part IV

where do we go from here?

CHAPTER 11

energy and economic prosperity

Dennis Anderson (United Kingdom)

ABSTRACT Energy demand in developing countries will rise enormously as per capita incomes and populations grow. By reference to the situations of people without access to modern energy forms, the chapter shows why energy is an economic 'good', and thus why energy supplies will need to be expanded to meet emerging demands if living standards are to be improved and developing countries are to achieve prosperity. Energy demand in industrialised countries is also likely to remain strong, notwithstanding—and to some extent, because of—continuing gains in the efficiency with which energy is produced and used. Both energy resources and financial resources are amply available to meet market needs.

But will solving the 'pollution problem' from energy use prove too costly from an economic perspective? There is no evidence that it will, and most assessments point to the likelihood of an improvement, not a deterioration, in economic prospects with enlightened environmental policies. Technologies are now available for addressing the most serious forms of local and regional pollution from fossil fuel use, at costs that are small relative to the costs of energy supplies. So there is every reason to be sanguine in this respect. In fact, developing countries are in a position to address their local and regional pollution problems at a far earlier phase of development than were the industrialised countries before them—within the first third of this century if they wish. Furthermore, there are highly promising options for addressing global warming in the long term—renewable energy, hydrogen-related technologies and fuel cells, for example—which could be developed through enlightened research, development, and demonstration policies.

Much therefore will depend on energy and environmental policies. In reviewing the ground rules for such policies, the chapter shows that the aims of developing countries for achieving economic prosperity and of industrialised countries for improving theirs are fully consistent with those of simultaneously meeting rising world energy demand and realising a low-pollution future. ■

> Modern energy forms are often viewed as economic 'bads'. In fact, they are an economic good, capable of improving the living standards of billions of people.

Despite rising energy taxes, demand-side interventions, and supply shortages in many countries, world consumption of commercial energy continues to rise. The increase averages 1.5 percent a year, or 150–200 million tonnes of oil equivalent energy (6.5–8.5 exajoules) a year—an amount equivalent to two-thirds of the annual energy consumption in France or the United Kingdom. Developing countries in Asia, Latin America, the Middle East, and Africa account for most of this growth (table 11.1). In North America, Europe, and Japan energy markets have matured and aggregate growth is low; in the transition economies of the former Soviet Union and Central and Eastern Europe consumption has declined substantially with economic recession and restructuring.

The reasons for the rapid growth of consumption in developing regions are well known. Income elasticities of demand for energy are high, and as per capita incomes grow people want their energy needs met—just as people in industrialised countries did before them. Nearly 2 billion people are without access to modern energy forms such as electricity and gas, while average consumption levels of the 2 billion people who do have access are barely one-fifth of those in the economies of the Organisation for Economic Co-operation and Development (OECD). With population growth, perhaps as many as 6 billion more people will require access to modern forms of energy over the next half century. With successful economic growth—and especially with catch-up in the developing regions—world economic product is set to rise 10-fold or more this century, much as it did in the industrialised countries in the last century. Large increases in world energy demand thus lie ahead in any scenario of economic success. (For further details see the scenarios for the growth of populations, economic output, and energy use in chapter 9.)

TABLE 11.1. PRIMARY ENERGY CONSUMPTION BY REGION, 1987 AND 1997 (EXAJOULES)

Region	1987	1997	Total increase	Annual percentage increase
United States and Canada	86	101	15	1.7
Europe	74	76	2	0.2
Former Soviet Union	58	38	–20	–4.1
South and Central America (including Mexico)	15	20	5	3.4
Middle East	10	15	5	4.6
Africa	8	11	3	3.0
Asia and Pacific (including Japan)	64	101	37	4.8
Total	**315**	**362**	**47**	**1.5**

Note: Converted at the rate of 1 billion tonne of oil equivalent energy = 43.2 exajoules.

Source: BP, 1998.

This chapter provides an economic perspective on the questions posed by the prospective increases in consumption:

- How important is meeting emerging energy demand to the achievement of economic prosperity in all regions of the world in this century? What of the 2 billion people still without access and the demands of new populations—how are their demands to be met, and what would be the economic and environmental consequences of failing to meet them?
- What will be the impact on economic growth of meeting the environmental challenges discussed in chapter 3?
- How, and under what conditions, will market liberalisation, the changing role of government, and globalisation of the energy industry—all inter-related developments—help to meet the challenges of achieving energy market growth, extending services to unserved populations, and solving the environmental problem?
- Modern energy forms are often viewed ad economic 'bads.' In fact, they are an economic good, capable of improving the living standards of billions of people.

Energy consumption and economic well-being

Notwithstanding the historical importance of modern energy forms in raising economic output, they are often viewed as economic 'bads' not 'goods'—a view that has gathered force in recent years and is the source of much confusion in energy and environmental policies. In some countries energy use is under attack not only from environmental groups but also from finance ministries who see high energy taxes as a means of simultaneously raising revenues (which of course they do) and reducing pollution (at most a secondary effect).

In fact, modern energy forms are an economic good, capable of improving the living standards of billions of people, most of all the billions of people in developing countries who lack access to service or whose consumption levels are far below those of people in industrialised countries. It is the pollution arising from energy production and use that is the economic bad, not energy use itself.[1] This distinction, however elementary, is not trivial. Technologies are available, emerging, or capable of being developed that can solve the pollution problem at a small fraction of the overall costs of energy supplies. The more policies recognise the distinction, the more likely will we be able to meet rising world energy demands with greatly reduced pollution. Furthermore, once the benefits of pollution abatement are taken into account, economic output and well-being are likely to be higher not lower.

No country has been able to raise per capita incomes from low levels without increasing its use of commercial energy. In industrialised

TABLE 11.2. PER CAPITA INCOMES AND CONSUMPTION OF COMMERCIAL ENERGY FOR SELECTED DEVELOPING AND INDUSTRIALISED COUNTRIES, MID-1990S

Country	Per capita income, 1995	Per capita consumption of commercial energy, 1994 (gigajoules)[a]
India	340	10
Ghana	390	4
China	620	28
Egypt	790	25
Brazil	3,640	30
Korea, Rep. of	9,700	125
United Kingdom	18,700	158
United States	26,980	327
Germany	27,510	173

a. Converted at the rate of 1 kilogram of oil equivalent = 0.0418 gigajoules.

Source: World Bank, 1997.

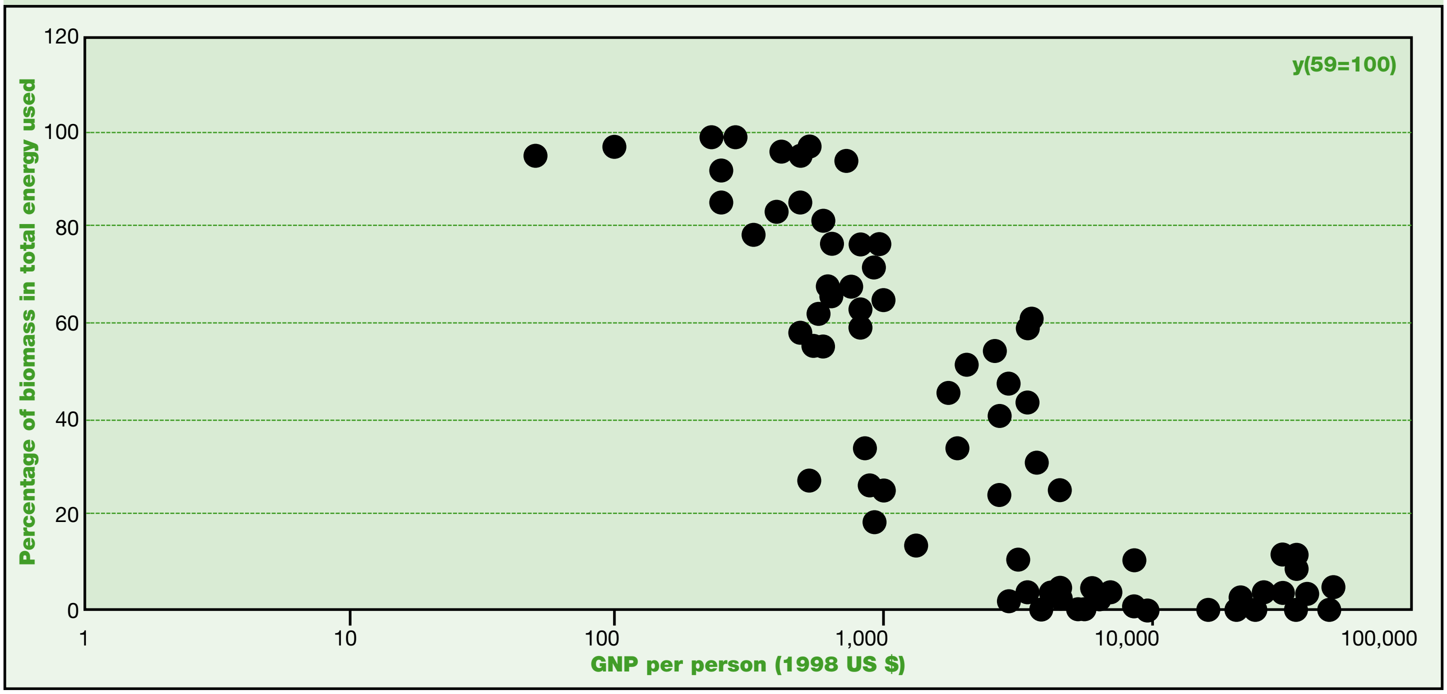
countries demand for fossil fuels has expanded more than 50-fold (in energy units) since 1860. Horsepower per worker in industry and agriculture has grown commensurately and contributed to enormous increases in labour productivity. Cross-sectional data show unequivocal correlations between the use of energy and power and the quality of life (see figure 1 and table 1 in the overview). A similar pattern is evident in comparisons of per capita consumption levels of commercial energy in selected developing countries with those in industrialised countries (table 11.2).

These are, of course, simple correlations that leave open the questions of how much energy actually contributes to economic well-being and how much energy per person is needed to achieve a satisfactory standard of living. These questions are considered below, first with reference to people without access to modern energy supplies in developing countries today and then to people in industrialised countries before modern energy supplies were widely available.

The transition from traditional to modern energy sources

Alongside the nearly 2 billion people in developing countries who lack access to electricity and modern fuels[2] are some 1.3 billion people—more than twice the populations of the United States and the European Union combined—who were newly served with electricity during 1970–95. Large regions of the developing world are not standing still, and technical progress is making the transition from traditional to modern fuels possible at a much earlier phase of development than was the case for industrialised countries. In the United States the transition from 90 percent dependence on wood fuels to virtually none took 70 years (1850–1920), by which time average per capita income was nearly $5,000 (in 1997 prices).[3] In

FIGURE 11.1. USE OF BIOMASS AS A COOKING FUEL RELATIVE TO GNP PER CAPITA IN 80 COUNTRIES



Source: World Bank, 1996.

the Republic of Korea the transition was substantially complete by 1980, when average per capita income was about $3,000. For developing countries today the transition to modern fuels tends to be nearly complete when per capita incomes are in the range $1,000-2,000 (World Bank, 1996; figure 11.1).

Technical progress and lower costs. Why is this transition taking place at lower incomes? The main reasons are that modern energy forms are more abundant and the costs of energy are much lower than they were when today's industrialised countries were making the transition. Electricity was not available a century ago, when per capita incomes in the now-industrialised countries were five times those in South Asia and Sub-Saharan Africa today. When electrification began, the costs, at $1.7 a kilowatt per hour (in 1997 prices), were 20 times today's costs (World Bank, 1992). Natural gas and liquefied petroleum gas (LPG) were also unavailable. Lebergott (1993, pp. 106-107) notes that, notwithstanding the massive increase in energy consumption in the United States in the 20th century, as families began to heat and later to cool every room in the house, U.S. consumers spent no more on heating and cooling their homes in 1990 than they did in 1900: "Despite all the factors driving up expenditures for fuel, …. they actually spent less than 3 percent [of their incomes]—compared to 3 percent in 1900. The explanation? Persistent productivity advance by businesses that mined fuel and produced electricity". These productivity advances were made possible, in part, by public policies that permitted the energy companies and utilities to earn good returns on their investments (this point is developed further in the section on liberalisation and globalisation).

The importance of per capita income growth. Although modern energy forms contribute appreciably to economic welfare, they are not affordable until incomes rise above a certain threshold (see figure 11.1). Technical progress and falling costs are lowering this threshold, but ultimately income growth is what matters. Countries that have been able to raise productivity and incomes on a broad basis—through good macroeconomic management, trade, and investment in human and physical resources—have been able to extend service most rapidly.

The benefits of service extension

At the same time, improving access to modern energy forms yields appreciable economic and health benefits.

Savings in time and labour in the home. As the World Bank's (1996) report on rural energy and development noted, when wood fuels are scarce, the time people spend collecting fuel is time they cannot devote to productive activities. Recent surveys in Nepal show that women spend up to 2.5 hours a day collecting fuel wood and fodder in areas where wood fuels are scarce.

The saving in time and labour, however, extends far beyond the saving arising from the displacement of fuel wood. It includes the economic convenience of modern energy forms and the advances they make possible, including hot and running water, washing machines, refrigeration, food and crop processing, extension of the day through electric lighting, and an array and diversity of other uses in homes, industry, and commerce too numerous to list here. Table 11.3 illustrates this point with a few comparative statistics for a developing and an industrialised country. Lebergott (1993, p. 112) comments:

> From 1620 to 1920, the American washing machine was a housewife. As late as 1920 the family laundry took about seven hours a week. The typical housewife washed some 40,000 diapers for her four children.4 Lacking running water, she carried 9,000 gallons [40 tons] of water into the house each year, then boiled most of it. And she relied on a scrub board, not a washing machine.

The heavy reliance on family labour to provide for the most basic of energy needs—for cooking food and, in many climates, keeping the family warm—is an immense opportunity cost to the family. When used for pumping, modern energy forms also improve access to water. In developing countries today a family of six people consuming 30 litres of water per person per day (a low level of consumption, about one-fifth to one-tenth of that consumed in industrialised countries) will fetch and carry by hand around 35 tons of water a year from wells and hand-pumps, often over appreciable distances.[5] Surveys of low income families consistently reveal the economic importance of the saving in family labour made possible by substituting fossil for wood fuels and of the contribution modern energy forms may make, among other things, to improving access to water.[6]

Reductions in pollution and improvements in health. The switch to modern fuels reduces the level of indoor pollution by several orders of magnitude, eliminating a major health risk now afflicting billions of people (see chapter 3). A study of air pollution in developing countries found air pollution levels from biomass combustion at several multiples of the World Trade Organisation (WHO) peak guidelines: 6 times greater for Zimbabwe, 11 times for China, 5 to 34 times for Kenya (daily average), 9 to 38 times for Nepal, 1 to 39 times for Papua New Guinea, and 16 to 90 times for India (a 15 minute peak) (Smith 1988). Fitting stoves with flues lowers pollution levels to well within WHO guidelines and leads to considerable gains in efficiency as well.

TABLE 11.3. APPLIANCE USE IN HOUSEHOLDS WITH ELECTRICITY IN INDONESIA AND THE UNITED STATES, 1987 (PERCENTAGE OF HOUSEHOLDS)

Appliance	Indonesia (low-income households)	U.S. households
Lighting	100	100
Television	31	100
Irons	21	—
Refrigerator	1	100
Washing machine	—	73
Air conditioning	0	62

— Not available.

Source: World Bank, 1996, and Lebergott, 1993.

TABLE 11.4. POPULATIONS SIZE AND ESTIMATED PER CAPITA CONSUMPTION OF COMMERCIAL ENERGY BY COUNTRY GROUP, 1998

Energy form and country group	Estimated commercial energy consumption	Population (millions)
Primary energy	gigajoules per person	
• OECD	230	900
• Countries of the former Soviet Union	125	300
• Developing countries	23	4,800
Peak electricity demand	killowatt hours per person	
• OECD	1.8	900
• Countries of the former Soviet Union	0.9	300
• Developing countries	0.2	4,800

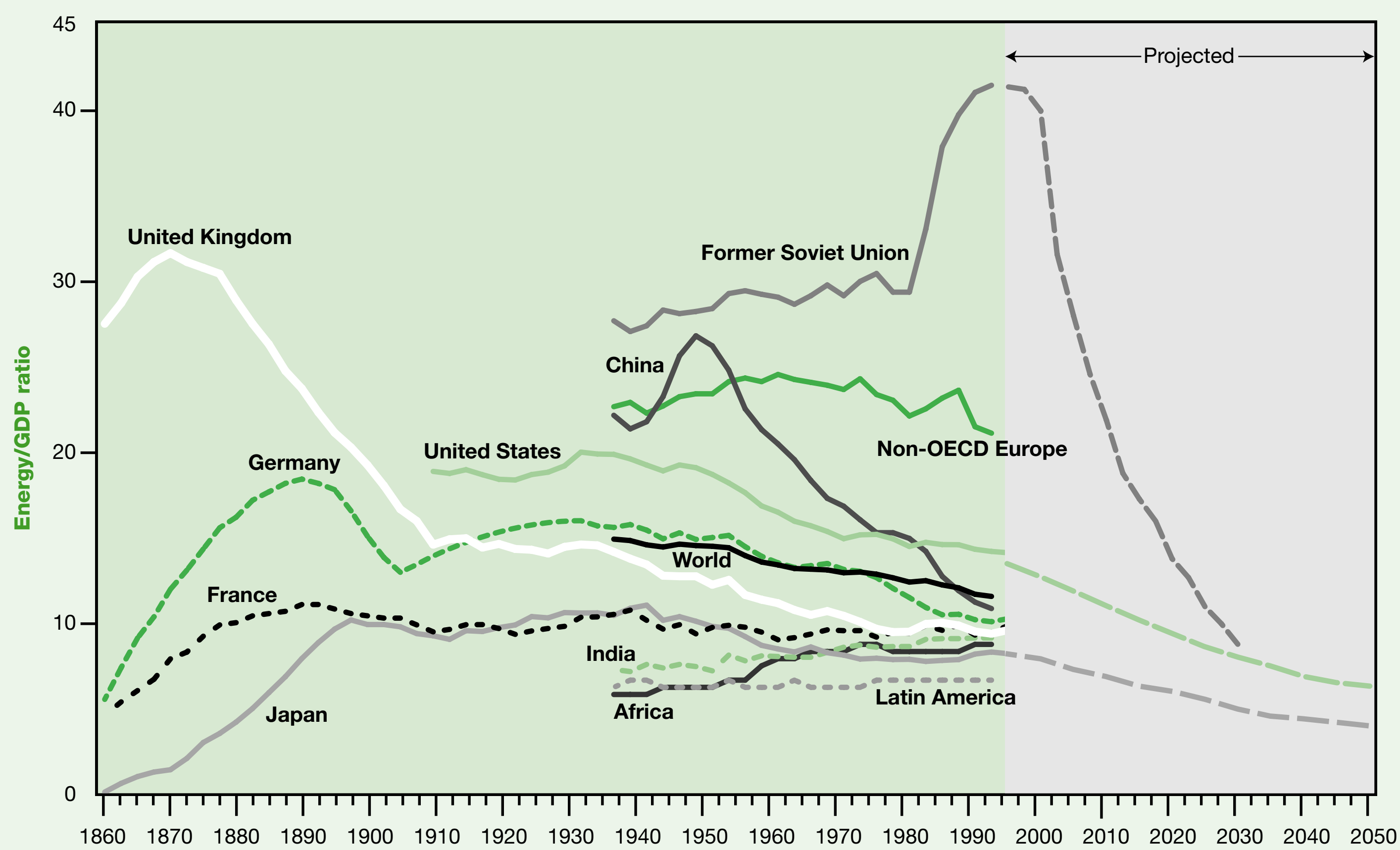
Note: Consumption estimates are based on statistics for 1992 and OED projections, assuming a 55 percent load factor for electricity demands. Population estimates are based on World Bank projections from 1992.

Source: OECD, 1995, for consumption; World Bank, 1992, for population.

Reductions in environmental damage. The transition to modern fuels *reduces* pressures on forests and land, and thus on watersheds and groundwater resources and even on biodiversity. The dangers of flash flooding are also reduced. By some estimates the consumption of wood, crop residues, and animal dung for cooking fuels amounts to 1,000 million tons of oil equivalent energy a year, more than three times the coal mined in Europe in a single year and twice that mined in the United States and China in a year (World Bank, 1996). The same amount of useful heat could be produced with only 100 million tons of LPG (in oil equivalent units) or 200 million tons of kerosene, which is equal to only 3 percent of world oil and gas consumption.

Gains in energy efficiency. Thus the transition to modern fuels can lead to large gains in energy efficiency. LPG and kerosene are just two woodfuel substitutes that result in large efficiency gains. The use of biogas from agricultural residues leads to similarly large gains. It is not surprising, therefore, though the point is often overlooked, that a rise in commercial energy use among the poorest people in the world *reduces* their energy demand, a pattern that

FIGURE 11.2. RATIO OF ENERGY CONSUMPTION TO GDP FOR SELECTED COUNTRIES AND REGIONS, 1860–1996, AND PROJECTIONS



Note: Energy consumption is measured in megajoules; GDP in 1990 U.S. dollars in purchasing power parity. Pre-1961 GDP calculations are based on exchange rates. Energy data exclude energy from biomass.

Source: IEA, 1997, 1998; CEC 1996; Chandler, and others, 1990; ISI 1999 continues until incomes reach quite high levels—in the case of Brazil, for example, to somewhere between 2 and 5 times the minimum wage (see figure 3 in the overview; chapter 10 provides further data on the efficiency of the alternative fuels for cooking).

Energy use forecasts and energy efficiency

In light of the contribution of modern energy forms to higher incomes and greater economic well-being, the expansion of supplies should be welcomed from both economic and commercial viewpoints. Energy markets are potentially very large and are set to grow for most of the century. Recall that per capita consumption levels of commercial energy and electricity in developing countries are barely one-tenth of those in OECD countries, while their populations are over five times larger (table 11.4). The energy scenarios presented in chapter 9 point to an increase in the world's consumption of commercial energy over this century of roughly 2.5 to 5 times today's levels.

Forecasts of long-term energy demands vary considerably with assumptions about the growth of per capita incomes and populations.[7] They also vary with assumptions about future gains in energy efficiency. The assumptions about energy efficiency gains warrant further discussion because of their impact on assessments of the amount of energy required to support economic production and provide for people's energy needs.

It has been widely observed that the energy intensity of an economy (the ratio of energy consumption to GDP) rises during the early and middle phases of economic development, when the industrialisation and 'motorisation' of economies are strong, and then peaks and declines as the less energy-intensive service sector begins to occupy a larger share of economic activity (figure 11.2).[8] The later a country industrialises, the lower its peak energy intensity because of intervening improvements in the efficiency of energy conversion processes—especially for electricity generation—and energy use. This pattern has held for more than a century, as a comparison of the experiences of the United Kingdom, Germany, the United States, France, and Japan shows (see figure 11.2). Developing regions are exhibiting the same pattern. (Exceptions are economies in transition, which have experienced abnormally high energy intensities historically, but which are now expected to decline with new investment and gains in energy efficiency.) A number of engineering and economic studies have shown that the possibilities for further gains in energy efficiency are far from exhausted, such that we can expect a continual lowering of the peak intensity as more countries become developed.[9]

Such improvements in energy efficiency mean that developing countries are likely to need less energy to produce a unit of GNP and to meet consumer needs per unit of income than was the case for the industrialised countries. How much less is controversial, because of ambiguities in the evidence and oversimplifications in both the engineering and economic models of energy consumption. However, no empirically based study has shown that developing countries can achieve prosperity without very large increases in demand for energy, even with strong assumptions about improvements in energy efficiency.

Ambiguities in the evidence and shortcomings in methods

Another perspective on the links between income growth and energy consumption is provided by economic estimates of income elasticities of energy demand. These show a rising trend as per capita income grows from very low levels and then a declining trend at high income levels (table 11.5). The income effect is weak among the most impoverished people in the world—whose main initial demands, as incomes begin to rise, are for meeting such basic needs as food, safe water, and improved health services—but becomes very strong as incomes rise above a certain threshold. Recall figure 11.1, which shows that once income moves into the \$1,000–\$2,000 range, substitution from biofuels to modern energy proceeds as rapidly as income growth permits. The income effect is also strong in the industrialisation phase of development, but it then begins to decline as markets mature, falling to a low value at high income levels, such as those of the OECD economies in the 1970s and 1980s.

An intriguing estimation result in table 11.5 is the *negative* per capita income elasticity in the highest income range. Judson, Schmalensee, and Stoker (1999) caution that this estimate may not be statistically significant, commenting that it is "more likely to reflect some sort of isolated measurement problem than a real economic phenomenon. We are on balance fairly confident that beyond per capita incomes of \$1,500 or so (in 1985 dollars), there is a tendency of the economy-wide income elasticity of demand for energy to fall with per-capita income, but the evidence for a negative income elasticity at high income levels is, in this sample, less than compelling".

Yet engineering studies also point to the possibility of a decline in energy demand per capita at high income levels even as per capita incomes increase. As energy markets become satiated at high income levels, long-term improvements in the efficiency of energy use may more than offset any further increases in demand

TABLE 11.5. VARIATION IN PER CAPITA INCOME ELASTICITIES OF DEMAND FOR COMMERCIAL ENERGY WITH PER CAPITA INCOMES

Income (1985 U.S. dollars in purchasing power parity)	Income elasticity
≤ 823	0.219
823-1430	1.098
1,430-2,545	1.400
2,545-4,249	0.784
4,249-8,759	0.394
≥ 8,759	–0.312

Source: Judson, Schmalensee, and Stoker, 1999.

arising from income growth.[10] The effects are complex, and it is not surprising that the study by Judson, Schmalensee, and Stoker (1999) is inconclusive. Economic models have so far not been able to capture the effects in a satisfactory way.

Per capita consumption levels of commercial energy and electricity in developing countries are barely one-tenth of those in OECD countries.

There are five effects on energy demand that need to be considered: income, price, population, energy efficiency as a means of *reducing* energy demand for a particular purpose, and energy efficiency as a means of reducing the price of energy and thereby *raising* energy demand (sometimes called the rebound effect). These effects can be summed up in the simplified model of energy demand growth:

$$e = \gamma.g - \beta.p\{x\} - x + n$$

where e is growth of per capita energy demand; g is growth of per capita income; p is growth of prices; n is population growth; x is the growth of what is sometimes called the autonomous energy efficiency index; γ is the income elasticity of demand for energy; and β is the numerical value of the price elasticity. The notation $p\{x\}$ summarises the fifth effect, of price as a function of—and generally declining with—energy efficiency.

Most energy demand studies using econometric techniques have not attempted to estimate x, the rate of improvement in the autonomous energy efficiency index. The review by Grubb and others (1993, p.453) sums up the uncertainties. First they note the wide range—from less than 0.5 percent to more than 1.5 percent a year—in x. They then add:

> We cannot suggest a definite value for this parameter, but it is important to understand it. The parameter has been badly misnamed: it is a measure of all non-price-induced changes in gross energy-intensity—which may be neither autonomous nor concern energy efficiency alone. It is not simply a measure of technical progress, for it conflates at least three different factors. One indeed is *technical developments*…. another is *structural change,* i.e., shifts in the mix of economic activities…. The third is *policy-driven uptake of more efficient technologies*…. [Emphasis in original.]

Compounded over a century, the 1 percentage point difference in estimates of the autonomous energy efficiency index results in a 2.7-fold difference in energy demand projections and helps to explain the large differences in the scenarios of energy demand developed in chapter 9.

Energy efficiency as a beneficial stimulus to energy use

Environmental studies frequently argue for improvements in energy efficiency as a means of reducing environmental damage. There are, however, two dangers in placing too much reliance on this argument. One is that improving energy efficiency, by lowering costs and prices, may also increase demand (the rebound effect noted above).[11] The second is that the argument neglects an important economic benefit of energy efficiency: it makes energy more affordable and accessible to consumers, which is especially important today for developing countries.[12]

Consider the following examples. The efficiency of motive power rose from less than 1 percent for the early steam engines of Newcomen and Smeaton in the 18th century and 5 percent with the invention of the stream condenser by Watt later in the century to 20 percent for gasoline and diesel engines and 40 percent for electric motors today (after allowing for losses in electric power stations). This was a 40-fold increase over two centuries. It is conceivable that without such efficiency improvements the industrial revolution—and the unprecedented increase it brought about in per capita incomes in the industrial economies in the past two centuries—might not have taken place.

Or consider lighting. The efficiency in lumens per watt rose 20-fold following the displacement of kerosene by electric incandescent lamps and then another 5-fold with the invention of fluorescent lamps in the 1930s. These improvements help explain the massive growth in commercial lighting over the past half century. Another socially important example, mentioned earlier, is the contribution of modern fuels to the efficiency of cooking and heating devices in the homes. These were a primary cause of the movement away from traditional fuels and of improvements in the economic well-being of billions of people.

To take a final example, the conversion efficiency of power stations fired by fossil fuels rose from around 3 percent at the beginning of the 20th century to more than 50 percent for combined-cycle gas-fired power stations today (Anderson, 1993). This improvement has contributed to a 20-fold drop in the costs of electricity since 1900, stimulated industrial expansion, and brought the benefits of electricity consumption to more than 3 billion people in the world today. Numerous other examples could be cited, from commercial heating (insulation, heat pumps, double glazing, energy management systems, combined heat and power) and air conditioning to refrigeration and industrial processes.

In sum, the main benefits of improvements in energy efficiency are that they make modern energy services more affordable and accessible by reducing the energy required for any particular purpose and thereby reducing costs. It is only in the high-income economies that there is some suggestion that per capita energy use might eventually decline as incomes grow and energy needs become satiated. In developing countries, however, demand is set to grow substantially, even allowing for—and to some extent because of—improvements in energy efficiency, in any scenario of economic success.[13]

Reconciling increased energy consumption and environmental protection

Two important issues that arise in any discussion about meeting growing energy demand are: What will be the environmental impact, and can the impact be ameliorated at an affordable cost for developing countries? To answer these questions we need to distinguish between local and regional pollution on the one hand and global pollution from greenhouse gases on the other. For local and regional pollution the technologies are well developed, based on 40 years of operational experience in industrialised countries. For global warming the required technologies, while promising, are at a much earlier phase of development and use and raise different issues for policy.

Reducing local and regional pollution

Studies have estimated high social costs of pollution from energy production and use in developing countries (Lvovsky and Hughes, 1999; Lovei, 1995; Downing, Ramankutty, and Shah, 1997). The costs of pollution in cities are especially high:

- Marginal damage costs per ton of local pollutants vary greatly across sources and locations and are much higher for small (low-stack) sources because of the dispersion pattern.
- For some fuel uses the marginal damage costs are as high as producer and retail prices—or even higher.
- Diesel-powered vehicles and small stoves or boilers burning coal, wood, or oil impose the highest social costs per ton of fuel.
- Sulphur deposition levels are already at 5–10 grams per square meter per year in the industrial areas of Indonesia, Malaysia, the Philippines, and Thailand, and at more than 18 grams in China. By comparison, deposition levels in the most heavily polluted parts of the industrialised world—the black triangle of Central and Eastern Europe—are about 15 grams.
- Local health effects dominate the damage costs. Lead blood levels during the early 1990s were 25 micrograms per decilitre in Mexico City and Budapest, 30 in Cairo, and 40 in Bangkok,

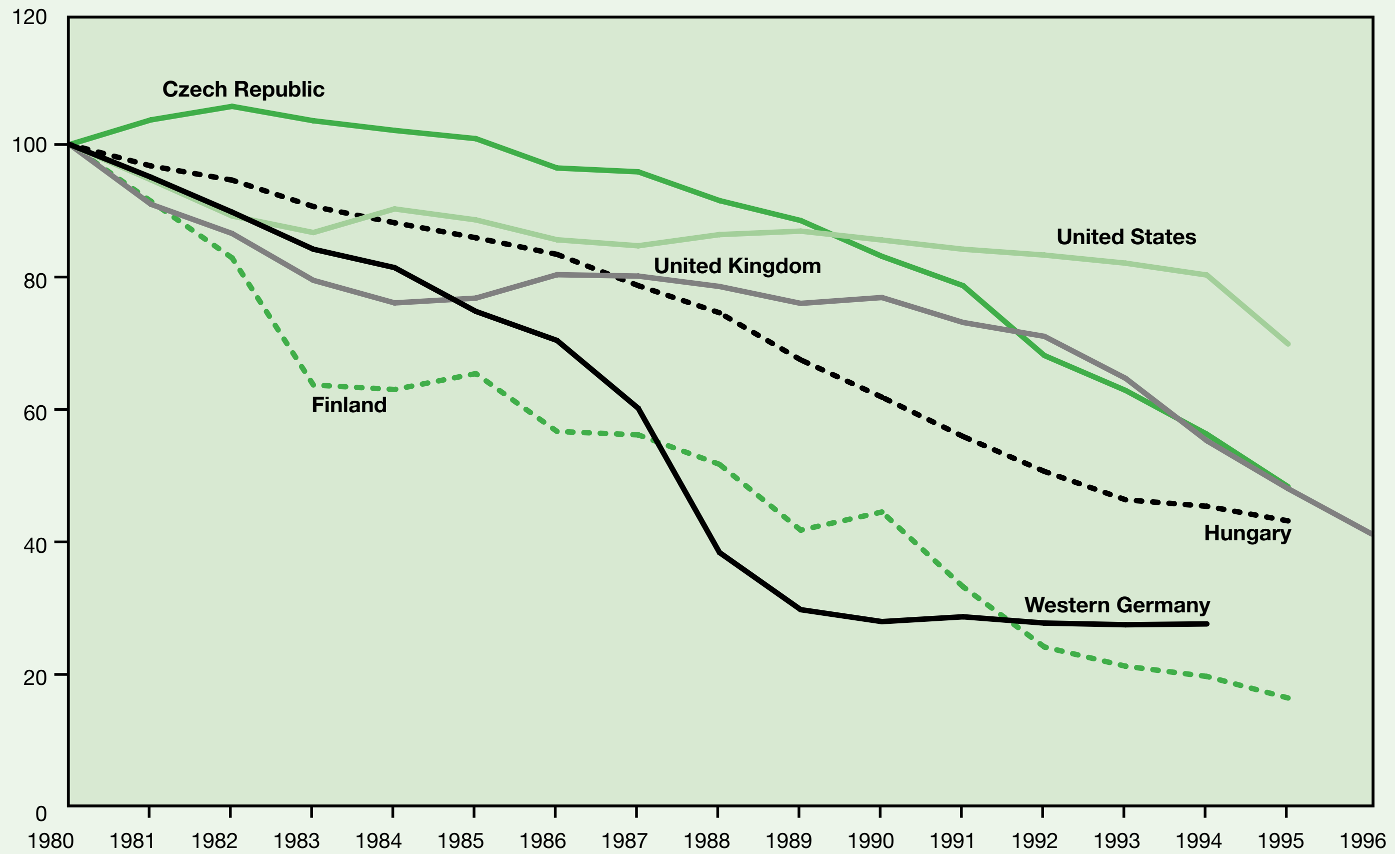
TABLE 11.6. RELATIVE POLLUTION INTENSITIES AND COSTS OF SELECTED LOW-POLLUTING TECHNOLOGIES FOR ENERGY PRODUCTION AND USE (INDEX = 100 FOR ALL HIGH-POLLUTING TECHNOLOGIES)

Source and pollutant	Low-polluting technology	Costs as share of supply or user costs (percent)[a]	Nature of low-polluting alternatives
Electricity generation (coal)			Natural gas; electrostatic precipitators, bag-house filters, flue gas desuphurization, integrated coal gasification combined-cycle technologies, and fluidised bed combustion (for coal); low nitrogen oxides combustion and catalytic methods.
Particulate matter	<0.1[b]	<0–≈2[b]	
Sulphur dioxide	0–0.5	5	
Nitrogen oxides	5–10	5	
Motor vehicles			Unleaded/reformulated fuels; catalytic converters.Improved fuel injection, engine design, maintenance. and 'proper' fuel use; catalytic converters.
Gasoline engines			
Lead	0		
Carbon monoxide	5	≈4–5 share of lifetime cost of vehicle fuel and equipment costs, for gasoline and diesel engines	
Nitrogen oxides	20		
Volatile organic compounds	5		
Diesel engines			
Particulate matter	≈10–20		
Nitrogen oxides	≈40		
Traditional household fuels (wood and dung) in low income countries			Gas, kerosene.
Smoke (particulate matter, carbon monoxide, and sulphur)	<0.01	<0[d]	
Carbon dioxide emissions from combustion of fossil fuels			Advanced solar energy, wind, and other renewable energy technologies for power generation; biomass for liquid fuels and power generation; hydrogen from renewable energy sources and fuel cells for power generation and vehicles.
Electricity (developing countries)	0		
Electricity (developed countries)	0	≈0–≈20[e]	
Liquid fuel substitutes	0	≈30–50	

Note: Except for carbon dioxide all the estimates are based on technologies and practices commonly in use.
a. Net private marginal costs are used because some technologies and fuels have benefits that go beyond their environmental benefits—use of gas as a domestic and industrial fuel is an example. Such investments are routinely justified in terms of their economic convenience or productivity relative to the alternatives, without reference to their environmental benefits, however important. b. Negative costs arise if gas is available for power generation as a substitute for coal. c. High emissions (especially of particulate matter) in developing countries stem very much from ageing vehicles, poor maintenance, and improper use of fuels (for example, kerosene instead of diesel). d. In urban areas and where traditional fuels are scarce, modern fuels are generally cheaper to use once the costs of household labour are taken into account, in part because of their higher energy efficiency (see chapter 10) and their convenience and savings in time (see discussion in text). e. Estimates are much lower for developing countries than for the northern industrialised countries because solar insolation is two to three times greater in developing regions and its seasonal fluctuation is one-third less. Estimates are of long-term costs.

Source: ADB, 1991, and Charpentier and Tavoulareas, 1995 for electricity; Faiz, Weaver, and Walsh, 1996, for motor vehicles; Smith, 1993, for traditional fuels. Anderson and Chua, 1999, review the engineering economic literature, and Kiely, 1997, provides an introductory text on technologies; both have ample bibliographies.

FIGURE 11.3. TRENDS IN SULPHUR DIOXIDE EMISSIONS, SELECTED COUNTRIES, 1980–96



Source: Data from OECD, 1997; U.S. EPA, 1997; and U.K. Department of Environment, Transport, and the Regions National Air Quality Archive (http://www.aeat.couk/netcen/airqual/).

well above the 2 micrograms per decilitre in the United States (reflecting an eightfold decline over the preceding 15 years).

There are several options for substantially reducing local and regional pollution loads over the long term. This is evident both from the experience of industrialised countries (table 11.6) and from comparisons of pollution loads in industrialised and developing countries (figure 11.3). Given the time required to incorporate low-polluting options in new investments and to replace the old capital stock, however, pollution is likely to rise before it falls. But the experiences of industrialised countries also shows that there is little doubt that major reductions of local and regional pollution from energy use could be achieved in the long term with supportive policies.

Low-polluting technologies, in wide use in industrialised countries, have led to appreciable reductions in smog, acid deposition, and emissions of lead, particulate matter, and volatile organic compounds; and although energy consumption per capita is an order of magnitude *higher* than in developing countries, local and regional pollution is an order of magnitude or more *lower* or (in the case of acid deposition) headed in that direction. (See chapter 3 for a full discussion of pollution loads in the industrialised and developing countries.)

The costs of controlling local and regional pollution are small relative to the total costs of energy supply or use. If coal is used as the principal fuel in electricity generation, the costs of pollution abatement range from 2 percent of supply costs for particulate matter (the most environmentally damaging of pollutants) to 5–10 percent for acid deposition. If gas is used as the principal fuel, the costs of pollution abatement are negative once allowance is made for the higher thermal efficiencies and lower capital costs of the power plant. For motor vehicle emissions the absolute cost of abatement, including the cost of catalytic converters, is estimated at less than $0.04–0.15 per gallon of fuel consumed. Similarly, supplying modern fuels to households in place of traditional fuels significantly reduces both indoor and local pollution (see chapter 3) and, except in remote communities, the costs of energy supplies as well.

Simulations of the effects of introducing abatement policies for reducing acid deposition in Asia illustrate the potential of innovation for enabling developing countries to address environmental problems at an earlier phase of their development than did industrialised countries (Anderson and Cavendish, 1999; figure 11.4). Studies that assume that environmental problems will not be addressed until the

> For some fuel uses the marginal damage costs are as high as producer and retail prices—or even higher.

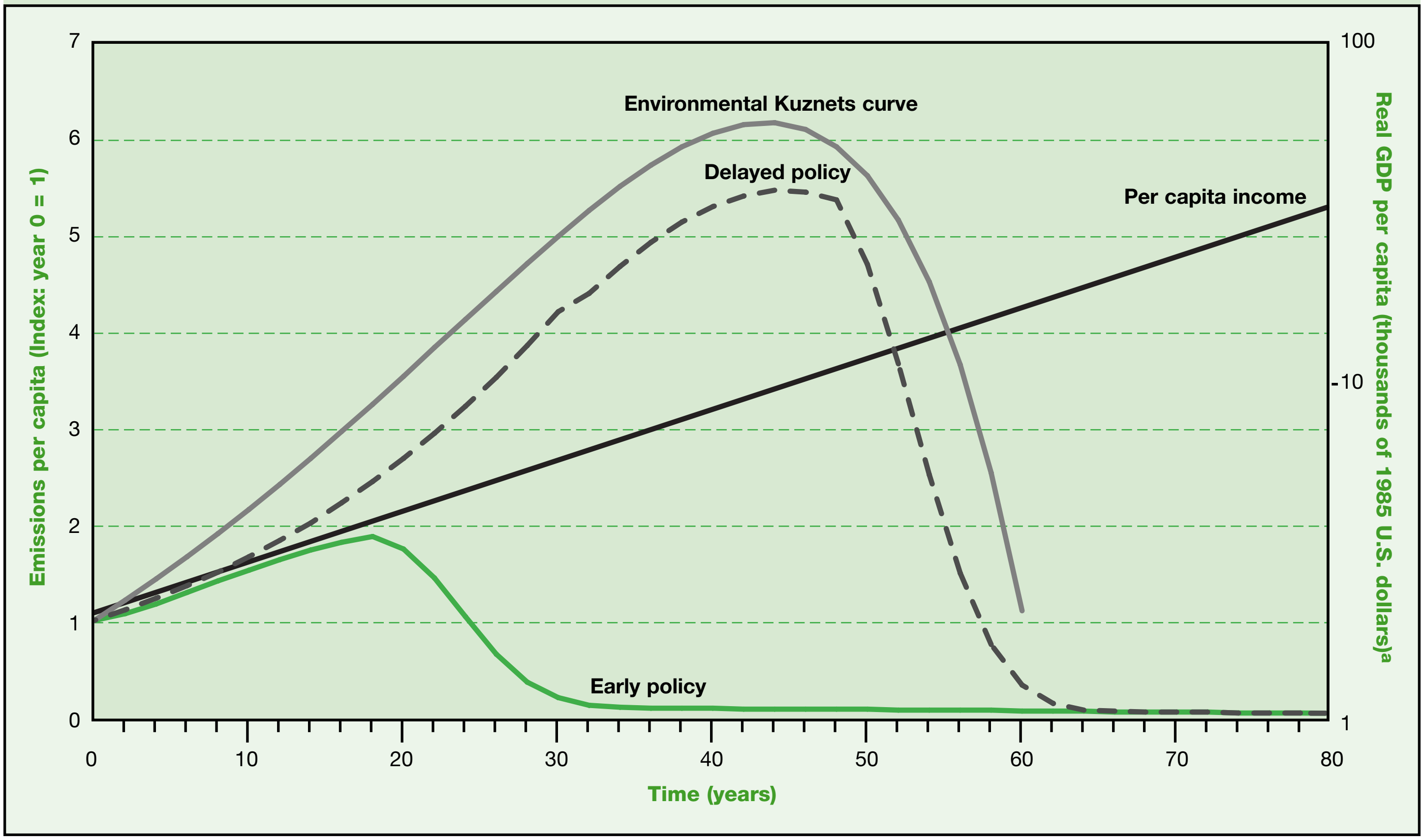
per capita incomes of the main emitters in the region (China and India) approach those of industrialised countries when they began to address acid deposition in the 1970s (about $10,000[14]) put that date at half a century from now for China and nearly a century from now for India, even under optimistic growth rate assumptions. When the simulations are run under the assumption that countries in Asia take advantage of new methods of sulphur dioxide abatement that have emerged in recent years, including coal desulphurization and the use of gas for power generation (now a rapidly growing possibility in East Asia), the results clearly show the opportunity for solving the problem much earlier with greatly reduced pollution loads. Downing, Ramankutty, and Shah (1997), in a study of acid deposition in Asia, come to similar conclusions; so do the scenarios in chapter 9.

The relatively low costs of pollution control suggest that the required financing can be generated through policies that allow prices to reflect the marginal costs of supply, including the costs of pollution control — the central goal of internalising externalities in market prices. Simulation studies consistently show that the extra investments would not only become self-financing, but would over time be offset by efficiency gains in the industry as a result of new thermal efficiencies in power plants, improvements in plant availabilities, reductions in distribution losses, and gains in managerial efficiency from liberalisation and improved forms of regulation (Cavendish and Anderson, 1994; World Bank, 1992). Thus while subsidies should not be necessary to finance investments in reducing local or regional pollution, environmental regulation and taxation would be.

In addition, experience in industrialised countries has shown that there are good economic returns to such investments through improvements in people's health and reduced damage to natural resources (chapter 3). In a review of U.S. experience, Davies and Mazurek (1998, p. 148) conclude that:

> The macroeconomic effects of pollution control and regulation are generally modest. Regulation has had some adverse effects

FIGURE 11.4. SIMULATED EFFECTS ON SULPHUR DIOXIDE EMISSIONS IN ASIA OF EARLY AND LATE ENVIRONMENTAL POLICIES



a. Adjusted for real comparative purchasing power using Penn World Table, mark 4 (Summers and Heston, 1991).

Source: Anderson and Cavendish, 1999; Selden and Song, 1994, for the environmental Kuznets curve.

on GDP growth, but most economists think that the effect has been relatively small, and the negative effect fails to take into account most of the benefits of regulation.… When looked at as a whole, U.S. environmental progress has made economic sense. It can be shown that benefits exceed costs in a great number of cases.

In developing countries the net effects on growth should be even greater, since their environmental priorities in the energy sector include the elimination of smoke, emissions of particulate matter, lead in fuels, and the indoor air pollution and damage to soils and forests arising from the use of traditional fuels. Thus there is no reason from an economic perspective why developing countries cannot adopt ambitious policies for reducing local and regional pollution from energy production and use. The technologies and practices are now available that should, if the 'right' policies are put in place, enable developing countries to reduce such sources of environmental damage at a much earlier phase of development than was the case for industrialised countries.

Mitigating global warming

The other energy-related environmental concern is global warming. For understandable reasons developing countries have been reluctant to commit themselves to emission reduction targets for greenhouse gasses. The costs of mitigation are thought to be too high, and there is some resistance to the notion that developing countries should not use fossil fuels to further economic development, as the industrialised countries did in the 19th and 20th centuries.

Yet developing countries may stand to benefit unexpectedly over the long term from international policies on climate change, particularly from the use of the renewable energy technologies now emerging from the energy research, development, and demonstration (RD&D) programmes of the industrial countries. In fact, some countries, such as Brazil, China, and India, have themselves begun to put resources into the development of renewable energy. The development and use of renewable energy have also become a focal point of the Global Environment Facility, the financing arm of the United Nations Framework Conventions on Climate Change and Biodiversity. What makes the technologies promising is the abundance of renewable energy resources and the falling costs being brought about by technical progress. (For more detailed information about renewable potentials and technologies, see chapters 5 and 7.)

Abundant renewable energy resources. The Earth receives a yearly energy input from the sun equal to more than 10,000 times the world's consumption of commercial energy. Solar insolation varies from 2,000 kilowatt hours per square metre to more than 2,500 a year over vast areas of developing countries, from 800 to 1,700 in Europe, and from 1100 to over 2,500 in the United States. Photovoltaic systems and solar-thermal power stations

TABLE 11.7. USE AND COMPARABLE COST OF SELECTED RENEWABLE ENERGY TECHNOLOGIES, 1998

Technology	Average cost (U.S. cents per kilowatt hour unless otherwise indicated)	Comments
Wind (electric power)	5–13	Costs declined fivefold from 1985 to 1995.
Biomass		
Electric power	5–15	Steam cycle of 25 megawatts Brazil data. Declined by factor
Ethanol	$2–3/gallon ($15–25 gigajoule)	of three since 1980s.
Photovoltaic systems		Based on costs of $5–10/peak watt. Costs have declined
Insolation, 2500 kilowatt hours/square metre	20–40	50-fold since 1975, 5-fold since 1980, 2-fold since 1990.
Insolation, 1500 kilowatt hours/square metre	35–70	Medium- and long-term storage a major issue. With battery
Insolation, 1000 kilowatt hours/square metre	50–100	storage, cost of $8–40/ peak watt in off-grid, stand-alone applications are commonly reported; see chapter 7.
Thermal solar (electric power)	10–18	Parabolic troughs. Latest vintages, around 1990, in high insolation areas only.)
Geothermal	3–10	Costs vary greatly with location.
Gas-fired, combined-cycle power plant	3–5	Higher figure is for liquefied natural gas.
Grid supplies		
Off-peak	2–3	Depends on spikiness of peak
Peak	15–25	
Average, urban areas	8–10	
Average, rural areas	15 to >70	Rural areas in developing countries

Note: All figures are rounded. Estimates are adjusted to 10 percent discount rates.

Source: Based on the author's interpretations of the following reviews, of more than 500 papers and studies: Mock, Tester, and Wright, 1997, on geothermal; Larson, 1993, on biomass; Ahmed, 1994, on solar and biomass; Gregory, 1998, on several technologies, including fossil fuels; World Bank, 1996, on renewable energy and grid supplies in rural areas; and chapter 7 of this report. Refer to those sources for details and qualifications.

are capable of converting 10–15 percent—15–30 percent with further development—of the incident solar energy into electricity.

In theory, all of the world's primary energy requirements of 8 gigatons of oil equivalent a year could be met on an area of land equal to about 0.25 percent of the land now under crops and permanent pasture.[15] There is thus no significant land constraint on the use of solar energy. The main issue is cost. Other renewable energy technologies, such as biomass and wind power for electricity generation, have greater land intensities than solar energy; they have already attracted significant investment.[16]

Developing countries may enjoy a five-to-one cost advantage in using direct solar technologies.

Encouraging technical progress and falling costs. The relative costs of fossil fuels and renewable energy can be assessed only within broad limits, even assuming reasonable stability of fossil fuel prices (table 11.7). The estimates shown indicate why niche markets have emerged for renewable energy in favourable locations: geothermal, wind, biomass for power generation; solar thermal in areas of high insolation; and photovoltaic systems for off-grid markets and for distributed generation when there is a good co-incidence of solar peak and demand peak. Renewable energy installations (excluding hydropower) generate about 30,000 megawatts world-wide. While small relative to the world's generating capacity (more than 3 million megawatts), this experience has provided good information on the costs and reliability of renewable energy technologies.

Two factors, often neglected, are also important to cost calculations. One is the comparative advantage developing countries may have in using renewable energy. Solar insolation, for example, is two to three times greater than in the northern regions of industrialised countries, and seasonal swings are much lower. For this reason developing countries may enjoy a five-to-one cost advantage in using direct solar technologies. The second factor concerns differences between average and marginal costs. In off-peak times the marginal cost of grid supplies may be one-quarter to one-third the average cost, while in peak times marginal costs can be as much as two to five times higher than average costs—or even more. This differential has been obscured in many countries by the common practice of average cost pricing and, too often, by subsidies. But when there is a good co-incidence between solar peaks and demand peaks, there is an economic case for using photovoltaic systems for distributed generation. Better efficiency in the level and structure of prices will also be needed to provide proper incentives for solving the problem of intermittence in renewable energy supplies. Differential pricing, with high peak and low off-peak rates, provides the ideal incentive. Such pricing structures have already emerged at the bulk supply level in some countries with liberalised electricity markets (the United Kingdom is a prominent example).

Energy research, development, and demonstration. But we need to go beyond the (undoubtedly important) principle of 'getting prices right' for commercial investment and to revisit the case for technology development policies. Most member countries of the International Energy Agency have such policies in one form or another, aimed at developing new alternatives to fossil fuels. International economic co-operation to foster trade, investment, and the diffusion of know-how in these technologies has also begun to emerge, albeit on a small scale considering the task in hand (see section on liberalisation and globalisation).

The principal example of international co-operation is the Global Environment Facility. The marketable permit systems and other flexibility mechanisms of the Joint Implementation and Clean Development Mechanism, if implemented, will be important extensions of these initiatives. But while public support for commercialisation and international co-operation has been growing, energy RD&D programmes in OECD countries have declined precipitously in the past 20 years. Many question whether they have declined too far, considering the severity of environmental problems and the competition from fossil fuels (see box 11.1 for a discussion of energy research and development).

Cost uncertainties and scenarios of carbon emissions. Notwithstanding the promise of renewable energy, the uncertainties remain appreciable. The future use of renewable energy will depend on its costs relative to the costs of fossil fuels and on taxes and regulation of carbon emissions. Minor changes in assumptions about the effects of innovation on costs, when extrapolated over long periods, lead to large differences in estimates of the energy supply mix, as do differences in assumptions about climate change policies.

It is possible (and many people hold this view) that renewable energy will remain confined to niche markets in the absence of climate change policies. It is also possible (and many others hold this view) that with further innovations and scale economies in manufacturing and marketing, renewable energy will eventually meet a substantial share of the world's energy needs.

Uncertainties about the costs of non–fossil fuel technologies and different assumptions about climate change policies are the main reasons why scenarios of carbon emissions differ so greatly. Industry scenarios (for example, Kassler's 1994 report for the Royal Dutch Shell group of companies) and the recent lower emission scenarios of the International Panel on Climate Change (Nakićenović, Victor, and Morita, 1998) show carbon emissions rising from 6 gigatons of carbon a year today to a peak of 10 gigatons by the middle of the century and then declining to low levels by the end of the century. These scenarios also allow for the emergence of other non–fossil fuel technologies and for technological surprise.

These results can be reproduced using elementary simulation models. The results of one such simulation for a developing country are shown in figure 11.5. They contrast the emissions associated with the country's early introduction of climate change policies with those that would arise if the country were to wait until its per capita income began to approach that of industrialised countries today, a projected delay of roughly half a century. Note the long lags before the full effects of the policies are felt, a (further) delay that arises from the scale of the problem of replacing fossil fuels in the energy supply mix and the longevity of investments in energy supplies from fossil fuels.

There is a wide range in costs for the early policy scenario. Significant investment would be required in the early decades, as is clear from the data in table 11.7 and from the report of the President's Committee of Advisers on Science and Technology noted in box 11.1. However, the costs in the long term may well prove to be small or negative. When the full probability distributions for the parameters representing the effects of technical progress on costs are included in the analysis, it can be shown that there is a significant chance of a technological and an economic surprise arising, so that alternatives might become less expensive than fossil fuels for a large number of applications. This outcome is consistent with the findings of the industry scenarios (Kassler, 1994). We cannot say with certainty that such a favourable outcome will materialise, and it may well be that a transition to renewable energy will eventually require a permanent and significant tax or regulation on the use of fossil fuels. But reflecting on the technological developments and reductions in the costs of energy over the past century, who could say with confidence that the scope for innovation in alternatives to fossil fuels is exhausted or that addressing climate change is unlikely to yield a technological or an economic surprise?

BOX 11.1. HAS PUBLIC SUPPORT FOR ENERGY RESEARCH AND DEVELOPMENT DECLINED TOO FAR?

Public support for energy research, development, and demonstration (RD&D) programmes in OECD countries has declined considerably since 1985: by 80 percent in Germany, 75 percent in Italy, 50 percent in Canada, and 10 percent in Japan (where, as in France, nuclear power occupies the bulk of the budget) and the United States (IEA 1997a). Recent public energy RD&D expenditures in International Energy Agency (IEA) countries are about $8.5 billion a year. About 55 percent of spending goes for nuclear power and 40 percent for renewable energy and conservation.

In most countries the cuts were made across the board and equally applied. The cuts were motivated in part by market liberalisation, whose aim was to shift the onus for innovation to the private sector, and in part by competing demands on public revenues for social sector programmes. The decline in public support for RD&D also reflects discouragement with state-selected programmes supported by direct state expenditures in the period from around 1950 to 1990.

Following a major re-assessment of the approach over the past 15 years, public policies in several OECD economies are now moving towards a complex mix of incentives based on:

- Regulatory requirements for private industry to develop technologies with low carbon emissions.
- Technology-neutral tax incentives for the development of low carbon technologies.
- Marketable permit and related systems, such as the proposed programmes of Joint Implementation and the Clean Development Mechanism.
- Special financing facilities such as the Global Environment Facility that blend their own concessionary or grant finance with the hard finance of the multilateral development banks and industry to achieve a softer financial blend for innovative environmental projects.

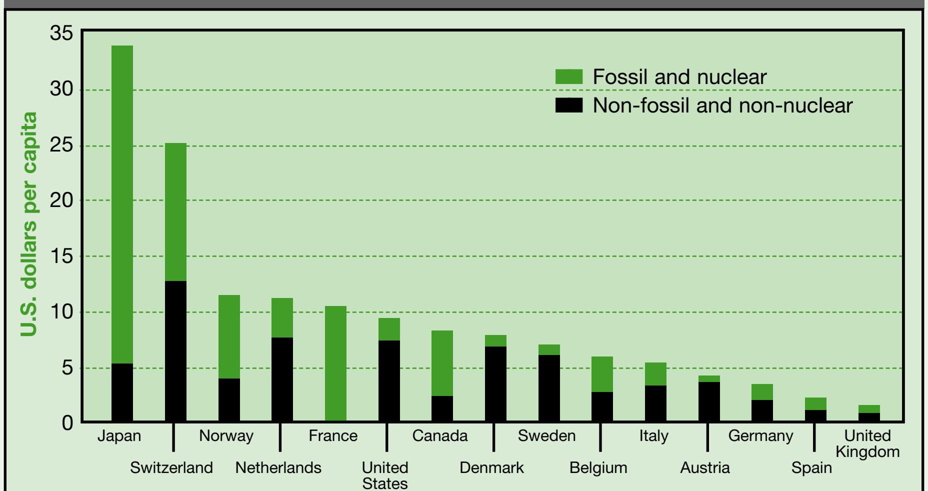
These are all clearly more market-oriented initiatives that avoid the problems encountered previously under state-directed programmes. The main issue is whether the incentives provided today are sufficient in light of the emerging environmental problems and the continuing competition from fossil fuels.

The U.S. President's Committee of Advisers on Science and Technology (1999, p. ES-5) concluded that they are not. "[U.S. federal RD&D programmes] are not commensurate in scope and scale with the energy challenges and opportunities the twenty-first century will present….especially…in relation to the challenge of responding prudently and cost-effectively to the risk of global climatic change from society's greenhouse gas emissions". Yet on a per capita basis U.S. RD&D programmes on non-fossil and non-nuclear technologies are among the largest in the OECD (see figure).

What are the alternatives to providing incentives for RD&D? The costs of the non-fossil components of energy RD&D programmes are about $2.3 per ton of carbon emitted in IEA countries including nuclear power and less than $1 per ton excluding nuclear power. Economic estimates of the carbon taxes required to address the climate change problem are much larger, at five to several hundred dollars per ton.[1] When uncertainties are large, as they are in the case of developing technological alternatives in response to a highly uncertain problem such as global warming, it is a good policy, well supported by the principles of economic analysis, to invest in options that reduce uncertainties and costs.

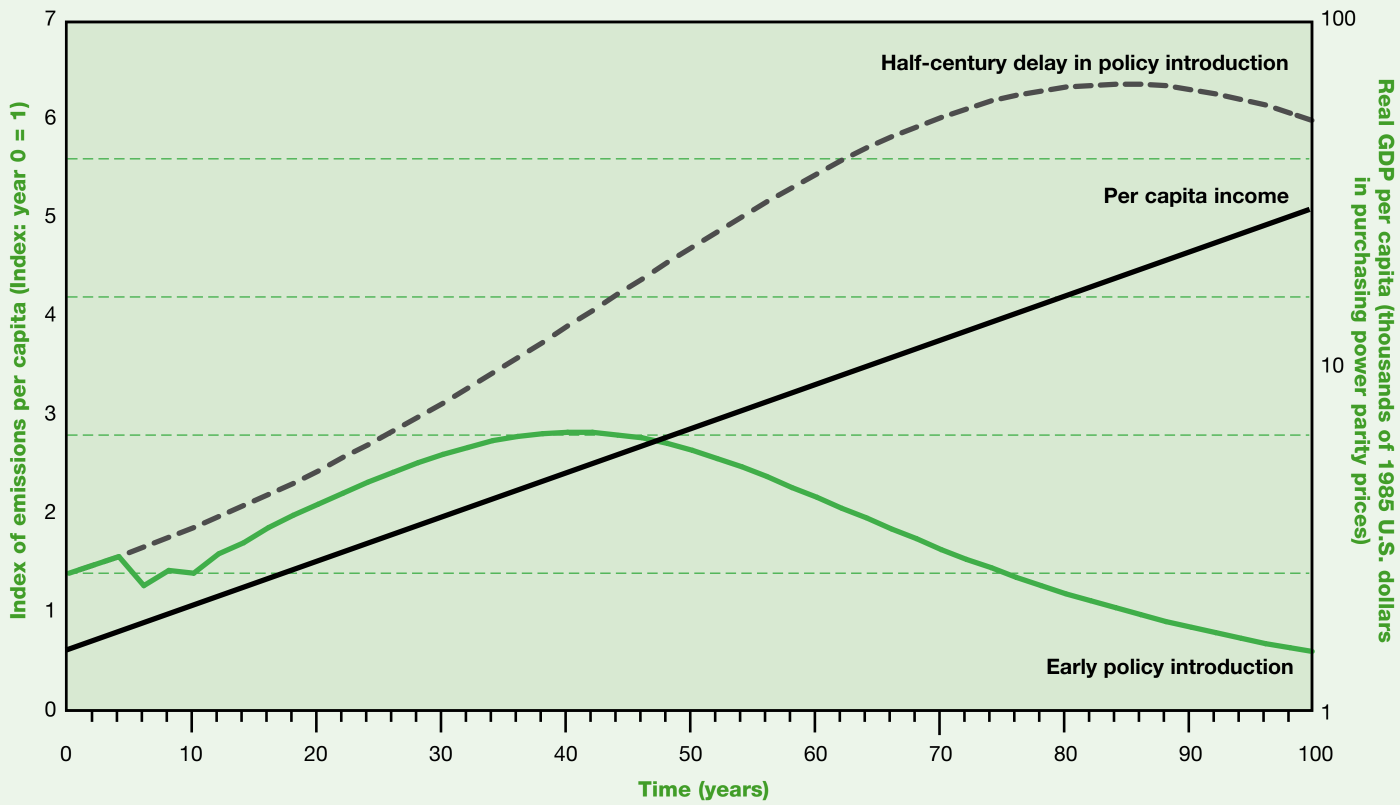
1. "The World Bank Global Carbon Initiative", attachments to a published speech by James D. Wolfensohn to the UN General Assembly, June 25, (available from the World Bank Global Environment, Washington D.C.).

Public expenditure per capita on energy RD&D



Note: This figure understates the actual level of public RD&D in energy related matters since RD&D in some sectors—in transport and building sectors in particular—also has a large bearing on the development of energy-efficient technologies and practices. *Source: IEA 1997a.*

FIGURE 11.5. SIMULATED EFFECTS OF ENVIRONMENTAL POLICY ON CARBON DIOXIDE EMISSIONS FOR A DEVELOPING COUNTRY



Note: Initial GDP per capita is $1,500 and growth is 3 percent a year. The early fluctuations in emissions in the 'early policy' case arise from the initial price effects on demand.

Source: Special run by the author using the model described in Anderson and Cavendish, 1999.

Competition from fossil fuels and lessons from the history of nuclear power. In addition to the above-mentioned uncertainties, competition from fossil fuels continues to increase. Estimates of fossil fuel reserves are far greater today than they were 40 years ago, when nuclear power programmes were being initiated. Estimates for the 1955 UN Atoms for Peace Conference put proven reserves at 480 gigatons of oil equivalent and ultimately recoverable reserves at 2,300 (United Nations, 1955)—respectively one-quarter and one-twelfth of current estimates. With the convenience of hindsight, we now know that the underlying premise of the nuclear power programmes that were being advocated at the time—that fossil fuels would be severely depleted by the first half of the 21st century—was wrong, as were two other assumptions: that growing pressures on reserves would increase the costs of fossil fuels, while technical progress would lower those of nuclear power.

In fact, the opposite happened. Except during the oil price shocks of the 1970s, real oil prices have consistently been in the $10-20 per barrel range (in 1995 dollars) for 120 years, despite huge increases in demand. The prices of coal and natural gas (per unit of energy) have generally been even lower than those of oil (BP 1996).[17] Low costs were made possible not only by continued discoveries, but also by technological progress in exploration and production and throughout the downstream industries. In addition, continued technological progress in the electricity industry reduced both the capital and the fuel costs of generation from fossil fuels. In the 1950s the thermal efficiencies of new fossil fuel–fired stations were 30–35 percent; today they are around 45 percent for new coal-fired plant and 55 percent for gas-fired plant.

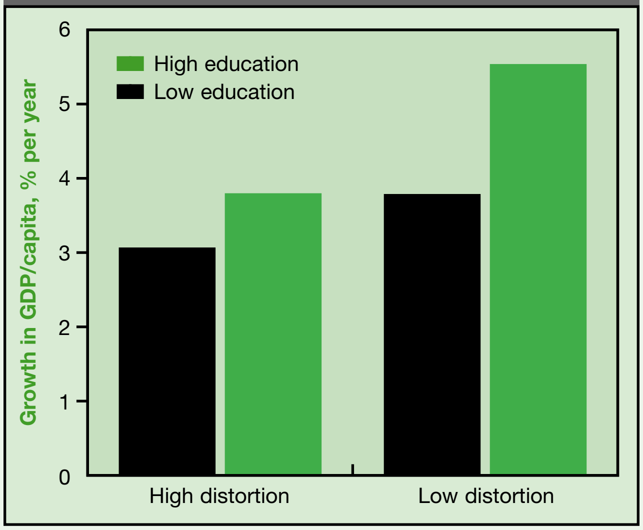
Technological progress and discoveries of reserves thus reduced the costs of power generation from fossil fuels relative to nuclear power. The history of oil and gas is replete with predictions of rapidly depleting reserves and rising prices.[18] In addition, there are promising options for hydrogen production from natural gas and for coal bed methane in which carbon dioxide is re-injected in coal beds for enhanced methane recovery (on a closed, non-net-carbon-emitting cycle), used for enhanced oil recovery, or sequestered deep in saline aquifers (see chapter 8). In sum, non–fossil fuel technologies, including the emerging renewable energy technologies, will continue to face intense competition from fossil fuels for many years ahead.

Nevertheless, from an economic perspective the evidence allows for an optimistic conclusion: technologies are emerging that should

BOX 11.2 HOW MARKET LIBERALISATION AND EDUCATION POLICIES INTERACT TO AFFECT GROWTH AND POVERTY REDUCTION

Studies of investments in education demonstrate the influence of a single policy variable on growth and poverty reduction in an environment of market liberalism. One study (World Bank, 1991) found that education investments have much larger impacts in countries that already enjoy a degree of economic liberalisation than in those that do not. The combination of liberal market policies and investments in education is particularly striking.

Box figure. Liberalisation, education investment, and growth of GDP in 60 developing economies, 1965–87



Note: High and low levels of distortion relate to the foreign exchange premium, a reasonable indicator of trade liberalisation. High distortion reflects a foreign exchange premium of more than 30 percent; low distortion, a premium of 30 percent or less. Education is measured by the average years of schooling, excluding post-secondary schooling, of the population ages 15–64. High education is defined here as more than 3.5 years; low education, as 3.5 years or less. *Source: World Bank, 1991.*

The difference between the higher and lower growth cases is 2.5 percentage points a year. This estimate of what good policies might accomplish greatly understates the effect, as the authors acknowledge, because it concentrates on only two policy variables, is based on average figures for a large number of countries, and makes modest assumptions about what constitutes high education.[1] Yet even 2.5 percent a year, when compounded over a century, would mean a 10-fold increase in per capita incomes relative to the low-growth case—the difference between failure and success in development over the century.

1. World Bank (1997, fig. 5, p. 13) updated the estimates to allow for the quality of institutional development. This raised the estimate from 2.5 to 3 percentage points a year.

enable the virtual elimination of carbon emissions from energy use should the need arise. This is so even if the higher energy demand scenario (scenario A) in chapter 9 were to materialise. The estimated incremental costs of abating carbon emissions are modest in relative terms: most studies put them at 1–6 percent of world economic product to achieve 50–60 percent abatement by the middle of the next century and 2–8 percent of world product by the end of the century.[19] Even at the higher end these estimates would amount to less than two year's growth of world product over a 50 year period and four year's growth over a century. They would shave less than 0.1 percentage point a year off the long-term growth rate (which averages about 2 percent a year in industrialised countries and more than 4 percent a year in developing countries with progressive economic policies).

In sum? A scenario of low carbon emissions in the long term is technologically and economically achievable and is fully consistent with the goals of developing countries achieving economic prosperity (and enjoying higher levels of energy consumption) in the present century, and of the industrialised countries improving their prosperity.

Liberalisation and globalisation

In the past half century successive multilateral rounds of reductions in the barriers to trade and foreign investment have led to considerable increases in the level and globalisation of economic activity. Between 1971 and 1995, as world GDP expanded at almost 3 percent a year, international trade increased at 5.6 percent a year and now stands at more than 22 percent of world economic product. Foreign direct investment expanded even more rapidly, at 12 percent a year between 1980 and 1996, encouraged by liberalisation and privatisation of formerly state-owned companies. It accounted for more than 10 percent of total domestic investment in 1995.

What are the implications of globalisation for the energy industry? Market liberalisation in the industry over the past two decades can be seen as a response to a range of problems and opportunities:

- The growing difficulties of raising finance (especially in the electricity sector), a consequence of high levels of government intervention and subsidies.
- The growing difficulties of the public sector in providing for the financial losses of the state-owned industries.
- Deteriorating service levels in many countries, reflected in frequent black-outs and brown-outs.
- The need to reduce losses and cost inefficiencies.
- The increasing transparency of costs and investment decisions, in the electricity, nuclear power, and coal industries in particular, which led to increased questioning of the cost-efficiency of public investments in the industry.
- The rapid growth of energy markets in developing regions and related opportunities for trade and investment in all energy sectors—electricity, coal, gas, and oil.
- New opportunities for trade and investment in high-efficiency technologies, such as combined-cycle power plants, brought about by the growth of world gas reserves.

But as the world economy has become more integrated, there are fears that the rapid growth of trade and investment will have two undesirable side effects. The first is that the most impoverished people will be left out of the process of economic growth and development—only higher income groups will benefit—and inequality, poverty, and social conflict will intensify. The second is that there will be deleterious effects on the environment.

Technologies are emerging that should enable the virtual elimination of carbon emissions from energy use should the need arise.

These fears are not unfounded. But they rest on the (perhaps less commonly articulated) assumption that complementary policies will not be put in place to achieve growth on a broad basis and to protect the environment. It is not possible to predict reliably whether such policies will be pursued, but we do know that the effects will be profound one way or the other. (See box 11.2 for a discussion of the influence of just one policy variable, investment in education, that has been shown to be crucial for improving growth and reducing poverty.)

If complementary policies are in place, the rate of economic growth and development on a broad basis will be appreciably higher under liberalisation. Environmental policies and a range of other policies—health and population, agricultural extension, vocational training, physical infrastructure, and social infrastructure, including a regulatory framework for industry and commerce[20]—are also complementary to the growth process. No policy of market liberalisation can succeed without them.

On the environmental front there has already been a substantial response by the energy industry. Trade and foreign investment—in environmental as in other technologies—are ideal conduits for technology transfer and a means of enabling developing countries to address their local and regional environmental problems at a much earlier phase of development than industrialised countries did. The new forms of regulation that are accompanying liberalisation of energy markets also provide an opportunity for incorporating investment incentives for the development and commercialisation of environmentally friendly technologies (renewable energy, hydrogen and fuel cells).

The problem of access will be more of a challenge. Providing modern energy services to perhaps 6 billion new customers must be one of the primary goals of the energy industry in this century. But it is clear from the range of complementary policies that are needed for market liberalisation to work that the industry cannot accomplish this alone. All markets in open societies function within a framework of laws, legislation, standards, and public and private information services designed to improve the clarity, integrity, and equity of economic transactions. This framework is the 'ghost in the machine'. Without it the risks of investment rise for any industry attempting to address the problem of access by investing in low-income markets, and without it sustained income growth in these markets will also be more difficult to achieve.

While there is much evidence to show that liberalisation should facilitate service extension, progress will need to be monitored. There is a danger that the industry may concentrate on the easier, more established markets in urban areas where demand growth is high. Some financial or regulatory incentives may be required to address the problem. While the evidence is still ambiguous, it is noticeable in the electricity sector that private investment in liberalised markets has so far been concentrated either in greenfield investments in power generation or in the acquisition of assets, with relatively little investment in the expansion of distribution (table 11.8).

While it is possible that these investments in assets are a prelude to service expansion and extension, service extension is too important to rest solely on unmonitored assumptions. There will thus be a need for independent oversight both of the industry and of the regulatory process. Ground rules for regulation (discussed in the concluding section) will not only need to concentrate on the usual goals of monopoly avoidance and economic efficiency, but also on the problems of widening public access to energy services.

Conclusion: economic perspectives on policy

Over the next half century the energy industry will need to reach another 6 billion people or more (depending on population growth), while meeting the rising demands of the 4 billion already served. It will need to do this while substantially reducing local and regional pollution levels, particularly in developing regions, where the task of pollution abatement has hardly begun, and while developing new technologies and practices for reducing global carbon emissions and other greenhouse gases in the long term.

Several lessons of experience and ground rules for policy can be derived from a large number of studies that have reviewed energy and environmental policies:

The extension of modern energy supplies to people currently without them cannot be accomplished by the industry acting in isolation, but will depend also on the quality of development policies. Income growth is the main determinant of people's ability to afford and use modern energy forms. If development policies fail to promote economic growth on a broad basis, attempts by the energy industry to widen access will have limited success. If development policies are progressive, the industry (and its regulators) can be confident that markets will emerge in low-income as well as higher income communities to meet emerging demand and so will improve the social and economic situation of billions of people.

The liberalisation of energy markets, which experience has

TABLE 11.8. PRIVATE INVESTMENT IN DEVELOPING COUNTRY POWER SECTORS, 1994-98

Type of activity	Capacity financed (gigawatts)	Investment (billions of U.S. dollars)
Greenfield	36	46
Privatisation	26	14
Distribution	0	58
Total	62	117

Source: Martin, 1999, who comments that the greenfield investments are mainly in generation.

Providing modern energy services to perhaps 6 billion new customers must be one of the primary goals of the energy industry in this century.

shown to be fundamental for the efficient growth of the industry, is also crucial for widening access. The liquefied petroleum gas (LPG) market in Brazil illustrates this point. By 1991 it served nearly 90 percent of the population. As a cooking fuel LPG is 10 times more energy efficient than wood fuel and several thousand times less polluting. In Brazil it is supplied entirely by private enterprise. The only times investment and progress towards the extension of LPG service suffered were when the government heavily regulated its price and distribution (Reis, 1991). The World Bank (1996) reports a similar experience in Hyderabad, India. As a consequence of liberalisation of the energy markets, LPG use expanded from the richest 10 percent of households in 1980 to more than 60 percent of households in the early 1990s, even as the population doubled.

The goals of liberalisation extend to trade and foreign investment in energy technologies and services. Enabling trade and foreign investment in energy technologies and services will allow the energy industry to apply its considerable financial, technical, and managerial resources to improving and extending energy supplies. Trade and foreign investment are also ideal conduits for the transfer of efficient end-use and environmentally improved technologies.

Economic efficiency provides a good basis for regulation. It points to a range of indicators for assessing an industry's performance. It requires regulators to look at measures of cost and price efficiency, at environmental performance (since the persistence of undesirable external costs is a source of economic inefficiency), and at the industry's efforts to extend service. The following are some ground rules for the electricity industry; parallel ones can be developed for gas:

- *Price efficiency.* Prices reflect the level and structure of the marginal costs of supply, differentiated by time of day, season, and voltage levels (an outcome of pool pricing and supply competition in liberalised markets). Marginal costs include the costs of compliance with environmental policy.
- *Subsidies.* These are avoided, with financially minor but socially important exceptions, and are not such as to undermine the financial performance of the industry. They are also unnecessary, since the industry has long been capable of financing its own expansion—including the expansion of service to new consumers—through retained earnings and recourse to capital markets. Exceptions may be 'lifeline' rates for household consumers with low levels of consumption, allowances for the higher fixed costs of the extension of service to new areas, and investments in RD&D projects.
- *Cost efficiency.* Typical yardsticks are the costs and efficiencies of thermal plant relative to known international best-practice standards, reserve plant margins, electrical losses, and plant availability factors.
- *Quality of service.* Probabilities of loss of load and brown-outs are good indicators of service quality.
- *Widening access.* The portion of the population served by grid or off-grid schemes is monitored and used as a measure of progress towards the goal of providing universal service.
- *Commercialisation policies for environmental innovation.* New forms of arm's length regulation following market liberalisation provide opportunities for establishing new forms of incentives for the development and commercialisation of environmentally friendly technologies. These include competitive bidding processes and incentives for private investment. The modularity of many of the emerging technologies means that the financial risks are small, especially relative to those of the nuclear power industry in the 1950s to the 1970s.

Taxing energy is not an effective instrument of environmental policy, notwith-standing many claims to the contrary The case for energy taxes has long been widely accepted on the grounds that they are an efficient form of taxation—they raise revenues without, it is thought, seriously distorting economic activity. The case for imposing additional energy taxes on environmental grounds, however, is not well founded. Such taxes increase revenues while having negligible effects on pollution. If pollution is to be reduced, there is no substitute for taxing or regulating pollution directly.

There is no reason, from either a technological or an economic standpoint, why the world cannot enjoy the benefits of both high levels of energy use and a better environment. Technological and managerial options are already available or capable of being developed that would substantially solve both local and global environmental problems from energy use at costs that may be large in absolute terms but are small relative to the long-run costs of energy supplies. Reducing local pollution is likely to raise rather than diminish economic output because of the attendant reduction in external costs. This conclusion should be especially heartening to developing countries, whose energy consumption will rise substantially as they strive to achieve economic prosperity.

In light of the promise of new, 'environmentally friendly' energy technologies on the one hand, and of emerging environmental problems on the other, there is a good case for revisiting the role of technology policies, including public support for RD&D. There is ample evidence of market-led technical progress in the energy industry: reductions in the costs of off-shore oil and gas exploration, improvements in the thermal efficiencies of power plant and reductions in the costs of electricity supply, reductions in power plant lead-times, and the ability to develop technologies for reducing pollution by orders of magnitude, to note a few.

Yet many people have argued, in response to concerns about climate change—and governments in the OECD countries are, by and large, accepting the arguments—for public or regulatory support for the industry to develop new non–fossil fuel technologies, based on renewable energy and fuel cells and hydrogen. Such policies, which differ in detail and scale but not in intent between countries, hold the potential for economic and technological surprise. These areas are fertile ground for industry RD&D—areas that the industry might otherwise have ignored because of the abundance of fossil fuel reserves.

In view of the climate change problem, energy technology development and commercialisation programmes for climate friendly technologies also need to become more outward looking and international in scope. Developing countries especially need to become engaged in the development and use of such technologies. Aside from bilateral initiatives there are three complementary instruments of policy well suited to this purpose: the Global Environment Facility, the financing arm of the Framework Conventions on Climate Change and Biodiversity; Joint Implementation and the Clean Development Mechanism, which, if ratified, will enable companies to reduce carbon emissions through foreign investment when (as it often will be) it is cheaper to do so abroad than in the home country; and regulatory and tax policies to provide financial incentives for the early development and use of non–fossil fuel options in developing countries. There are now many examples in the OECD countries to show that such policies can be pursued in market-oriented ways without compromising the financial integrity of the industry.

Financial analysis consistently shows that, under enlightened regulation, the energy industry is capable of mobilising the financial resources required to expand services and address environmental problems through a mix of internal cash generation and recourse to the financial markets. As the report of the World Energy Council (WEC 1997, p. iv) concludes: "global capital resources in principle are more than adequate to meet any potential demands coming from the energy sector. These demands are unlikely to exceed 3-4 percent of global output, the same proportion that has prevailed over past decades", a period of rapid industry expansion similar to that of the trajectory in the high-growth scenario (Scenario A) in chapter 9. The same conclusion applies to the provision of finance to meet the cost of solving local and regional environmental problems. These costs are unlikely to exceed more than 5–10 percent of the costs of supply, and any increase in costs is likely to be more than offset by gains in efficiency. Pollution should be greatly abated and the costs of energy supplies should fall. The financial requirements of the RD&D effort required to develop new non–fossil fuel technologies are also likely to be relatively small.

The main financial problem ahead could be posed by the capital requirements of developing countries. But if this materialised, it would be a self-inflicted problem. As the World Energy Council (WEC 1997, p. iv) further argues, "Contrary to popular belief, savings rates in many developing countries are double those of the US and generally one third greater than those of Europe or Japan". A large proportion of the required finance could be generated internally, with the remainder coming from international capital markets, which should in a favourable economic environment find investments in energy among the most attractive of options. The key is to offer a system of arm's length regulatory policies that allow investors to enter energy markets and to earn good rates of return while enabling the industry to extend service and reduce pollution.

Notwithstanding an immense literature on the subject of energy and the environment, four propositions remain needlessly controversial and a source of much confusion, not least among the policy-making community. They are that:

- Local, regional, and global pollution arising from energy production and use can be virtually eliminated through technological substitution towards low-polluting forms of energy. With the important but partial exception of carbon dioxide abatement, where significant RD&D and commercialisation efforts for new technologies are merited, alternative fuels and technologies are already available or emerging.
- Thanks to developments in pollution prevention and control, most stemming from recent policies in industrialised countries, developing countries can aspire to eliminate major forms of pollution at a far earlier phase of development—in most cases in the first third of this century—than the industrialised countries before them.
- The costs would not be large in relative terms and could be financed internally through the application of standard instruments of environmental policy.
- A low pollution future is fully consistent with higher levels of energy use in developing countries and the achievement of economic prosperity on a broad basis. A low pollution future is also consistent with high levels of energy use in industrialised countries, provided that efforts to develop the required technologies and practices continue.

In workshops and though other forums we need to debate such propositions further, to show just what enlightened policies might accomplish.

Notes

1. See glossary for definition of terms.

2. This figure, reported in World Bank (1996), was compiled and presented initially by Zihong Ziang in an unpublished research note for the World Bank. Ziang surveyed energy statistics from a large number of reports in the World Bank's files. Figure 3.1 in chapter 3 provides a regional breakdown of the estimate of unserved populations.

3. See Lebergott (1993, table II.16, p 107), World Bank (1996, p 39-40), and Pearson (1994).

4. Explaining this statistic, Lebergott footnotes: "As of 1990, a yearly estimate of 4,420 cloth diapers per child, plus 8,060 gallons of water to rinse and wash them and 2.5 years in diapers" appears in a survey by Arthur D. Little Inc.

5. The estimates from a survey by Whittington, and others. (1994) on water vending in Ukunda, Kenya. are based on an unpublished survey undertaken by water supply engineers in Lagos in 1986 in connection with a World Bank project; the average distance over which the water was carried was a quarter of a mile.

6. Recent surveys of rural families in countries as diverse as Colombia, Jordan, Nepal, and Ukraine on their preferences for cooking fuels yielded identical results: the preferred fuel was gas or LPG, followed by kerosene and then wood. But the actual choice depended crucially on availability and costs (with costs varying immensely with the accessibility of the village and the quality of roads). Where wood was locally abundant, low- (but not high-) income families would use it until local resources were depleted. I thank the following students for undertaking surveys on preferences of rural people: Mike Hugh (in Jordan), Paras Gravouniotis (Nepal), Ernesto Salas (Colombia) and Nick Fraser (Ukraine) on field trips to these countries. The results are available in UNDP files.

7. Forecasts are reviewed in IPCC (1995 a, b) and Nakicenovic, Victor, and Morita (1998), which summarise more than 300 projections of world energy demand and carbon emissions.

8. I thank Eberhard Jochem for this figure and comments on it.

9. See Schipper and Meyers (1992); U.S. Congress (1995 a, b); Watson, Zinyowera, and Moss (1996); WEC (1993); and IPCC (1995); chapter 6 provides further evidence and an ample bibliography.

10. As discussed below, the annual rate of improvement in energy efficiency is thought to be in the range of 0.5 to 1.5 percent a year. If the latter figure holds, or even a figure of 1 percent a year, then an economy whose per capita income elasticity has declined to the 0.25. to 0.5 range and whose long-term growth rate is 2–3 percent a year could easily enter a period in which the long-term trend in energy demand is negative.

11. The actual effect on demand depends on two factors: the effects on costs and prices, and the price elasticities. The change in demand (D) following a change in price (P) is given by DD/D = aDP/P, where a is the price elasticity. Suppose energy efficiency reduces energy needs for a given application by a factor of 2, but also reduces the costs by the same amount; if the price elasticity is – 0.5, demand will fall by only 0.5 x 0.5, or 25 percent, not by half as predicted by engineering calculations, which neglect the point that the number of applications commonly rise following a reduction of price. Overall, since energy demand is fairly price inelastic, the prevailing consensus is that energy efficiency will lower energy demands relative to prevailing trends. However, the effect is smaller than often thought, and much depends on the price elasticity for the particular application. Also important, of course, are the prices of the appliances.

12. In this respect it is lamentable that a commonly used index of environmental damage is energy consumption, when as argued earlier energy is a good not a bad, and the essential task for environmental policy is to abate the pollution from energy use not energy use itself.

13. For values of $\gamma = 1.0$, $g = 4$, $n = 2$, $x = 1.5$ (the higher limit), for example, and neglecting for now any declines in the costs and prices of energy brought about by further improvements in energy efficiency, the long-term growth rate would still be more than 4 percent a year in developing regions, with demands doubling every 15 to 18 years.

14. In 1985 prices. In these studies of the environmental Kuznets curves, per capita incomes are based on real comparative purchasing power data provided from the Penn World Tables (mark 4; Summers and Heston, 1991). Such data point to significantly higher real incomes in developing countries than are provided in national income data converted at official exchange rates. The environmental Kuznets curve (the inverted U-shaped hypothesis) is controversial and was never put forward by the late Simon Kuznets himself. As a device for predicting future trends in pollution, it has been discredited.

15. In practice, rooftops and desert areas would be used for the direct solar technologies, such that there would be little or no competition for arable lands arising from these technologies.

16. Visual intrusion is often a serious problem with wind and is now leading several European countries to move to introduce ‘offshore’ wind farms.

17. The prices per British thermal unit (Btu) were $3.20 for oil, $1.50–2.50 for gas, and $1.50 for coal in 1995, with the price of gas varying with region. The figure

for coal is based on a conversion factor of 27 million Btu per tonne.

18. See Odell (1998), who draws attention to past errors of under-estimating the capacity of the fossil fuel industry to discover new reserves and lower costs, and the moral to be drawn from this.

19. See Weyant (1993) and Grubb, and others (1993). Estimates vary with assumptions about the rate of progress in the development of non-carbon technologies. As noted earlier, these estimates are conservative and fail to consider the possibilities of the innovation leading to technologies with costs lower than those of fossil fuels. So the ranges are actually from < 0.0 to the upper estimates cited here.

20. For an earlier assessment of the effects of social and economic policies on growth, see Harberger (1984). The World Bank's *World Development Reports* provide several syntheses of the effects of social and economic policies on the growth and distribution of per capita incomes and contain ample bibliographies.

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