is a vital prerequisite for economic growth and development. Although some "delinking" between energy consumption and economic growth has occurred at high income levels (Fig. 2), increases in total energy consumption, and perhaps especially total electricity consumption, are an inevitable concomitant of higher GDP. Even by 1989, per capita energy consumption in the LDCs was only 488 kgoe compared with 5,194 in the developed countries (Fig. 1).

80. *Greater energy efficiency in the LDCs and EE is a high-priority way to mitigate the harmful environmental consequences of growing energy consumption.* We underline four interrelated advantages. *First*, it requires measures which are in any case in the economic self-interest of the LDCs and EE. In that sense, it is cost-effective and can be seen as a good example of a "no regrets" insurance policy. Of course, political obstacles may make it difficult to take these measures, but that is the challenge which lies at the heart of economic development. In particular, there are well-established techniques for dealing with concerns over low-income consumers, for example through "lifeline" rates or direct income support. *Second*, it will help to conserve the world's supply of non-renewable fuels, especially fossil fuels. *Third*, it will encourage appropriate fuel switching, based on relative economic costs and values. This can be expected to favor natural gas, which is less carbon-intensive than coal, for example; and advanced gas turbines, which are more efficient than conventional, coal-fired steam turbines. *Fourth*, it not only addresses local and national problems, but also contributes significantly to solving regional, trans-national and even global warming questions.

81. *Any strategy to make energy production and use more efficient must rely more extensively than heretofore on markets which are allowed to function with less interference from Government.* The crucial components in an appropriate strategy include: more domestic and external competition; the gradual elimination of energy pricing distortions; the reduction of macroeconomic and sectoral distortions, for example in foreign exchange and credit markets; and reform of energy supply enterprises, including less State interference, more financial autonomy and a greater role for the private sector. While these are ambitious goals, they are precisely the types of measures identified by the World Bank in 1991 as crucial to economic development in general: they are not peculiar to

[52] G.S. Eskeland, "Demand Management in Environmental Protection: Fuel Taxes and Air Pollution in Mexico City," *Paper Presented at the American Economic Association Annual Conference*, New Orleans, January 3, 1992.

energy markets.[53] If the right climate and conditions are created for the operation of energy supply enterprises, they can be expected to play a much more active role in efficient demand-side management. For example, a public electricity supply company, if subjected to more competition from the private sector and with more cost-consciousness, could manage shared savings contracts, in which the benefits of reductions in electricity consumption are shared between the consumer and the supplier, without the danger of hidden subsidies and additional bureaucracy. The integration of demand-side management with least-cost supply options, through the methodology of Integrated Least-Cost Planning or Integrated Resource Planning[54] is an excellent way to identify the considerable technical potential for improving end-use energy efficiency, which we discussed in para. 9. Nevertheless, we would argue that the best chance of realizing that potential is to ensure that the right policy conditions are present, e.g., to provide the economic incentives for consumers to select more efficient lights, space heating, electric motors, etc.

82. Of course, as we have emphasized, market forces may need to be harnessed or supplemented by policy instruments which allow for environmental externalities. But, given the substantial agenda of policy actions necessary to improve the functioning of the energy market and strengthen competition, *we are not convinced of the need for non-market approaches, beyond those geared to correct externalities, provide essential information, support basic research and development (R&D) and possibly promote pilot projects*. Governments in many LDCs have a role to play in providing *basic information*: competition is generally enhanced in a well-informed market. Similarly, Governments in the developed countries and, albeit to a lesser extent, the LDCs and EE, may have to support *fundamental R&D*, notably in areas where the results are in the nature of public goods and it is difficult to grant property rights. Basic research on combustion and materials, and the environmental consequences of energy production and use, especially concerning carbon-free energy sources, as well as applied research on the testing and demonstration of generic new technologies (including pilot projects), fall into this category. A relatively modest diversion of the technological effort in the developed countries, much of which has concentrated on nuclear energy, could reap substantial dividends in the field of global warming.[55] However, the role of Government in energy R&D must always be carefully scrutinized: improving incentives to the private sector may be more effective.[56]

83. We have focussed a great deal of our attention on "no regrets" policies, which are defensible in terms of the basic self-interest of EE and the LDCs. We also conclude that *a Government is far more likely to take action to reduce an environmental externality, if it captures benefits within its own national boundaries which exceed the costs of the action*: dealing with transnational and global problems normally involves an international effort, since other countries receive at least a portion of the benefits, and raises the crucial issue of burden sharing. Proceeding from the self-interest

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[53] World Bank, *World Development Report 1991, the Challenge of Development*, Oxford University Press, 1991, especially Chapters 4 and 5.

[54] "Incorporation of Environmental and Health Impacts into Policy, Planning and Decision Making for the Electricity Sector," Key Issues Paper No. 4, *Senior Expert Symposium on Electricity and the Environment*, Helsinki, Finland, 13-17 May 1991, International Atomic Energy Agency, Vienna, 1991, pp 151-154; and E. Hirst, "Improving Energy Efficiency in the USA: the Federal Role" *Energy Policy*, Vol. 19, No. 6, 1991.

[55] Nuclear energy accounted for 60% of total public expenditures on energy R&D in the IEA countries in 1989. See D. Anderson, *op. cit.*, p. 39.

[56] R.W. Bates, "Energy Conservation Policy, Energy Markets and the Environment in Developing Countries," *op. cit.*

argument, we see the reduction of the large difference between energy prices and economic costs in the LDCs and EE as a more immediate issue than the debate over carbon taxes, which is taking place as part of the policy initiatives on global warming.

84. *For the future, we see an indispensable role for the developed countries in facilitating improvements in energy efficiency in the LDCs and EE. First,* they can encourage an improved flow of beneficial technology, making use of commercial mechanisms wherever possible (e.g., through trade and licensing); and, as appropriate, supporting private initiatives in R&D. The LDCs have an important role to play here, in establishing a policy framework to permit these flows, notably through long-term partnerships between the private sectors of the LDCs and the DCs. However, it is worth noticing that, at least in the large developing countries, considerable advances have already been made in thermal power technology. Large and efficient units of 400-600 MW are in operation or under construction in Thailand, India, Indonesia and China; and gas-fuelled combined-cycle installations total 4 GW in the LDCs, with 20 GW expected by 2000. The LDCs and EE are lagging more in the operation of power plants and in the application of emissions control technology. Fig. 9 shows the far higher emissions in Indian power plants compared with OECD. Furthermore, while the capital costs of Indian and typical OECD power plants are about the same -- US$1000/kW for coal steam plants and US$540/kW for gas-fuelled combined cycle plants -- the operational experience is quite different. In India, the load factors achieved by coal thermal plants are only 50-55%, due to poor quality coal, coal shortages, low quality spare parts and low staff morale. The typical OECD thermal plant factor for base-loaded capacity is 70-75%. As a related matter, more work is also needed in analyzing the successes and failures in both supply- and demand-side management in the OECD countries; and in integrating the experience into the LDCs and EE. A *second* role for the developed countries is to increase conventional aid, to help finance both the normal energy investment requirements of the LDCs and EE and the need for additional expenditures to protect against local and national environmental degradation. *Third*, the developed countries will have to accept a greater share of the burden of safeguarding the global commons. The developed countries accounted for about 60% of cumulative worldwide CO_2 emissions from fossil fuels during 1950-1987[57] and have already attained most reasonable goals of development. They can therefore reasonably afford to substitute environmental protection for further growth of material output. On the other hand, the LDCs and EE can be expected to participate in the global effort only to the extent that it does not impede their immediate economic and social development objectives. The LDCs and EE will therefore need some level of compensatory financial assistance, on concessionary terms, that is additional to existing conventional aid to address global environmental concerns.[58] In EE particularly, help will be needed in restructuring economies, and in securing the flow of capital that goes along with it. Some mechanisms already exist to mobilize concessionary funds. Apart from the US$240 million raised for implementation of the Montreal Protocol, there is the US$1.5 billion Global Environment Facility (GEF), a cooperative venture between national governments, the World Bank, UNDP and UNEP.

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[57] World Resources Institute, *op. cit.*, p. 14.

[58] The argument is developed further in M. Munasinghe and S. Munasinghe, *op. cit.*

1969-1989 World Energy Consumption

Energy Consumption
(mtoe)

Year	LDCs	DCs	E. Europe	U.S.S.R.	Others	World
1969	581	2,973	234	733	45	4,566
1979	1,257	3,850	369	1,126	70	6,672
1989	1,944	4,202	414	1,470	142	8,172

Average Growth
(% p.a.)

Period	LDCs	DCs	E. Europe	U.S.S.R.	Others	World
1969-1979	8.02%	2.62%	4.66%	4.39%	4.52%	3.87%
1979-1989	4.46%	0.88%	1.16%	2.70%	7.33%	2.05%

Source: Bank Economic and Social Database

Energy Regional Breakdown for 1989

North America	27.2%
Western Europe	15.5%
Japan	5.3%
Australia	1.1%
New Zealand	0.2%
Sub-total	49.3%
Latin America	5.5%
Middle East	2.5%
Africa	3.1%
Asia (except Japan)	14.1%
Sub-total	25.2%
U.S.S.R.	18.1%
Eastern Europe	6.3%
Sub-total	24.4%
Others*	1.1%
TOTAL	100.0%

Note: "Others" are countries that are not categorized in the database and are not included in any of the designated regions.

Source: Bank Economic and Social Database (BESD)

Energy Consumption in LDCs and EE
1989

	Consumption (mtoe)	Share (%)	Cumulative (%)
China	662	28.1%	28.1%
India	188	8.0%	36.0%
Brazil	132	5.6%	41.6%
Poland	126	5.3%	47.0%
Mexico	109	4.6%	51.6%
Romania	81	3.4%	55.0%
Korea	79	3.4%	58.4%
Czechoslovakia	74	3.1%	61.5%
Algeria	61	2.6%	64.1%
Others	846	35.9%	100.0%
Total LDCs and EE	2,358	100.0%	

Source: Bank Economic and Social Database

Energy Intensity in 1989

Countries	GDP (US$ billions at 1987 prices)	Energy Consumption (mtoe)	Energy Intensity (kgoe/US$ of GDP at 1987 prices)
All low-income	969	968	1.000
China	345	662	1.915
India	295	188	0.637
Other low-income	329	119	0.362
All middle-income	2,056	1,475	0.717
Eastern Europe	296	414	1.399
Other than E. Europe	1,760	1,061	0.603
Mexico	147	109	0.741
Poland	67	126	1.889
Romania	55	81	1.494
Brazil	314	132	0.421
Low- and middle-income	3,025	2,443	0.808
Sub-Saharan Africa	243	135	0.557
East Asia & Pacific	3,853	1,460	0.379
South Asia	371	224	0.604
Europe, M. East & N. Africa	6,258	3,639	0.582
Latin America & Caribbean	746	447	0.599
High-income	13,688	4,201	0.307
United Kingdom	736	212	0.288
France	953	212	0.223
Germany, Fed. Rep.	1,192	266	0.223
United States	4,794	1,948	0.406
Japan	2,628	428	0.163
Total reporting countries	16,713	8,172	0.489

Note: U.S.S.R. is excluded from the middle-income countries.

Source: Bank Economic and Social Database (BESD)

TABLE 5

Energy Intensities for Selected Less Developed Countries
1971-1989

Year	Country	Energy Consumption (mtoe)	Energy Consumption (kgoe/US$ of GDP at 1987 prices)
1971	Brazil	44	0.348
	China	251	2.490
	India	66	0.483
	Mexico	42	0.585
	Poland	84	n.a.
1978	Brazil	83	0.376
	China	436	3.070
	India	102	0.576
	Mexico	74	0.673
	Poiand	117	n.a.
1982	Brazil	93	0.374
	China	464	2.524
	India	126	0.638
	Mexico	105	0.747
	Poland	117	2.272
1987	Brazil	117	0.384
	China	612	2.005
	India	166	0.648
	Mexico	107	0.758
	Poland	128	1.995
1989	Brazil	132	0.421
	China	662	1.915
	India	188	0.637
	Mexico	109	0.741
	Poland	126	1.889

Note: n.a. = no available data for GDP

Source: Bank Economic and Social Database (BESD)

TABLE 6

Energy Intensities for Selected Developed Countries
1971 - 1989

Year	Country	Energy Consumption (mtoe)	Energy Consumption (kgoe/US$ of GDP at 1987 prices)
1971	France	164	0.274
	Germany	239	0.299
	Japan	295	0.243
	United Kingdom	217	0.448
	United States	1,617	0.558
1978	France	199	0.267
	Germany	279	0.291
	Japan	348	0.208
	United Kingdom	214	0.375
	United States	1,827	0.506
1982	France	189	0.232
	Germany	256	0.254
	Japan	344	0.175
	United Kingdom	197	0.342
	United States	1,672	0.457
1987	France	207	0.234
	Germany	277	0.248
	Japan	395	0.166
	United Kingdom	217	0.317
	United States	1,771	0.394
1989	France	212	0.223
	Germany	266	0.223
	Japan	428	0.163
	United Kingdom	212	0.288
	United States	1,948	0.406

Source: Bank Economic and Social Database (BESD)

Relative Contributions to Global Warming

Sector	CO_2	CH_4	Ozone	N_2O	CFC	Percent Warming
Energy	35	3	6	4	n.a.	49
Deforestation	10	1	n.a.	n.a.	n.a.	14
Agriculture	3	4	n.a.	2	n.a.	13
Industry	2	n.a.	2	n.a.	20	24
Percent Warming by Each Gas	----- 50	----- 16	----- 8	----- 6	----- 20	----------- 100

Source: World Resources Institute, *World Resources 1990-91*, Table 2.4.

Costs of Environmental Control Technologies on Steam Plants (1987 US mills/kWh)

	Coal	Oil	Gas
FGD			
(Capital Cost, $/kW)	(150)	(135)	(0)
Capital	2.72	2.45	-
Operating Variable	0.39	0.60	-
Operating Fixed	1.71	1.54	-
Subtotal	4.82	4.59	0
SCR			
(Capital Cost, $/kW)	(55)	(32)	(15)
Capital	1.00	0.58	0.27
Operating Variable	0.47	0.51	0.49
Operating Fixed	2.61	0.81	0.35
Subtotal	4.07	1.90	1.11
CC			
(Capital Cost, $/kW)	(10)	(10)	(10)
Capital	0.18	0.18	0.18
Operating Variable	-	-	-
Operating Fixed	-	-	-
Subtotal	0.18	0.18	0.18
FGD, SCR, CC			
(Capital Cost, $/kW)	(215)	(177)	(25)
Capital	3.90	3.21	0.45
Operating Variable	0.86	1.11	0.49
Operation Fixed	4.32	2.35	0.35
	----	----	----
TOTAL	9.08	6.67	1.29

Source: International Energy Agency, *Emission Controls in Electricity Generation and Industry*, OECD, 1988 (Pages 110, 111 and Table A-6).

Comparison of Thermal Power Plants

Plant Type	Capital Cost (US$/kW)	SO_2 (mg/kWh)	NO_x (mg/ MMBTU)	CO_2 (kg C /kWh)	Efficiency (%)
Gas steam	760	trace	180	.14	36
Coal steam (with scrubber)	1,600	600	300	.25	34
Gas combined cycle	520	trace	15	.10	47
Coal combined cycle (with gasification)	1,700	60	25	.20	42
Coal PFBC (with combined cycle)	1,200	600	60	.19	42
Gas STIG	410	trace	15	.12	40
Coal STIG (with gasification)	1,300	60	25	.24	36
Gas ISTIG	400	trace	10	.10	47
Coal ISTIG (with gasification)	1,030	60	20	.20	42

Notes: The SO_2 emissions per kWh depend on the sulphur content of the particular coal and vary widely. The figures shown for SO_2 emissions in the Table are representative only, and correspond to 90% SO_2 reduction for coal steam and PFBC plants using typical coal; and 99% SO_2 reduction for coal combined cycle, STIG and ISTIG plants.

PFBC = Pressurized fluidized-bed combustion
STIG = Steam-injected gas turbine
ISTIG = Intercooled steam-injected gas turbine

Source: "Energy from Fossil Fuels," *Scientific American*, September 1990, (Page 133).

Fuel Price Elasticities for Selected Countries

	(1) Argentina S-R	(1) Argentina L-R	(2) Brazil S-R	(2) Brazil L-R	(3) India S-R	(3) India L-R	(4) Pakistan S-R	(5) Thailand S-R	(6) Philippines S-R	(7) Mexico S-R	(7) Mexico L-R	(8) OECD L-R
Petroleum Products			-0.15	-0.82		-0.10					-0.60	-0.45
Gasoline			-0.32	-1.00	-0.27		-0.10	-0.35	-0.40			
Regular	-0.22	-1.38										-2.12
Premium	-0.10	-0.50										
Kerosene	-0.24	-1.52	-0.11	-0.28	-0.10		-0.15	-0.20	-0.09			
Gas Oil	-0.06	-0.47										
Diesel	-0.81	-0.80	-0.09	-0.24	-.25 to-.10		-0.07	-.23 to-.14	-.29 to-.14			
Fuel Oil	-0.38	-0.77	-0.30	-0.97	-0.15		-0.10	-0.20	-0.32			-1.31
LPG	-0.07	-0.12	-0.10	-0.44	-.01 to-.10			-.10 to-.15	-.10 to-.15			-1.42
Jet Fuel					-0.23		-0.30	-0.30	-0.28			
Natural Gas			-0.30	-0.60								-0.69
Residential/Comm.	-.10 to-.21	-.21 to-.39					-0.10					
Industrial	-0.18	-0.23			-0.15		-0.10	-0.10	-0.10			-1.13
Electricity			-0.20	-0.83		-0.21						-0.45
Residential	-.05 to-.80	-.07 to-.19	-0.02	-0.22	-0.05	-0.22	-0.05	-0.18	-0.15	-0.11	-0.23	
Industrial	-0.15	-.42 to-.56	-0.22	-0.60	-0.18	-0.14	-0.07	-0.15	-0.18	-0.05	-0.38	-0.47
Commercial			-0.03	-0.26						-0.02	-0.13	
Agric./Rural					-0.20	-0.20		-0.20	-0.20	-0.01	-0.15	
												-1.39
Coal						-0.20						
Residential					-0.20	-0.18						
Industrial					-0.15	-0.15	-0.07	-0.15	-0.15			-1.29
Transportation					-0.32	-0.32						
Alcohol			-0.32	-1.00								

Sources and Notes: S-R = Short-run; L-R = Long-run

(1) World Bank data

(2) World Bank data

(3) M. Imran (World Bank) (S-R).
N.D. Uri, "Energy Demand and Interfuel Substitution in India," *European Economic Review*, Vol. 12, 1979 (L-R).
Figures for electricity (L-R) are somewhat higher in London Economics, *India: Long-Term Issues in the Power Sector*, 1991, Annex 9, Table 9.3.3, as follows: residential, -0.35; industrial, -0.50; commercial -0.35; agricultural, -0.25.

(4), (5) & (6) M. Imran (World Bank).

(7) World Bank data
T. Sterner, "Factor Demand and Substitution in a Developing Country: Energy Use in Mexican Manufacturing," *Scandinavian Journal of Economics*, Vol. 91, No. 4, 1989 (for petroleum products).

(8) V.B. Hall, "Major OECD Country Industrial Sector Interfuel Substitution Estimates, 1960-1979," *Energy Economics*, April 1986.
D. Conniffe and S. Scott, *Energy Elasticities: Responsiveness of Demands for Fuels to Income and Price Changes*, The Economic and Social Research Institute, Dublin, 1990.
M. A. Fuss, "The Derived Demand for Energy in the Presence of Supply Constraints," in *Energy Policy Modeling: United States and Canadian Experiences*, Vol. I, W.T. Ziemba, S.L. Schwartz and E. Koenigsberg (eds.), Vol. 1, Boston, 1980.
The estimates are for Ireland and Japan (overall petroleum products); U.S.A., Ireland and U.K. (average) (natural gas); Ontario (industrial gas); Ireland (overall electricity); Ontario, U.S.A., Japan and France (average) (industrial electricity); Ireland (overall coal); U.S.A. and Ontario (industrial coal).

Electricity Price Elasticities for Selected Countries

		Residential		Commercial		Industry	
		S-R	L-R	S-R	L-R	S-R	L-R
(1) Costa Rica			-0.50		-0.50		
(2) Paraguay			-0.50		-0.50		
(3) Columbia						-0.25	
(4) Dominican Republic			-0.50		-0.45		-0.65
(5) Mexico			-0.47				
(6) U.S.A.							
(i)		-0.21	-1.22	-0.52	-1.47	-0.37	-1.33
(ii)			-0.83		-0.54		-0.65
(iii)			-1.15		-0.96	-1.77	-1.64
(iv)			-0.97	-0.07	-0.67	-0.53	-1.00
(v)		-0.42	-0.59	-0.47	-1.32		
(vi)		-0.07	-0.81				
(vii)			-0.73				
(viii)		-0.81	-0.81				
(ix)		-0.33	-1.50				
(x)	(a)	-0.14	-0.43				
	(b)	-0.19	-0.58				
(xi)		-0.19	-1.40				
(xii)		-0.09	-1.21				
(xiii)		-0.12	-0.73				
(7) U.K.		-0.11	-1.30				
Mean		-0.28	-0.97	-0.35	-0.99	-0.89	-1.16

Notes:

S-R = Short-run
L-R = Long-run

(x) (a) = all househoulds (urban and rural).

(x) (b) = households served by Rural Electric Cooperatives.

Sources: All information in the Table is taken from Glenn D. Westley, "The Demand for Electricity in Latin America: A Survey and Analysis," *Papers on Project Analysis No. 35*, Inter-American Development Bank, February 1989. The references he provides are:

(1) G. Westley, "The Residential and Commercial Demand for Electricity in Costa Rica", *Papers on Project Analysis No. 24*, IDB, 1984.

(2) G. Westley, "The Residential and Commercial Demand for Electricity in Paraguay", *Papers on Project Analysis No. 19*, IDB, 1981.

(3) Econometría Limitada, "C. Sector Industrial", Unpublished, 1982.

(4) G. Westley, "An Aggregate Time Series Study of Sectoral Electricity Demand in the Dominican Republic", *Papers on Project Analysis No. 25*, IDB, 1984.

(5) E. Berndt and R. Samaniego, "Residential Electricity Demand in Mexico: A Model Distinguishing Access from Consumption", *Land Economics*, Vol. 60, No. 3, 1984.

(6) (i) T.D. Mount, L.D. Chapman and T.J. Tyrell, "Electricity Demand in the United States: an Econometric Analysis", National Technical Information Service No. ORNL-NSF-EP-49, Springfield, Virginia, 1973.

(6) (ii) D. McFadden and C. Puig, "Economic Impact of Water Pollution Control on the Steam Electric Industry", Ch. 3, Report EED-12, Tenekron Inc., Berkely, California, 1975.

(6) (iii) R. Halvorsen, "Residential Demand for Electric Energy", *The Review of Economics and Statistics*, Vol. 57, No. 1, 1975.

(6) (iv) R. Halvorsen, "Demand for Electric Energy in the United States", *Southern Economic Journal*, Vol. 42, No. 4, 1976.

(6) (v) G.S. Gill and G.S. Maddala, "Residential Demand for Electricity in the TVA Area: an Analysis of Structural Change", *Journal of the American Statistical Association*, Proceedings of the Business and Economic Statistics Section, 1976.

(6) (vi) L.D. Taylor, G.R. Blattenberger and P.K. Verleger, Jr., *The Residential Demand for Electricity*, Vol. 1, Electric Power Research Institute, No. EA-235, Palo Alto, California, 1977.

(6) (vii) D. McFadden, C. Puig and D. Kirshner, "Determinants of the Long-Run Demand for Electricity", *Journal of the American Statistical Association*, Proceedings of the Business and Economic Statistics Section, Part 2, 1977.

(6) (viii) M.P. Murray, R. Spann, L. Pulley and E. Beauvais, "The Demand for Electricity in Virginia", *The Review of Economics and Statistics*, Vol. 60, No. 4, 1978.

(6) (ix) W.S. Chern and R.E. Just, "Assessing the Need for Power: A Regional Econometric Model", *Energy Economics*, Vol. 4, No. 4, 1982.

(6) (x) R. Maddigan, W. Chern and C.G. Rizy, "Rural Residential Demand for Electricity", *Land Economics*, Vol. 59, No. 2, 1983.

(6) (xi) C. Garbacz, "A Model of Residential Demand for Electricity Using a National Household Sample", *Energy Economics*, Vol. 5, No. 2, 1983.

(6) (xii) G.R. Blattenberger, L.D. Taylor and R.K. Rennhack, "Natural Gas Availability and the Residential Demand for Energy", *The Energy Journal*, Vol. 4, No. 1, 1983.

(6) (xiii) W. Chern and H. Bouis, "Structural Changes in Residential Electricity Demand", *Energy Economics*, Vol. 10, No. 3, 1988.

(7) H.S. Houthakker, "Some Calculations on Electricity Consumption in Great Britain", *Royal Statistical Society Journal*, Series A, 114, Part III, 1951.

Price Cross-Elasticities for Selected OECD Countries

To Prices of: *Response of:*	*Petroleum Products*	*Gas*	*Coal*	*Electricity*
Petroleum Products	-	0.22 (Ireland) -0.53 (USA) -1.09 (Japan) -0.51 (France)	-0.79 (USA) -0.54 (UK)	1.34 (USA) 0.95 (Japan)
Gas	-0.68 (France) -0.89 (Argentina-fuel oil only)	-	0.50 (France) 1.22 (UK) 0.39 (Ontario) 0.49 (Ireland)	-0.09 (Ontario) 2.96 (Germany) 1.00 (Japan) 0.68 (Canada)
Coal	0.82 (Japan) 0.92 (Ireland)	1.01 (Ontario) 0.34 (UK) 0.41 (Canada) 2.52 (Japan) 0.43 (France) -0.54 (Ireland)	-	-1.83 (Japan) 0.80 (France) -0.12 (Ontario)
Electricity	0.24 (Ireland) -0.13 (USA) 0.10 (Japan) 0.06 (Italy) -0.11 (Canada)	0.26 (USA) 0.28 (Japan) 0.19 (France) -0.04 (Ontario) -0.11 (Ireland)	-0.03 (Ontario) 0.16 (USA) 0.07 (France) 0.13 (Canada)	-

Sources and Notes:

The Ontario estimates are arc elasticities

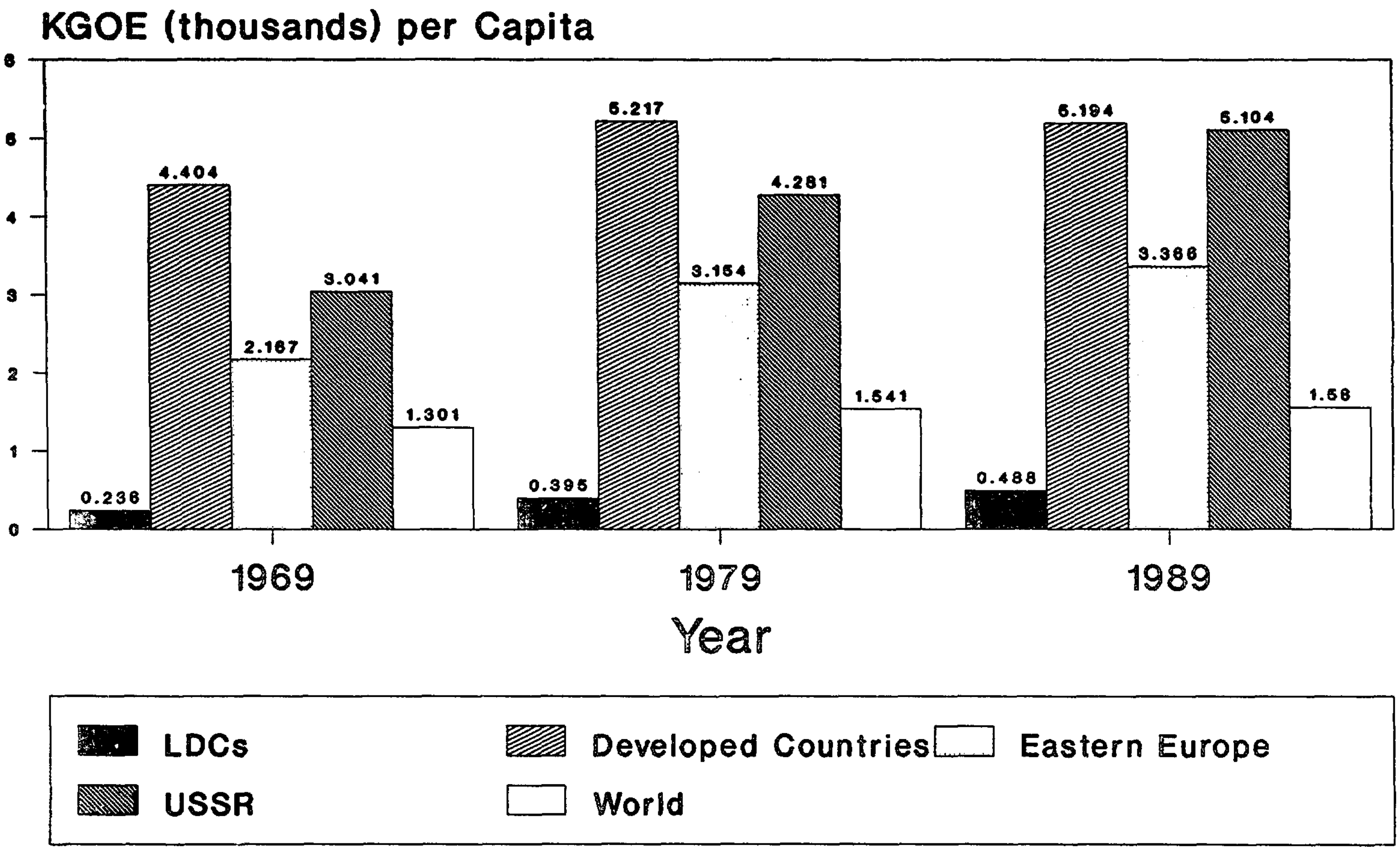
V.B. Hall, "Major OECD Country Industrial Sector Interfuel Substitution Estimates. 1960-1979," *Energy Economics*, April 1986. (Other than Ontario).

M.A. Fuss, "The Derived Demand for Energy in the Presence of Supply Constraints," in *Energy Policy Modeling: United States and Canadian Experiences*, W.T. Ziemba, S.L. Schwartz and E. Koenigsberg (eds.), Vol. 1, Boston, 1980. (Ontario).

D. Conniffe and S. Scott, *Energy Elasticities: Responsiveness of Demands for Fuels to Income and Price Changes*, The Economic and Social Research Institute, Dublin, 1990.

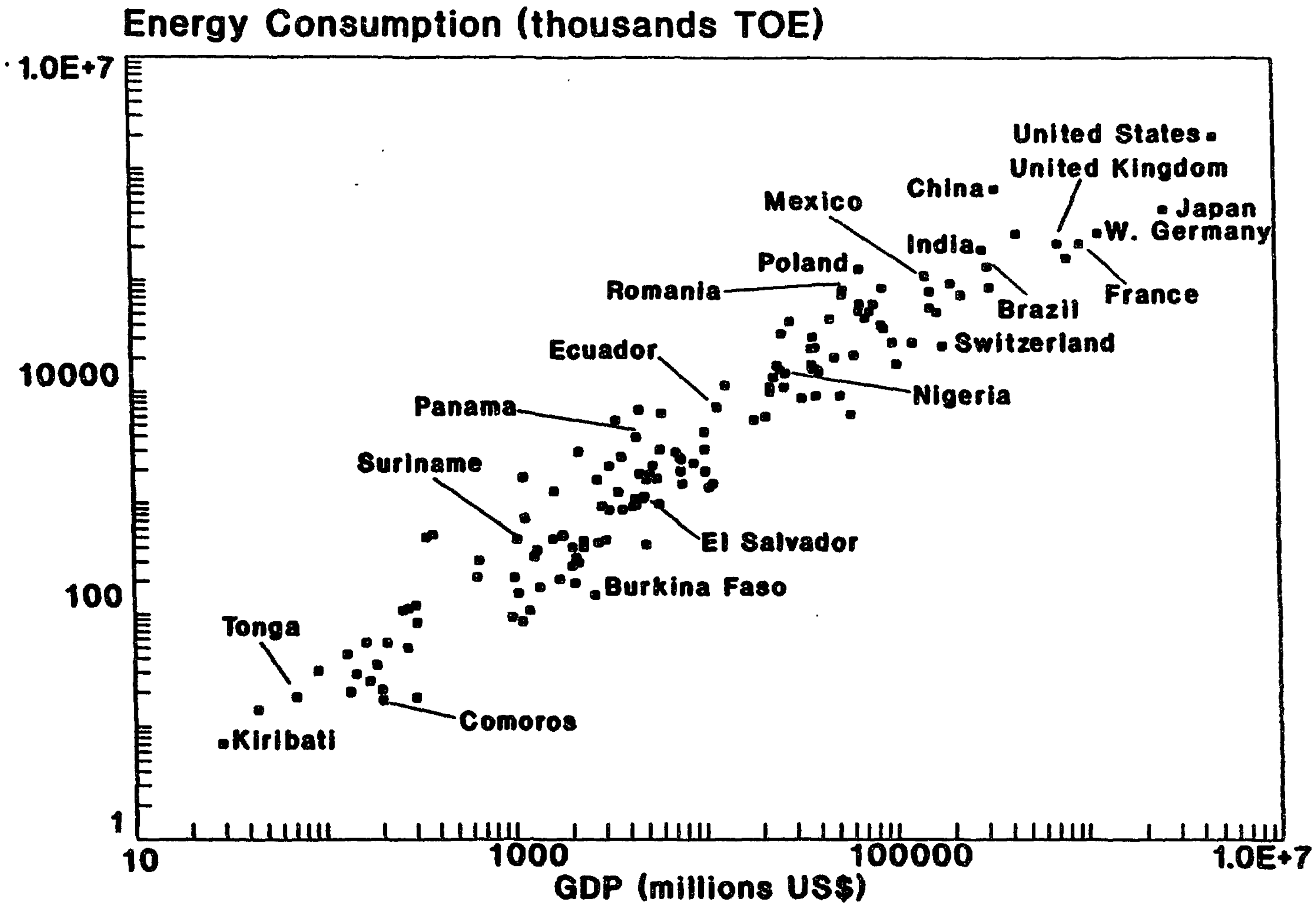
Energy Consumption Per Capita

1969 to 1989



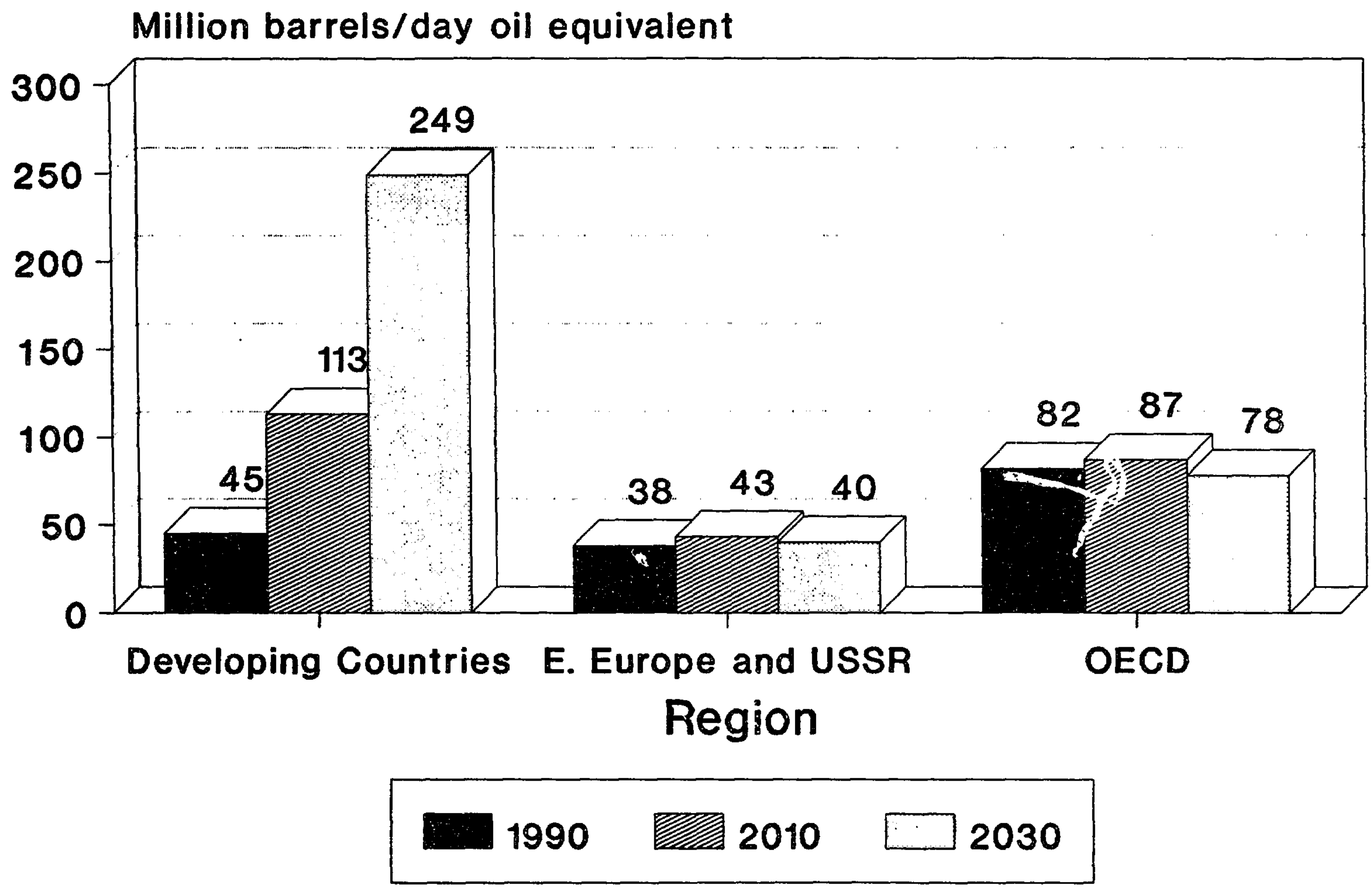
Source: The World Bank

TOTAL ENERGY CONSUMPTION AND GDP
1989



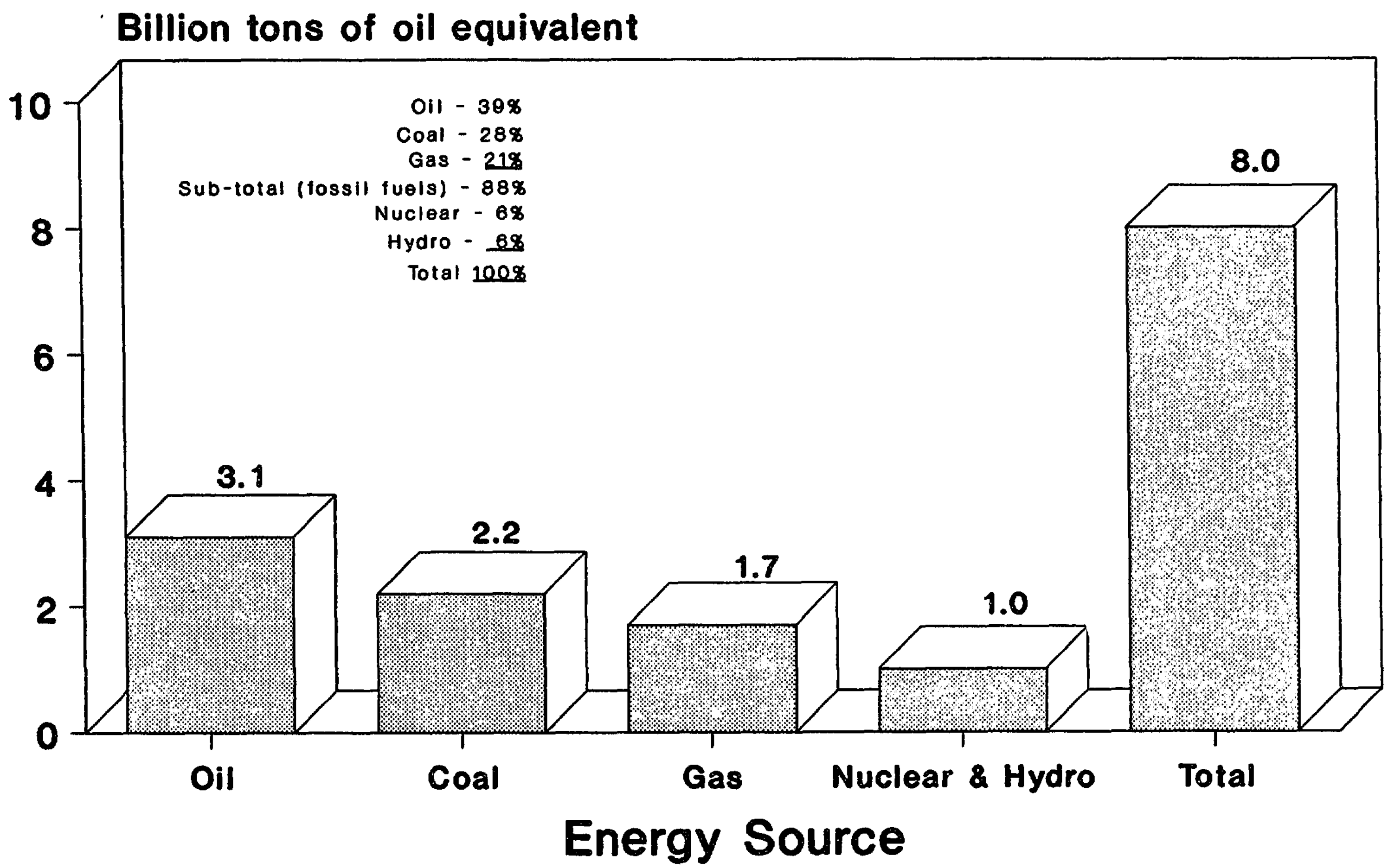
Source: The World Bank

An "Energy Efficient" Demand Scenario 1990 to 2030



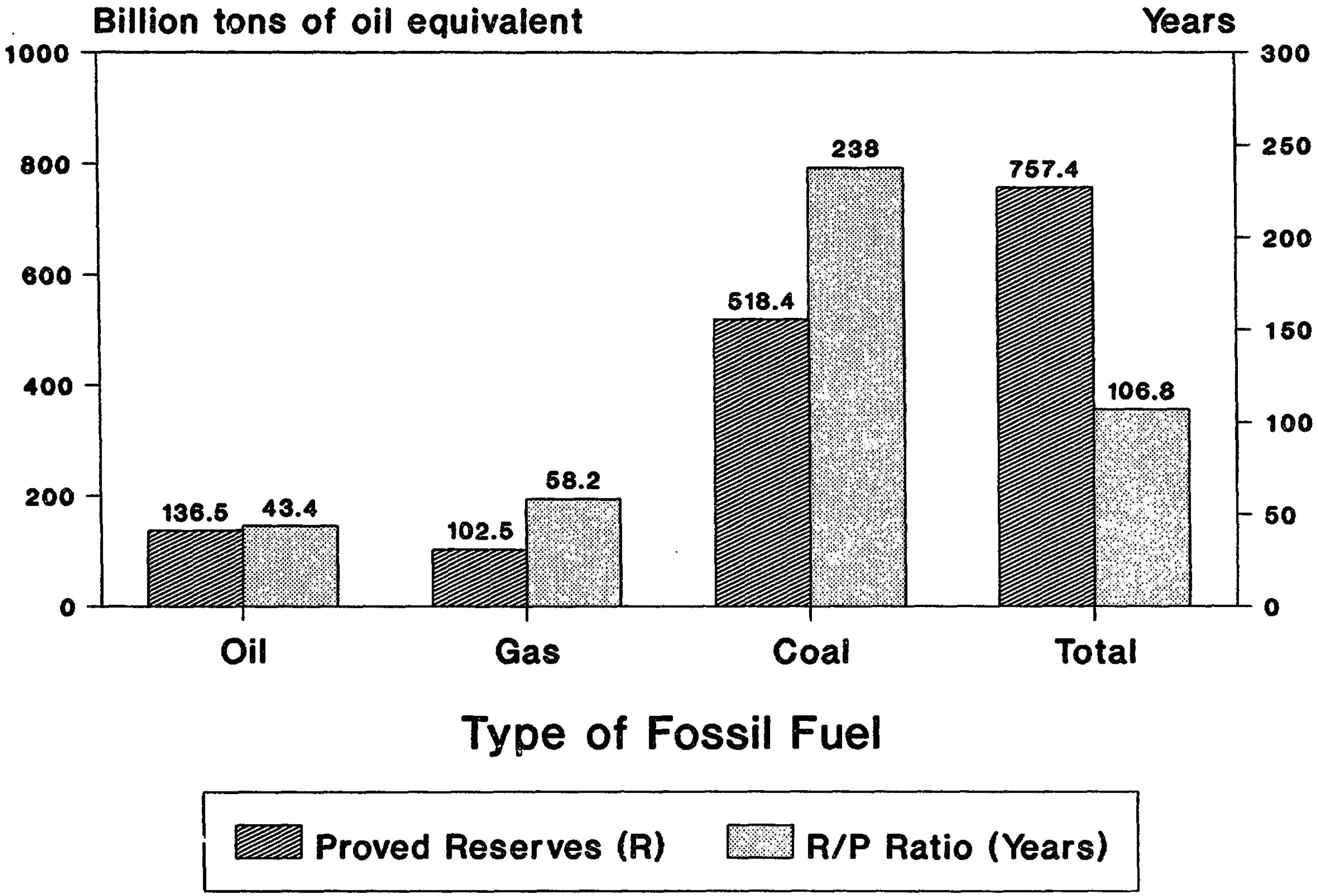
Source: Dennis Anderson, Energy and the Environment - *An Economic Perspective on Recent Technical Developments and Policies*, The Wealth of Nations Foundation, Special Briefing Paper No. 1, May 1991.

World Energy Supply
1990



Source: *B.P. Statistical Review of World Energy*, June 1991.

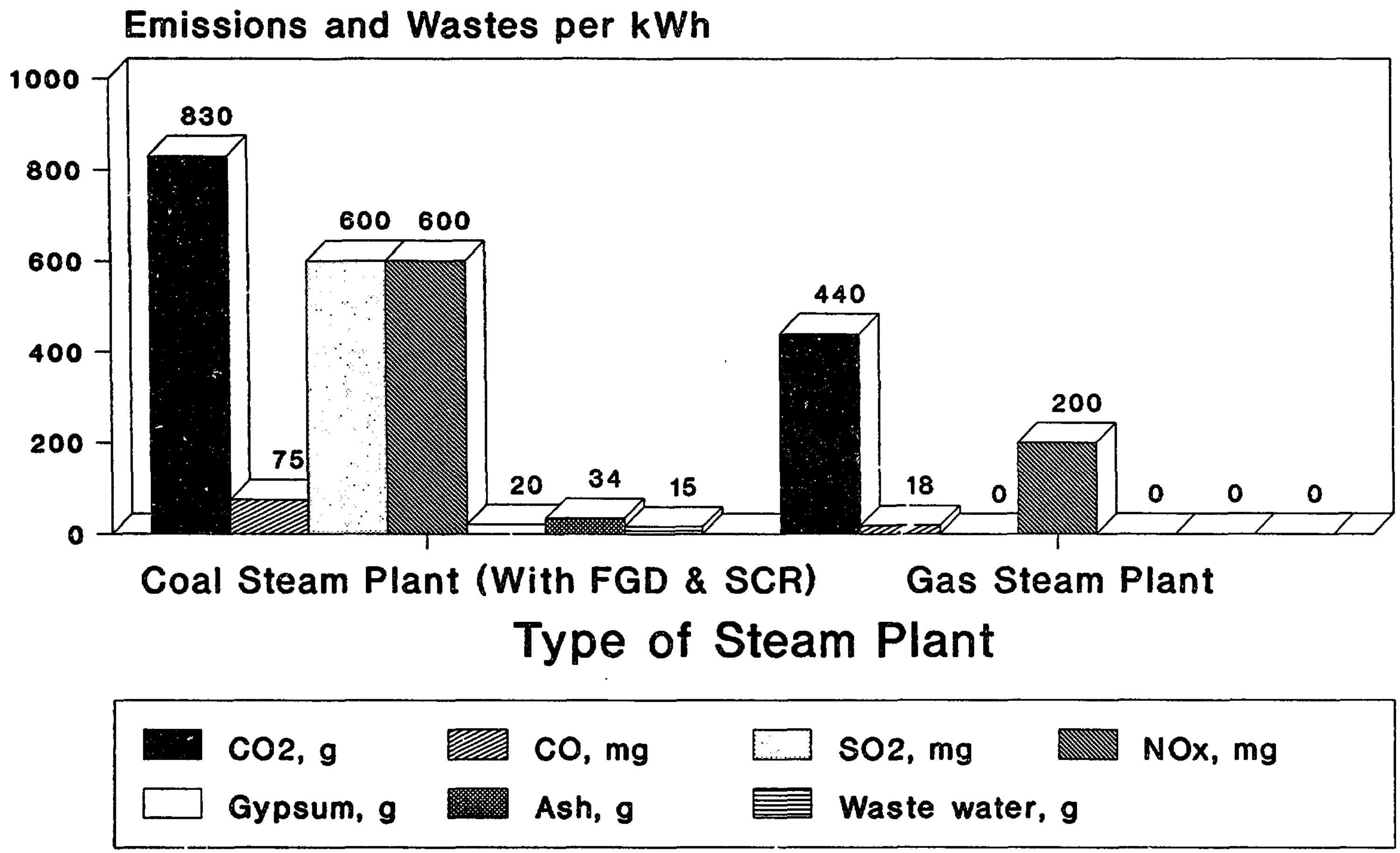
World Fossil Fuel Reserves and Production 1990



Source: *B.P. Statistical Review of World Energy*, June 1991.

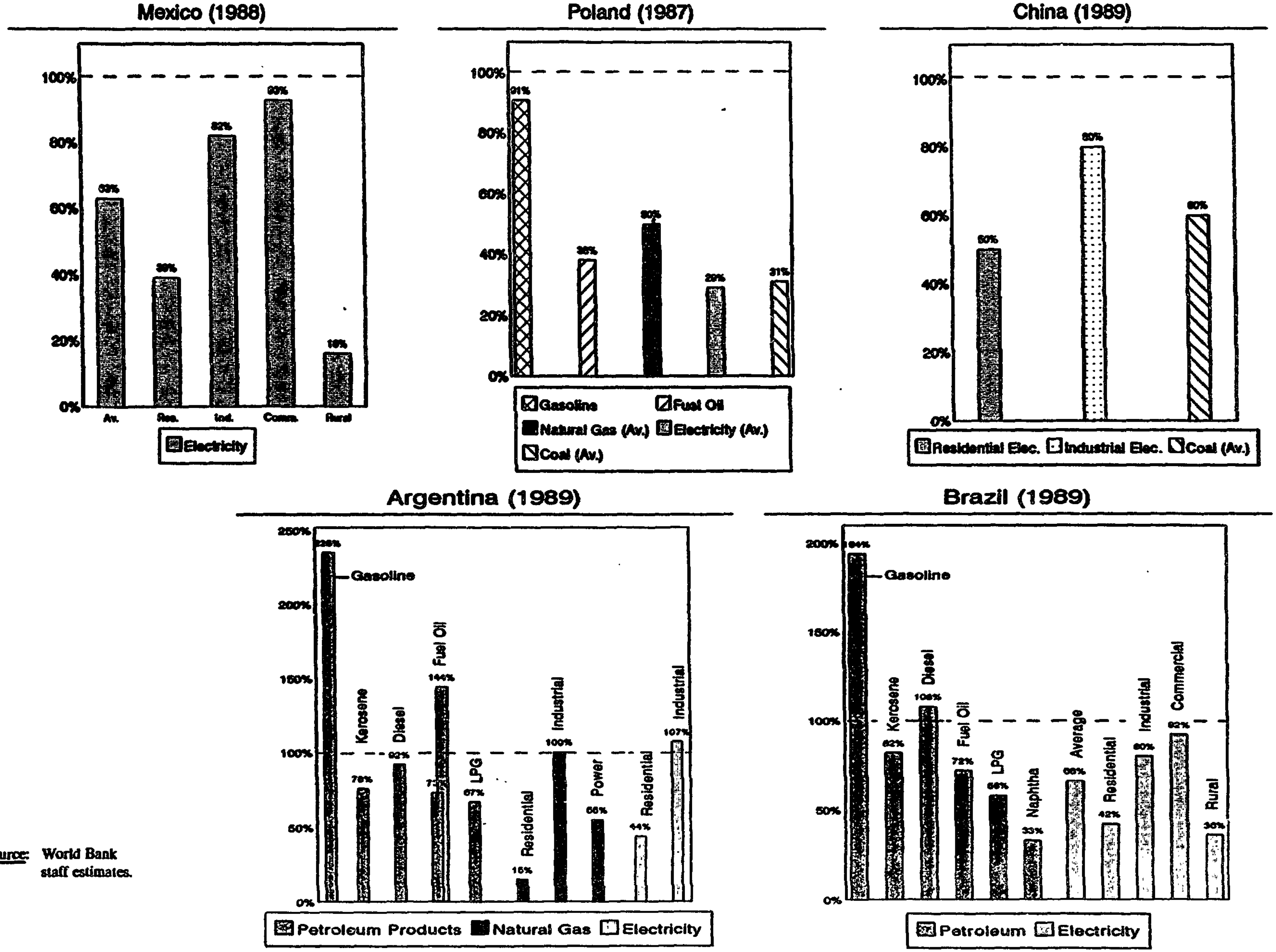
FIGURE 6

Emission Comparison of Coal- and Gas-Fired Steam Plants



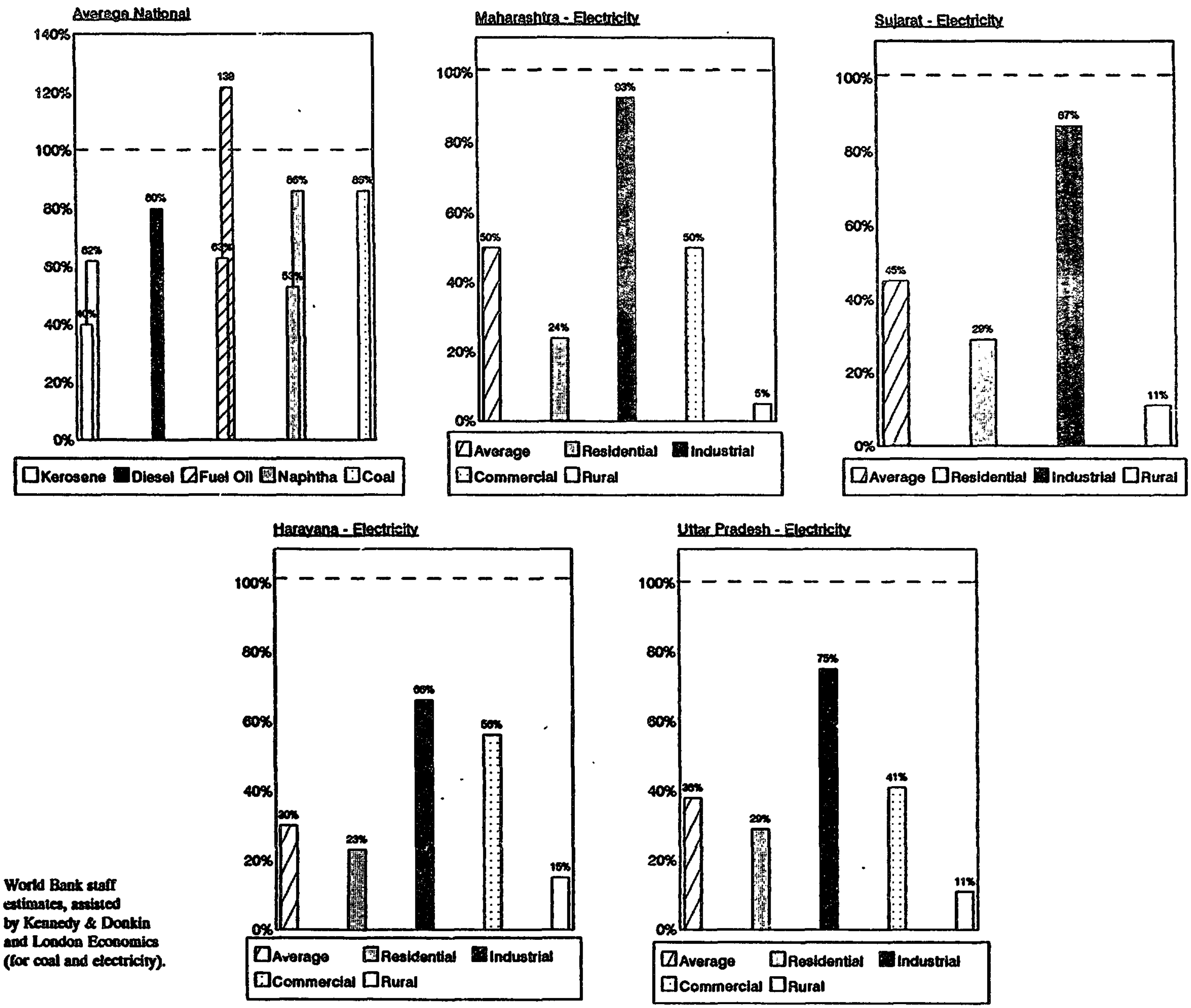
<u>Source</u>: "Combined Cycles Permit the Most Environmentally Benign Conversion of Fossil Fuels to Electricity," *ASME Paper 90-GT-0367*, June 1990, by Siemens AG-kWU Group.

Figure 7. Ratio of Retail Prices to Economic Costs for Fuels in Selected Countries



Source: World Bank staff estimates.

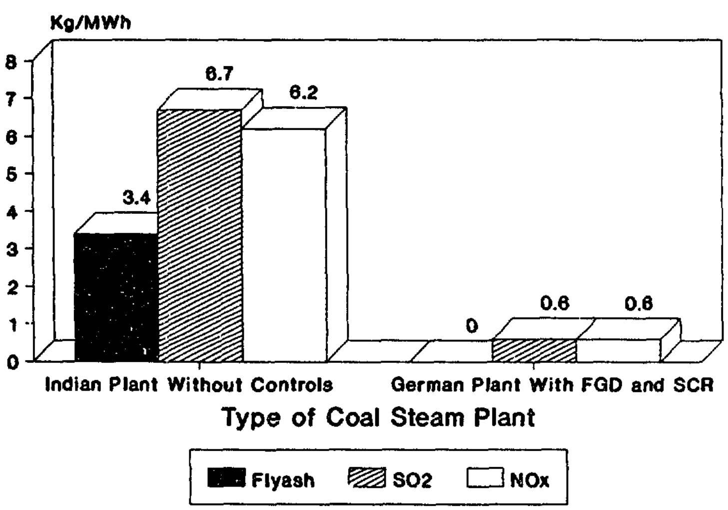
Figure 8. Ratio of Retail Prices to Economic Costs for Fuels in India (1991)

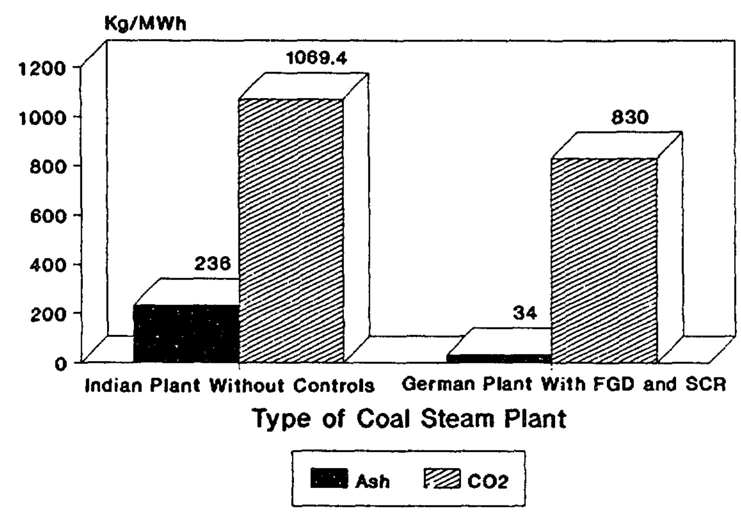


Source: World Bank staff estimates, assisted by Kennedy & Donkin and London Economics (for coal and electricity).

FIGURE 9

Comparison of Indian and German
Coal Steam Plant Emissions





Source: ASME Paper 90-GT-367, 1990 and London Economics 1991 Paper on Power Sector Issues.

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