

SUSTAINABLE DEVELOPMENT

A Global Energy Perspective

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Introduction

Among the issues any world summit concerned with sustainable development is obliged to confront is the role of energy in human welfare. If energy resources and their transformation into important “downstream” commodities like transportation fuels and electricity are expensive relative to per capita income, or if energy supplies are scarce and energy infrastructure is insufficient, people are less well off. Such circumstances are a special burden for the world’s poorer countries. Although historically, resource scarcity has invariably been overcome, significantly higher-cost energy could complicate the momentum toward a healthy economic future.

But energy commands attention not merely because of its implications for economic and social development. Many of the world’s environmental problems are uniquely connected with the production and use of energy resources: pollutants from fossil fuel combustion, ecological damage from hydroelectric dams, and unsolved problems associated with the nuclear fuel cycle, to name just a few obvious examples. Thus, matters of energy cost, economic growth, and environmental integrity together constitute a critical dimension of sustainability.

To convey a general sense of where we are and where we may be heading over the next several decades, I first sketch out highlights of the current energy situation and describe how things have evolved since the 1992 United Nations Conference on Environment and Development (UNCED) in Rio. I then discuss the prospective role of renewable energy resources and the outlook for enhanced use of natural gas—two sources that could lead to a better natural environment. Although renewables, as the name suggests, additionally promise an escape from the energy scarcity conundrum, natural gas and other fossil fuels may have more staying power than some people believe.

World Energy Ten Years after Rio

A snapshot of the world energy scene a decade after the 1992 Rio conference reveals a number of highlights:

- Commercial markets for primary energy sources are still heavily weighted toward fossil fuels (with attendant emissions of greenhouse gases and other pollutants): coal has a 22% share; oil, 40%; natural gas, 23%; nuclear power and hydroelectricity, 7% each; and nonhydro renewables, 1%. The last figure does not include the persistently high volume of nonmarket fuelwood and farm residues used in numerous developing countries. Estimates of such noncommercial energy use are not very reliable, but according to rough calculations by the International Energy Agency (IEA), they average around 25% of aggregate energy consumption and nearly 75% of household energy use in developing countries. But an important qualifier attaches to those numbers: not only are such nonmarket sources used inefficiently; their exploitation contributes to erosion and loss of soil fertility.
- Energy consumption continues to be centered predominantly in industrial regions. Given the oil-producing role of the Middle East, Africa, Indonesia, and Venezuela, energy production is more equally divided—with developing and industrial countries each accounting for about half. That asymmetry, especially as it relates to oil, frequently adds an element of political stress to purely market factors. Within the producing group, Russia is rapidly re-emerging as a consequential player.

- Of the total amount of primary energy resources deployed, major portions go into electricity generation and into transportation. Reflecting a steady 30-year rise, these uses now account for 40% and 25%, respectively.
- The world oil price (in 1999 dollars) has lately averaged about \$25 per barrel.
- Per capita energy consumption varies significantly around the world. Near the head of the list, the United States consumes 354 million British thermal units (Btus). Western Europe uses 170 million Btus per capita; Japan, 172; the countries comprising the former Soviet Union and Eastern Europe, 122; China, 25; India, 12; and developing parts of the world as a whole, 26.
- Not surprisingly, per capita energy consumption tends to track per capita income, with developing countries averaging one-seventh the income level of industrial countries and one-eighth their per capita energy use. But for several reasons—industrial structure, incentives to conserve energy, and (conversely) subsidies encouraging consumption—the two indicators frequently diverge, as is clear from figures on “energy intensity,” energy use per \$1 of gross domestic product (GDP). If this ratio is set at 100 for the United States, we find that the former Soviet Union and Eastern Europe have an energy intensity of 181; Canada, 119; Japan, 63; China, 95; India, 89; and the nations (largely industrial) making up the Organisation for Economic Co-operation and Development (OECD), 83. For the world as a whole, the index stands at around 90.

Does that picture differ markedly from circumstances prevailing ten years ago? Notwithstanding some notable technological improvements affecting incremental energy use—for example, a power plant coming on line today produces electricity with vastly greater efficiency than one that started operation in 1992—the energy “system” shows a substantial degree of inertia. In part, that arises from the long life of many energy-using assets, such as buildings. Low annual turnover limits the opportunity to introduce innovations with pervasive near-term impact.

The ten-year comparison also depends on the indicators being compared. The overall share of fossil fuels remains largely unchanged, although the proportionate importance of coal has declined, offset by somewhat higher shares for oil and natural gas.

Episodes of political and economic turmoil have caused some sharp swings in oil prices but no discernible trend away from the low- to mid-\$20s-per-barrel range. To the extent that price is a measure of emerging scarcity—never mind the legitimate debate about the future implications of increasing geographic concentration of oil supply—this relative stability comports with evidence regarding the world’s oil reserves: from 1990 to 2000, the world produced and used some 266 trillion barrels of oil, yet proved reserves were 5% higher in 2000 than in 1990, leaving the ratio of reserves to production largely unchanged at around 40. At least for the present, therefore, oil discoveries and development more than match demand.

If not as rapidly as would have happened under a rising price regime and, arguably, more proactive conservation policies—say, with respect to U.S. automotive transportation—energy intensity has tended to diminish in all principal regions. This is a development to which reduced subsidies and market-driven efficiency potentials no doubt contributed. The rise in efficiency varies with local circumstances but in general, a continuing reduction in energy use relative to economic output seems highly probable. Russia’s ability to reform its historically wasteful energy use patterns, the legacy of its Communist past, is just one case in point. (One should, however, recognize that the country’s economic modernization, including technologically improved petroleum drilling

and production, could *stimulate* energy use if it reduces energy costs.) In other regions, ranging from Eastern Europe to China, structural changes in the energy sector and pricing reforms are similarly impelling more efficient energy use.

The recent slowing of world population growth is of more than peripheral interest in an energy context, for it can mean less pressure on energy supplies and costs. The latest “medium” UN projections, issued in 2000, show world population rising from 6.06 billion in 2000 to 9.32 billion in 2050—some 1.5 billion less than what was projected just four years earlier. Looked at in another way, the “low” 2050 projection issued in 2000 conforms to the medium projection of 1996. Reductions like these are due in large part to strikingly lower birth rates in a number of populous developing countries. As a result, worldwide population growth over the next 50 years is currently projected to grow at an average annual rate of 0.86%, in contrast to the 1.77% rate during 1950–2000. Of course, reduced population pressure might also *stimulate* energy demand, to the extent that lower fertility may lift per capita income. But proof of an inverse tradeoff between population growth and per capita income growth remains elusive despite many years of study.

For now, access to affordable energy in many low-income regions remains forbiddingly limited, and that situation poses two major challenges over the coming decades, during which the bulk of energy growth is likely to occur in those poorer areas. The first is to ensure an improvement in real income that makes energy affordable. Numerous analysts and research groups have developed alternative projections and scenarios of income growth for today’s developing countries; their efforts suggest an annual rate of around 2.2% as a reasonable mid-range projection of per capita GDP growth. This rate would yield a level of per capita GDP of approximately \$10,600 (\$1999) by 2050—a solid if not wholly satisfying gain in living standards (per capita GDP in industrial countries is *today* around \$22,000). The disparity in per capita GDP for developing countries would thus shrink from one-seventh that of industrial countries today to perhaps one-fourth by 2050. Allowing for reduced population growth and improved efficiency of energy use, demand for energy, though slowing, will almost surely continue to grow (see box.)

The second challenge is to reconcile that increased energy demand with the kind of environmental imperatives that both rich and poor have reason to embrace. Two promising directions are greater roles for renewables and for natural gas.

Renewable Energy: Promise and Prospects

Nonhydro renewable energy remains by and large a small fraction of the energy mix around the world. Conventional hydroelectricity has generally been excluded from the renewable energy category. Even though a technologically mature energy system able to produce power at nominally low cost, new hydropower facilities are increasingly viewed as inimical to a whole host of social values: stream flow, ecology, tribal lands, and population settlements. Those values may figure less decisively in some developing countries—consider China’s Three Gorges Dam on the Yangtze River—where the hydro potential is large, but even energy-short developing countries have become sensitive to such considerations.

Notwithstanding some impressive progress, renewable energy systems, such as wind and solar power, are hobbled by the same constraints on market penetration facing both developing and advanced countries: the technological progress and cost advantages enjoyed by competing con-

ventional systems. IEA projections that show nonhydro renewable energy growing at a rate of 2.8% per year worldwide over the next two decades are scarcely breathtaking.

All serious studies of renewable energy's future must distinguish between technical potentials and realistic economic prospects. With respect to technical possibilities, the recent IEA study puts it well:

... renewable energy has the technical potential to meet large portions of the world's energy demand. Bioenergy has the technical potential to cover a much larger share of the world's energy needs in all sectors and applications: heat, power, and transport. The world's supply of wind, solar, and geothermal power can theoretically meet current global electricity demand many times over.

Geographic variability, however, is an important consideration. Sunny regions are obviously ideal for solar systems, coastal areas and plains for wind power, volcanic basins for geothermal energy, and forested and agricultural lands for biomass applications.

Even where the overall economics look favorable, substantial capital requirements for renewable power systems create a special burden for developing economies, with their chronic shortage of investment funds. Although the modularity of some renewable installations can help spread the up-front costs over time, raising the needed investment capital remains a challenge that dims the outlook for renewable energy in the developing world.

It is not merely the magnitude of capital requirements. A World Bank report points out, *[c]ommercial banks in developing countries can be an important constituent in the sustainable 'mix' of supporting infrastructure for renewable energy. But these potential partners are risk averse, and therefore require specialized training, persuasion, and risk sharing to equip them to support renewable energy development. Greater financial sophistication is needed to enhance energy service, choice, and access in rural areas. Capital markets should be capable of providing a broader base of financial resources that respond to the needs of rural electricity services markets.... Appropriate legal infrastructure and enforcement mechanisms are also essential if renewable energy businesses are to thrive. Legal mechanisms must protect the viability of credit, businesses, and foreign investment, and safeguard the rights of all players in the market. An effective, fair legal framework lowers risks and their associated costs for everyone.*

What are some specific considerations regarding each of the major renewable energy sources?

- Where the resource (including both wind speed and land) is abundant, **wind power** is the most cost competitive with conventionally generated electricity. The IEA anticipates that the narrowing gap will allow an annual wind power growth rate exceeding 10% over the next several decades, with China and other parts of Asia particularly well positioned. Wind power project analyses, however, must incorporate the phenomenon of intermittency (at least until electricity storage becomes an affordable and practical reality—something that appears to be a rather distant prospect). If that fact necessitates, as offset, increased system reserve margins, the economic balance of advantage for wind becomes more questionable.

- In tropical zones, where many of the world's developing nations lie, **solar** radiation (“insolation”) per unit of land surface is typically higher than in temperate regions. For example, the radiation-land ratio is about 80% higher in Riyadh or Brasilia than in Tokyo or Dresden. High insolation is an important factor governing the viability of solar photovoltaic and solar thermal energy, the former being the more likely application, especially in developing countries.

■ Competition from lower-cost conventional power production, notably by combined-cycle gas/steam turbine (CCGT) systems, will continue to slow market penetration by solar power, even with falling costs. (As with prospects for other renewables, unexpectedly steep price increases for natural gas would work to solar's advantage, however.) To the extent that solar power gains market share, it will likely be as part of electrification projects in isolated rural areas whose connection to a distant power grid would be unacceptably costly. As such areas enjoy increased integration into a nation's electricity grid that advantage may subside, though other decentralized power systems may become independently beneficial.

■ Exploitable **geothermal** resources exist in relatively few parts of the world. Only six countries (the Philippines, New Zealand, Iceland, Costa Rica, El Salvador, and Kenya) derive more than 5% of their national electricity output from geothermal reservoirs. In absolute terms, the United States produces the most geothermal electricity, but this source is just 0.4% of the country's electric power output. Worldwide, the share is an inconsequential 0.3%. As with wind power and solar photovoltaics, development of geothermal systems is capital intensive, with exploration and drilling costs a major part of required investment outlays. Although identifying geothermal reservoirs is less speculative than prospecting for petroleum, success in finding and extracting an economically sufficient volume is not assured. Generally speaking, though, countries with high-quality resources appear capable of sustained production at generating costs of about 4 cents per kilowatt hour—a price that bodes well for this renewable.

■ **Biomass** (or “bioenergy”) resources could contribute to meeting primary energy needs. Two prominent examples are forest products (including wastes from pulp and paper mills), used to provide direct heat or as a boiler fuel to generate electricity; and grain- or other plant-based products, convertible into liquid fuels for transportation. Biomass may not possess the environmental virtues of wind or solar—fuelwood combustion, after all, emits pollutants, intensive cultivation of energy crops can cause erosion, and indoor wood burning is widely regarded as a public health menace. Nevertheless, biomass offers some attractive features. In particular, using forest products for power generation involves an uncomplicated combustion technology; costs probably not far out of line with conventional systems; and when feedstock production is pursued in a sustainable-yield approach, a CO₂-neutral way of meeting energy requirements.

Present-day volumes of commercial bioenergy are small, and much of that depends on subsidies. For example, after Brazil subsidized an ethanol program beginning in the mid-1980s, sales of cars fueled only by ethanol grew to 96% of the new automobile market. As that program wound down and was then eliminated in 1999, the share rapidly approached zero. A state-of-the-art wood-fueled district heating plant near Graz, Austria, had half of its investment cost covered by a grant from the European Union, with additional subsidies from the national and provincial governments. There are many such examples.

In analyzing the economics of forest-based energy biomass, Roger Sedjo, of Resources for the Future, has compared the use of fuelwood for power production with the use of the same timber for making wood products. He finds that in some developing countries, the cost of wood from plantations is below the levels needed to be competitive with natural gas or coal. He cautions, however, that this very circumstance could prompt industrial wood producers to outbid electric generators for the biomass resource. Two possibilities could enhance fuelwood prospects. First,

fuelwood generation typically suffers from scale diseconomies compared with industrial wood enterprises, but if that disadvantage could be offset by improved combustion efficiency in converting biomass to electricity, the fuelwood electricity option could be economically more attractive. Second, limited cofiring with coal in conventional generating plants could create at least a niche market for bioenergy. And if a Btu of energy from sustainably grown wood can replace a Btu of energy from coal, the reduction in CO₂ emissions would make a contribution to dealing with global warming.

The overall conclusion from the IEA assessment of renewables is that only wind merits a present-day cost estimate of “relatively low”; costs of the other major contenders are characterized as “high” or “very high.” Yet every renewable technology could achieve significant cost reduction by 2020—even solar photovoltaic systems, whose current very high cost could, according to the IEA, fall by 30% to 50%.

A final point to keep in mind when calculating the economic balance of advantage among energy systems underscores the importance of a matter already raised: the extent to which the presence (or absence) of subsidies and environmental policies shape the competitive outcome. Where coal combustion is not charged or otherwise regulated for CO₂ emissions, coal-based electricity will be cheaper than otherwise. Where wind power receives a sizable production tax credit or other subsidy, its economic attractiveness is similarly enhanced or exaggerated. In the United States, at least, penalizing fossil fuel combustion according to its environmental impacts while reducing subsidization of wind power would still leave the latter short of competitive parity.

While unremitting subsidization of renewables therefore does no favors to sustainable development, it is also true that there is no clearcut way of reckoning the value of fossil-fuel externalities to be charged; estimating the damage from climate change, after all, is no simple matter. Nor, however, can one confidently decry all subsidies. Government has an undeniable role in supporting basic research for renewable and other energy systems whose lengthy developmental gestation may discourage private investors, even though the ultimate payoff to society could be significant. In short, helping renewables to sustain their technological momentum without trying to meet targeted energy market outcomes by crossing the line from basic R&D to commercial activism seems like constructive public policy.

Natural Gas

Among fossil fuels, exploitable coal deposits are so abundant that declining output, when it occurs, is much more likely to be due to environmental rather than scarcity factors. Aided by such exploratory breakthroughs as “3-D seismic” and enhanced production capabilities through deep-sea and horizontal drilling, development of oil reserves and oil production, as shown earlier, have kept pace with each other.

These recent technological advances apply to natural gas as well. And as with oil, the natural gas proved reserve/production ratio has remained stable (at around 60 years in both 1990 and 2000) even as large quantities of the resource have been produced. But unlike oil—whose exploration and production has by now occurred over a relatively wide swath of the earth’s surface—natural gas is, geologically speaking, a “young” resource that continues to reward worldwide exploration with many discoveries. And as the least polluting fossil fuel, natural gas has

become the focus of widespread interest in analyses and policy discourse about likely and desirable energy paths in coming years.

Proved reserves of natural gas currently stand at approximately 5304 trillion cubic feet worldwide, equivalent in heat value to about 885 billion barrels of oil. Assuming a 50% probability of future exploratory success, the U.S. Geological Survey (USGS) estimates another 700-billion-barrel oil equivalent in discoverable and recoverable natural gas. The geographic distribution of known and potential gas basins is wide, with significant concentrations in parts of the former Soviet Union, the northwest shelf of Australia, offshore Norway, and the Middle East. A geopolitical observation of perhaps some importance is that, compared with oil, proportionately far greater portions of proved and potential reserves lie outside the Middle East.

Utilization of gas can proceed in three ways: at or near the wellhead, transported to distant markets in liquefied form by tanker, and moved by pipeline. The first type of use has been common in the petroleum-producing Persian Gulf countries, where gas was often a by-product of oil extraction and not easily marketable. What was not reinjected to maintain reservoir pressure was used locally in power generation, desalination, and a few energy-intensive operations, such as aluminum smelting. Shipment of liquefied natural gas (LNG) has increased steadily—Japan, for example, receives significant supplies from Brunei—but the cost of liquefaction, specialized tanker transport, and re-gasification makes this a costly proposition, currently more suited to premium usage or dictated by local circumstances that militate against alternative fuels on environmental or economic grounds. That leaves pipeline transmission as the principal way to deliver gas. USGS estimates of gas resources suggest that much of the prospectively large gas reserves can, in fact, reach market via pipeline transmission, though Australia and the Middle East are largely dependent on LNG shipment.

In sum, natural gas seems almost certain to increase its worldwide energy share over the next 20 years. The IEA projects an average annual growth rate of 2.7%, and the U.S. Department of Energy predicts 3.2% growth, but in either case, the increase is more than 40% greater than that foreseen for oil. Neither agency ventures specific estimates of the real prices at which these supplies will be produced and delivered in different markets throughout the world, nor do they predict how gas prices might vary with world oil prices. But their discussion suggests an underlying judgment that prices will remain fairly level over the next two decades—and a stable natural gas price would not make the market penetration by renewables any easier.

Wrap-Up Observations

This discussion prompts five concluding thoughts:

1. The per capita energy consumption gap between the haves and the have-nots of the world is unlikely to escape attention at the Johannesburg World Summit. But the broader problem—of which energy is one component—is the per capita income gap. Energy, in the form of electricity to run motors, fuel for transport, and hundreds of other applications, is critical for boosting a nation's productivity and stimulating its economic growth. In turn, that very growth permits people to purchase the household necessities and creature comforts associated with increased energy usage. So it is no coincidence that per capita income of developing countries averages one-seventh the level of industrial countries, and the corresponding ratio for per capita energy use is a close one-eighth.

2. Notwithstanding this broad interconnection between income and energy, falling energy use per unit of economic output has emerged as a distinct and widespread global trend. During the 1990s, worldwide energy consumption per dollar of GDP declined at the rate of 1.7% annually. Although the complex of factors that will determine future energy-GDP relationships preclude precise forecasts, a continuation of that trend seems likely, as energy-saving opportunities are exploited and structural changes (especially in mature industrial economies) take hold. And even though total energy consumption is likely to continue growing for decades, the rate of growth is likely to decelerate. Such an outcome is desirable on economic and environmental grounds. Expenditures not needed for energy can be directed to other welfare-enhancing goods and services. Slower energy growth also means a lighter environmental burden, even apart from the benefits of a more benign energy mix.

3. The slowdown in energy demand growth will also occur because of a parallel slowdown, already apparent, in world population growth. The estimated annual rate of population increase over the next half century will be half that recorded over the past 50 years (see box.)

4. Two paths toward improving the environment, despite the inevitable increase in total energy use, involve the use of natural gas and of renewable resources. Increased market share of natural gas seems the more realistic nearer-term prospect. Renewable resources (among which wind power appears closest to economic viability) still trail conventional energy systems in cost competitiveness and technological maturity. Unexpected price increases for fossil fuels—especially natural gas—could improve the outlook for renewables, however, as could stricter regulations on energy-related pollution, such as coal combustion and dirtier forms of urban transport.

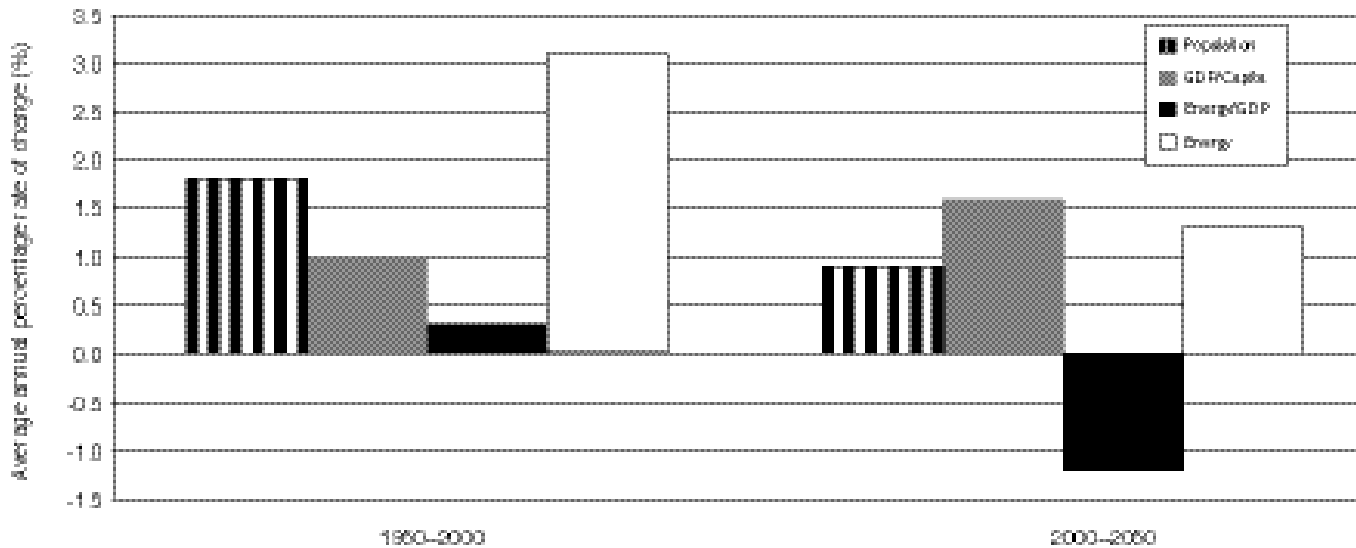
5. Supplies of fossil fuels do not appear to be limiting factors over the next several decades. Over a longer time horizon, diminishing reserves of oil and gas could boost market penetration of renewables, though scarcity could also help sustain roles for coal and nuclear power. A 1998 study undertaken by the International Institute for Applied Systems Analysis and the World Energy Council argued for the credibility of that very scenario. Thus environmental and political considerations may determine how the energy mix ultimately sorts itself out.

Long-Term Energy Trends

The chart on the following page shows the major factors contributing to long-term historical and possible future trends in global energy consumption: population, per capita GDP, and energy per unit of GDP.

If the projected trends prove true, the forces driving total energy growth will differ in three important respects from the past: population pressure will be a proportionately less important factor; per capita income growth will be more important; and diminishing energy intensity—that is, falling energy use per unit of economic output—will be critical. As the chart indicates, worldwide energy intensity is projected to fall at a rate of about 1.2% annually, in contrast to long-term past experience of little change. Note that the 50-year record includes the period of post-World War II reconstruction and economically wasteful energy use in Communist countries. As the main text points out, in the most recent decade the energy-GDP ratio fell throughout most of the world.

Long Term Historical and Projected World Population, GDP, and Energy in 1850–2000 and 2000–2050



Sources: Population from UN, *World Population Prospects—The 2000 Revision* (2001), historical GDP from N. Nakicenovic et al., *Global Energy Perspectives*, Cambridge Press, 1998, p.30 updated on the basis of information from US DOE, Energy Information Administration; historical energy estimate based on UN World Bank and DOE/EIA data and checked against chart in Nakicenovic, p.66 GDP and energy projections are discussed in accompanying text.

Further Readings

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