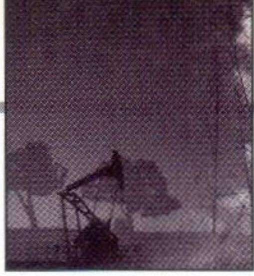

Energy and the Environment: Technical and Economic Possibilities

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Total energy consumption in developing countries is expected to soar over the next few decades. But this does not necessarily bode ill for the environment. Technological advances are making it possible to reduce pollution considerably, even as energy use increases.

DEVELOPING countries will soon be the world's largest markets for energy. Their total energy consumption today is only half that of the rich countries—and their per capita energy consumption a mere one-tenth of what it is in the rich countries—but it is doubling every 15 years and is expected to increase fivefold over the next three decades or so in the course of economic growth. This projection assumes significant improvements in energy efficiency, without which the increase could be higher yet. Moreover, even with an increase of this magnitude, per capita energy consumption in the developing countries would still be relatively low—allowing for population growth, it would be less than one-fourth of per capita energy consumption in the industrial countries today.

Will developing countries be able to increase energy use while reducing pollution? From a technical and an economic perspective, the answer is yes, if the environmental policies required are put in place. It is possible to reduce pollution by factors of 10 or more in the most serious cases, even if energy consumption levels rise fivefold. Furthermore, developing countries would find themselves better off both economically and environmentally.

A basic identity

Let us recall a basic identity relating pollution to energy use:

Emissions of pollutants = [energy use] x *[emissions per unit of energy use]*

In every country, opportunities to reduce energy use through efficiency improvements can always be found. Decreasing the subsidies—common in many countries—for fossil fuels and electricity production would reduce both physical and economic waste, as would innovations that improve the efficiency with which energy is used in factories, commercial establishments, homes, electricity production, and transport. In electricity production alone, the amount of fossil fuels needed to generate a kilowatt-hour has declined by 90 percent over the past hundred years, almost entirely because of technical advances that increased the thermal efficiency of power stations. Yet demand for electricity doubled every decade for more than 70 years, partly because energy efficiency also reduced costs and prices. The demand for energy in developing countries is highly income elastic: per capita income elasticities for the consumption of electricity, for example, are currently 2.0 or higher. Also, more than 2 billion people are still without (or are unable to afford) electricity, oil, or gas for domestic purposes. As incomes rise in developing countries, energy use can be expected to increase appreciably, even with continued gains in efficiency.

Hence we need to turn our attention to the second term on the right-hand side of the equation—emissions per unit of energy use. The evidence that these can be reduced is encouraging. Data on the emissions intensities of technically proven low-polluting practices relative to the emissions intensities of practices still in widespread use in developing countries are presented in the table. The pollution indexes show how large the scope for improvement is in four key areas:

- ***Household fuels.*** The pollution from smoke and the damage to natural resources (e.g., soil depletion and erosion) caused by the use of fuelwood and dung for cooking.
- ***Electricity production.*** Particulate matter emissions and acid deposition from the use of coal.
- ***Motor vehicles.*** A range of tailpipe emissions from diesel and gasoline engines.
- ***All fossil fuels.*** Carbon dioxide (CO_2) emissions and climate change.

The striking feature of the low-polluting practices listed is that emissions (or erosion, in the case of soils), with the partial exception of nitrogen oxides (NO_x), can be reduced to very low levels, often to one-hundredth or less of emissions levels resulting from polluting practices. Even if energy use

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Low-polluting technologies are available

Relative pollution intensities of polluting and low-polluting practices for selected activities and pollutants
(polluting practice = 100)

Source and type of emissions or environmental damage	Index per unit of output: Polluting	Index per unit of output: Low-polluting	Low-polluting practices
Household fuels			
Smoke from firewood, dung	100	0.0	Gas, kerosene
		<1 to 5	Stoves with flues
Soil erosion (sediment yield)	100	<1 to 5	Agroforestry; erosion-prevention practices such as contouring, mulching, use of vetiver grass, "no till" agriculture
Electricity production			
Particulate matter	100	<0.1	Natural gas; clean coal technologies;
Carbon monoxide (CO)	100	<0.1	scrubbers; low-sulfur fuels;
Sulfur dioxide (SO_2)	100	0 to <5	low NO_x combustion methods;
Nitrogen oxides (NO_x)	100	5 to 10	emission control catalysts
Motor vehicles: diesel engines			
Particulate matter	100	<10	Clean fuels and particulate traps
Sulfur dioxide (SO_2)	100	5	Low-sulfur fuels
Motor vehicles: gasoline engines			
Lead	100	0	Unleaded and reformulated fuels; catalytic converters
Carbon monoxide (CO)	100	5	
Nitrogen oxides (NO_x)	100	20	
Volatile organic compounds	100	5	
All fossil fuels			
Carbon dioxide (CO_2)	100	<0[1]	Renewable energy sources

Sources:
Energy-related pollution. Smith (1988) for household fuels. For electricity production, gasoline and diesel engines, CO_2 emissions, and marine pollution (oil), a review of technologies and evidence of pollution abatement are provided in Anderson (1991), drawing on Organization for Economic Cooperation and Development (1989), Asian Development Bank (1991), and Bates and Moore (1992). The possible negative figure for CO_2 emissions could be realized by using biomass—especially wood—as an energy source in a renewable way, since this would be associated with an increase of carbon storage.
Soil erosion. Site-specific evidence (for over 200 cases) of erosion with and without the erosion control methods noted is presented in Doolette and Magrath (1990). The decreases in erosion rates shown here are based on their data for 11 cases in Taiwan Province of China and correspond to the best agronomic (but not necessarily the most expensive) practices.
[1] Can be negative if biomass (wood) fuels are used.

expands fivefold, therefore, a 90 percent reduction or more is technically feasible in most cases, and a substantial reduction is possible in all cases.

Household fuels

The World Bank's *World Development Report 1992: Development and the Environment* (WDR 1992) noted that studies of smoke from the use of fuelwood and dung ("biofuels") for cooking in rural areas ". . . have found particulate matter levels which regularly exceed by several orders of magnitude the safe levels of WHO [World Health Organization] guidelines. . . . [S]moke contributes to acute respiratory infections that cause an estimated 4 million deaths annually among infants and children. Recurrent episodes of such infections show up in adults as chronic bronchitis and emphysema, eventually contributing to heart failure."

Nearly 2 billion people are dependent on these fuels. The report's conclusion—that indoor air pollution is one of the most severe environmental problems facing low-income developing countries—has not been disputed.

Indoor air pollution could be almost entirely eliminated by substituting gas, kerosene, or electricity for the fuels now used in cooking. Comparisons of fuel use across countries and over time show that a steady transition to cleaner fuels occurs as incomes rise and as industries expand. By the time per capita annual income in a given country has risen to around $1,500, the transition to modern fuels is almost complete. However, no fewer than 70 developing countries with populations totaling 3.5 billion have incomes well below this level and are likely to be dependent on biofuels for cooking for some time. Other measures thus need to be taken in the interim. It has been found, for example, that improved wood stoves with flues not only raise energy efficiency—typically, by 30–50 percent—but also reduce indoor pollution—by a factor of 20 to 100—to levels well within WHO guidelines.

What can be done about the other environmental impacts associated with the widespread use of biofuels, such as soil erosion, the loss of soil nutrients, and deforestation? As indicated in the table, changes in agricultural practices show immense promise, not only for accelerating afforestation and taking pressures off forests and woodlands but also for raising agricultural productivity by reducing soil erosion—in fact, by offering ways to regenerate topsoil—and improving the nutrient and moisture content of soils. Examples are agroforestry practices, contouring, terracing, bunding of fields (that is, creating embankments in them to control the flow of water), and the planting of vetiver grass.

Electricity production

Controls of particulate matter emissions through electrostatic precipitators were pioneered more than 40 years ago in industrial countries and have been widely adopted in new plant since the late 1950s. Emissions have been reduced by two to three orders of magnitude (factors of ten) relative to conventional coal boilers with mechanical controls.

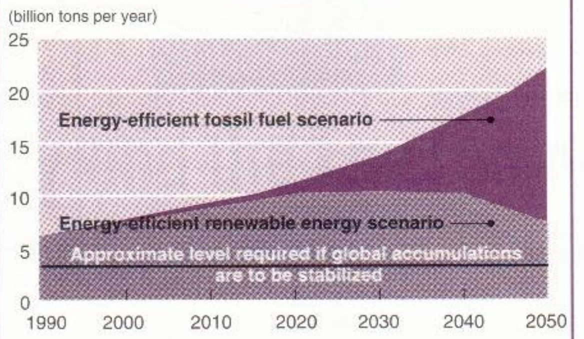
In the 1960s and 1970s, the problem of acid deposition became more widely recognized. Once again, there was an innovative response, this time in the form of flue gas desulfurization, a switch to low-sulfur coals and gas, and, more recently, developments in combustion technologies—often known as "clean coal" technologies—such as fluidized bed and coal gasification. The remarkable growth of commercially proven world gas reserves has also opened up new opportunities for a very low-polluting and efficient means of electricity generation. Abatement levels of 95 percent for sulfur dioxide (SO_2) are now feasible—and even of 100 percent, if gas is available. For NO_x, abatements of around 90 percent are feasible using catalysts and by changing boiler designs to reduce combustion temperatures.

Motor vehicles

In terms of the most harmful tailpipe emissions of local pollutants—particulates, lead, carbon monoxide, volatile organic compounds, and nitrous oxides—the story is roughly the same as for coal-fired plants for electricity generation. The rich countries have already greatly reduced emissions through the technologies now in use, mainly unleaded and reformulated gasolines and tailpipe controls. Urban air pollution in developing countries could be substantially reduced through application of these technologies.

There is, however, a major qualification—the effects of traffic congestion. Vehicle emission standards are usually based on "stationary tests." But emissions rise rapidly when vehicles accelerate, stand in traffic, and make frequent stops and starts—in short, when there is traffic congestion. In addition, the accumulation of pollutants in the atmosphere is the source of the damage, rather than the emissions per se. Thus, the picture is not quite as rosy as the data in the table suggest. However, we do know that pollution from lead in fuels can be eliminated; there has been a major improvement in industrial countries, compared with most developing countries, where reformulated gasolines and tailpipe controls are not in widespread use. Progress in reducing urban pollution from motor vehicles will therefore depend greatly on traffic management, congestion pricing, and urban transport policies, as well as on the introduction of reformulated fuels and tailpipe controls.

Chart 1
Global carbon emissions under two scenarios



Source: Anderson (1991), (1994).

Global warming

More than 90 percent of the world's primary commercial energy demands are met by fossil fuels, 7 percent by nuclear power, and 3 percent by hydroelectricity. Noncommercial traditional fuels—fuelwood, crop wastes, and animal dung—add another 10–15 percent to primary energy supplies. On current trends, the share of fossil fuels in total energy consumption seems likely to rise further for four reasons: the growth of commercially proven reserves; technical progress in extracting and using fossil fuels, and, thus, lower costs; the substitution of fossil fuels for wood and dung for cooking; and the relatively high costs and environmental problems associated with nuclear power. Will global warming change the situation? Are alternatives to fossil fuels emerging should there be a need for them?

Despite the uncertainties about global warming and its possible consequences, we do know that it will not be possible to prevent the accumulation of carbon in the atmosphere unless noncarbon (or non-net-carbon-emitting) alternatives become available. Improving energy efficiency will help and is important for economic as well as environmental reasons, but it will not prevent carbon accumulations from growing exponentially or indefinitely, so long as carbon emissions from the burning of fossil fuels exceed 2–3 billion tons per year—the current estimate of the "natural" net rate of absorption of carbon by the earth's oceans and land masses. Presently, the rate of emissions is around 6 billion tons per year, and emissions are growing almost in direct proportion to world energy demand; it is conceivable that emissions will exceed 10 billion tons in 20 years, and 20 billion tons in 50 years—and this would be in an energy-efficient world.

> ***"The main barriers to pollution abatement are policies and attitudes."***

Alternative technologies are emerging, however (Chart 1). These technologies are based on direct solar energy—primarily photovoltaics and solar-thermal schemes for power generation—or on other renewable energy sources such as wind and biomass. (See K. Ahmed and D. Anderson, "Where We Stand With Renewable Energy," *Finance & Development*, June 1993; Jennings, 1995; and World Energy Council, 1993.) To the list should be added geothermal resources, which hold considerable promise. These technologies have a number of attractive features:

• ***Potential for further development.*** Although already proven, they are a new industry and fertile ground for innovation and discovery. Costs continue to decline, and there is a rapidly growing market for solar and solar-derived technologies in developing countries. Private industry is especially active in their development.

• ***Modularity.*** All of these technologies can be designed for small or large-scale uses.

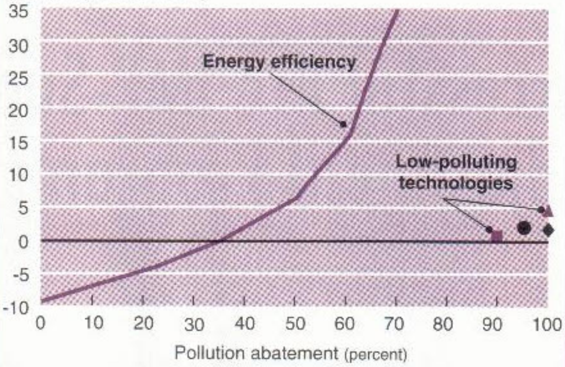
• ***Short lead times.*** Installation takes months, rather than years.

• ***Low land requirements*** (except for biomass). It has been estimated that the developing countries could meet all of their current and future energy needs with solar energy, using an area amounting to only 5 percent or less of the land now being used for crops agriculture. Moreover, unused areas are often the best locations.

A hurdle still to be overcome is the cost of storage. In the case of solar and wind energy, it may be necessary to produce hydrogen through electrolysis and to use fuel cells or combustion to reconvert the hydrogen back into useful energy. Alternatively, solar energy may be stored in other ways: electrically by using batteries (several advanced battery technologies are under development but are still expensive); kinetically (using ultra-high-speed flywheel devices with low-friction bearings); thermally (for example, using molten salts or even metals or heated bricks); thermochemically (using the high temperatures of solar concentrators to create synthetic gases); hydraulically (by pumping water into reservoirs); by the storage of compressed air, which can later be used to drive turbines; or in the form of biomass.

All of these options are under active research, and all are known to work. For example, the Weizmann Institute in Israel has successfully demonstrated an approach in which a synthetic gas is created from methane (CH_4) and carbon dioxide (CO_2) using solar heat. The gas can be stored until needed, when it can be desynthesized in the presence of a catalyst to give off the stored (solar) energy for use in electricity generation; the residuals are the original constituent gases (CH_4 and CO_2). The cycle can be repeated indefinitely.

These developments in solar energy and related storage technologies show much commercial promise. However, most of the world's energy requirements will be met by fossil fuels for some years to come. If renewable energy were to become the primary energy source—for environmental or commercial reasons, or both—the transition would take decades. In this period, the options for using fossil fuels more efficiently and in less polluting ways will be of much importance.



Source: Anderson (1994).

Declining costs

At the time the *WDR 1992* was published, the costs of the low-polluting practices examined in the report were large in absolute terms but quite small in relative terms. For vehicle fuels and emissions controls, for example, they were in the range of 5 to 15 cents per gallon of fuel used, including the annualized capital costs of equipment divided by annual fuel consumption. The report showed that reduction of particulate matter emissions and acid deposition from electricity generation would increase supply costs by about 5–10 percent, but that these costs could be fully offset by the gains in efficiency from the new technologies or if gas were available. For the supply of fuelwood through agroforestry, field studies consistently find that financial rates of return to farmers who introduce more sustainable practices are 15 percent or more. With respect to the global warming problem, it seems that the costs of the noncarbon technologies will be far from prohibitive and may even lead to a (pleasant) economic surprise because of technical advances in solar and solar-derived energy. In general, the costs of addressing environmental problems related to energy production and use have declined since 1992.

For electricity generation, estimates of the marginal costs of abating various pollutants are shown in Chart 2. The negative costs on the left side of the curve represent the economic benefits that would arise from pursuing the "win-win" option of energy efficiency—mainly by eliminating subsidies. To the right are points representing the marginal costs of turning to the low-polluting options. As can be seen, very high levels of abatement can be achieved using the new technologies—probably at a negative overall cost, once the economic benefits of efficiency are taken into account.

Policies

The main barriers to pollution abatement are policies and attitudes, not economics or the availability or costs of low-polluting technologies. The good news is that if appropriate policies are introduced, there will be a response from business and consumers, as in the past. The main policy instruments are familiar: environmental taxes on the main pollutants or sources of pollution; environmental laws and regulations, traditionally the instruments most favored by governments; and, for local pollution, negotiated arrangements, backed by local laws and institutions, between the polluting and polluted parties.

Three other policy instruments tend to receive less attention, but can be just as important in the long term as environmental taxes and laws. First are public and private research and development (R&D) programs—all the developments described above would not have taken place without such programs. Second, technologies need to be demonstrated before they become full-blown marketable propositions, in the present case stimulated by environmental taxes or laws. In this respect, tax incentives and investment grants in recognition of the positive externalities of innovation have a valuable role to play. Third, investment in education and training is crucial. Most people in business and finance are familiar with the technologies and practices already being used, and very often with some of the emerging options. However, significant investments are required to retrain staff and produce new generations of engineers and business leaders familiar with, and willing to invest in, new technologies and practices.

There is every reason to believe that developing countries will be able to increase their energy use in the future while greatly reducing pollution. Energy is an economic "good," not an economic "bad." Technologies and practices capable of addressing the environmental problems arising from energy use are either already available or in development. What is needed is broader recognition of their immense potential for abating pollution and supportive environmental policies based on economic principles. F&D

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