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How significantly does the size and growth of world population affect the demand for energy? The short answer: possibly less than one might expect. Whatever the extent of the population-energy connection, the concern that growing energy use threatens the sustainability of the underlying energy resource base is understandable, but perhaps unwarranted.

To address the issue of the effect of population size and growth on energy demand, the fact that the link between population and energy involves two intermediate connecting elements must be recognized. The first link relates to levels and changes in economic development, approximated by income or gross domestic product (GDP) per capita. (The two terms are used interchangeably throughout this article.) Typically, the greater a region's per capita income, the greater its per capita consumption of energy: The average per capita GDP and energy consumption of the world's developing countries are, respectively, only about one-seventh and one-eighth those of industrial areas. Notwithstanding this marked per capita disparity, given the sheer population size of developing regions—over three-quarters of the world total—the absolute amount of energy consumption and of GDP are relatively large: one-third of world energy use and about two-fifths of world GDP.

What is true of prevailing levels in the relationship between per capita income and energy is also true of rates of change over time since as income per capita rises, so does per capita energy use. The reason is evident. Energy—electricity to run motors, fuels for transport, and hundreds of other applications—is a vital complement to other investments for boosting productivity and stimulating economic growth. In turn, that very growth gives rise to acquisition of household necessities and creature comforts associated with increased energy usage.

Even though income and energy use are conspicuously correlated, the degree of the relationship is by no means perfect and unvarying, which raises the second point to consider in linking population and energy. Even at comparable levels of per capita GDP, the volume of energy use will differ among countries and regions, depending on structural characteristics of the economy, spatial features, climate, fuel and power prices, government conservation policies, and other factors. Similarly, changes in per capita income need not signify commensurate rates of energy use; for example, shrinkage of energy-intensive manufacturing and expansion of lower energy-use service activities can contribute to de-coupling growth of GDP and energy use.

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Such de-coupling has manifested itself in a number of advanced countries, and may, in time, manifest itself in the world's poorer countries as they continue to develop. In the United States, a plot of energy use per unit of GDP from the third quarter of the nineteenth century and well into the greater part of the twentieth century shows what is basically a bell-shaped curve, in that there was a rise in energy intensity peaking in the 1920s and falling steadily thereafter. In the first half of this period, greater energy use per unit of GDP was associated with the growth of large-scale manufacturing and energy-associated infrastructure. As that process of heavy industrialization began to taper off towards the last several decades of the twentieth century, a growing relative role of non-manufacturing activity meant a commensurate slowdown in the growth rate of energy consumption, although continuing, of course, its steady growth in absolute terms. That slowdown, it should be added, benefited as well from certain non-structural factors, such as energy and economic efficiency improvements in electricity generation and other sectors.

Quantifying the Linkage

With this background, consider Table 1 as a way of highlighting, for recent years and the projected near term, the complex interrelationships among changes in population, economic development, and energy consumption. Its aggregated and simplified layout notwithstanding, the table is instructive in identifying the three broad factors that go into the determination of changes in total energy use. (Strictly speaking, the change in energy use is the *multiplicative product* of the three factors; but, when relatively small numbers are involved, as here, it is effectively the *sum of additive* items.) The items in this de-composition, expressed in terms of percentage changes, are:

Population + GDP per capita + Energy per unit of GDP = Energy

The decade of the 1990s saw economic growth (i.e., GDP per capita) dominating population growth as a factor in energy consumption growth in both industrialized and developing regions. (Worldwide rates were strongly influenced by developments in the former Soviet Union/Eastern Europe, here included for completeness; but their erratic record for the greater part of the decade hampers meaningful analysis.) Even if population growth had been less than estimated, it is conceivable—though by no means assured—that offsetting economic performance would have accelerated the growth in energy use above that shown in the table.

An important step in this de-composition exercise is to flag the contribution of the changing relationship between energy and GDP, often referred to as changing "energy intensity." Interestingly, in both industrial and developing regions, its (negative) role in dampening the growth in energy use was vastly greater than the growth of population in stimulating it.

Note also that the framework employed in Table 1 is easily augmented to indicate the extent to which energy growth compounded or attenuated certain environmental problems. For example, with respect to the problem of greenhouse warming, a worldwide degree of *de-carbonization*—through, among other ways, limited substitution of (carbon-lean) natural gas for (carbon-rich) coal—which allowed carbon dioxide emissions to rise considerably less than energy consumption, can be demonstrated. In the future, that process of de-carbonization—aided by gradual introduction of (zero-carbon) renewable resources—is likely to endure, though not sufficiently to preclude an absolute, and perhaps dangerous, rise in carbon dioxide emissions.

Table 1 includes the U.S. Department of Energy's 20-year "business as usual" projections, showing a doubling in the annual rate of worldwide energy consumption growth, and reflecting—at least over that time span—the credible assumption of ample supply and relatively level prices into the future. For developing regions, the effect of a 0.4 percentage point reduction in the population growth rate is more than offset by a 0.7 percentage point increase in per capita economic growth. That observation is not meant to assert a demonstrated inverse trade-off between population growth and per capita income growth—a matter that remains elusive after many years of study and, in any case, demands a more in-depth analysis than that provided by the macro indicators employed here. Thus, a 1994 World Bank assessment—in line with other expert studies—notes that "[a]ttempts to demonstrate consistent cross-national macroeconomic effects of high rates of population growth have, for the most part, been inconclusive" although suggesting "that rapid growth (above 2 percent a year) inhibits efforts to raise incomes in poor countries with high fertility and youthful age distributions" (World Bank, pp.36–37).

The Longer-Term Picture

The 20-year time horizon sketched out above provides no reassurance that demographic-economic pressures building in the coming decades of the twenty-first century might not begin to put pressure on availability of the energy resources to which successful development prospects around the world are importantly tied. However, before turning to the question of the longer-term adequacy of exploitable energy resources, researchers should consider the plausible longer-term evolution of the demographic and economic factors underlying changes in energy use. To a degree greater than the 1990 to 2020 trend depicted in the table, growing energy requirements over the longer-term future will almost surely reflect the consequence of rising income to a significantly greater degree than the effect of population growth. The 2000 United Nations projections attest dramatically to decelerating population growth: The *medium* projections, issued in 2000, show world population rising from 6.06 billion in 2000 to 9.32 in 2050—a number that is 1.5 billion less than that projected just four years earlier. Looked at in another way, the *low* projection for 2050, issued in 2000, approximates the medium projection issued in 1996. Successive reductions like these are due in large part to strikingly lower fertility experience in a number of major developing countries. As a result, population growth between 2000 and 2050 is currently projected to grow at an average annual rate of 0.86 percent, in contrast to the 1.77 percent rate between 1950 and 2000.

Although long-term GDP per capita growth involves its own degree of uncertainty and conjecture, the range of possibilities considered in numerous analyses cluster around a mid-point of around 1.6 percent per year in the period 2000 to 2050. Coupling 0.86 percent population growth with 1.6 percent GDP/capita growth signifies total GDP growth of around 2.5 percent. There will, of course, be wide regional and national disparities around these worldwide averages. The implication for today's developing countries—with a prevailing per capita GDP of roughly $3500 (1999 price level) becomes especially important. A rough breakdown of the 1.6 percent per capita growth rate worldwide could mean a rate of around 2.2 percent for developing countries, which would yield per capita GDP of approximately $10,600 in 2050. This would represent a solid gain in living standards, although that income level is still well below the per capita GDP in industrial countries of about $22,000 in 2002. Nevertheless, compared with the prevailing disparity in per capita GDP (the one-seventh ratio mentioned above), the gap by 2050, implied by the assumption as stated, would narrow to a ratio of around one-fourth.

If worldwide GDP growth can reasonably be projected at a yearly rate of 2.5 percent, it also seems reasonable, in turn, to view 2.5 percent as the *upper* bound to long-term energy growth because, particularly in an era focused on technologies and practices that promote economically more efficient energy usage, a time trend of declining energy intensity can be taken as virtually certain. (To cite just one of many examples of such technological changes: A newly commissioned power plant can generate a kilowatt hour of electricity at less cost and using half the raw energy input than a plant built a mere dozen years ago.) These considerations and a review of various studies support the position that, with worldwide GDP growth over the next 50 years proceeding at an average annual rate of around 2.5 percent (that is, somewhat below the long-term historical trend), a *best guess* for the concomitant increase in energy use is an annual rate of approximately 1.3 percent, the difference reflecting an assumed annual energy intensity improvement factor of around 1.2 percent, about as large a reduction as can be defended on the basis of historical and empirical grounds.

If a yearly energy consumption growth rate of 1.3 percent seems strikingly below historical experience, it still implies that, compared to the year 2000, by the year 2050 the world will see a near-doubling in its annual level of energy consumption. It is widely expected that a disproportionately large share of the 2000 to 2050 increment will originate in today's developing countries, with China and India leading the demand. To graphically cap this discussion, the accompanying figure shows long-term historic trends and plausible projections in world population, per capita GDP, energy intensity, and energy use, using the de-composition elements introduced earlier. A conspicuous difference between the long-term past and long-term future clearly relates to the changing relative importance of population growth and per capita income growth combined with decreasing energy intensity in driving energy demand. The last two factors seem certain to be much more decisive in the decades ahead than population growth—a trend already foreshadowed in the near-term forecast shown in the table.

The Energy Resource Base

The extent to which the rate of energy growth falls below the rate of economic growth will remain a matter of unusually spirited debate. One important reason for the debate is that as the fall in energy intensity continues, the threat from climate change and other sorts of environmental deterioration, particularly if declining energy intensity is also accompanied by a shift toward non-fossil energy sources, will become more attenuated. On the other hand, as long as fossil fuel combustion remains a major part of the energy system, the challenge of mitigating climate consequences remains less tractable.

The last discussion leads to the *running out* question: Whatever the way population growth interacts with economic development to spur increased demand for energy, will the identified and likely discoverable resources of fossil energy be adequate to accommodate such future demands? There is no certain answer to that question. However, the fact that fossil fuel resources are finite in the earth's crust has little practical bearing on the answer since, over many decades, new discoveries and innovations in exploration and extraction technology have more than offset rising consumption, with the result that the long-term trend in the real price of energy—the most critical measure of scarcity—has barely changed.

Those facts, although they are often overlooked, deserve brief amplification. Consider, for example, that in 1967, the world's proven oil reserves were estimated at around 418 billion barrels. At then prevailing levels of consumption, projections were that that supply would last some 31 years. By the year 2000, notwithstanding a vast amount of cumulative consumption in the interim, proven oil reserves had risen to 1.05 trillion barrels, equivalent to approximately 40 years of reserves at current consumption levels. Aided by such exploratory breakthroughs as *3-D seismic* and enhanced production capabilities through deep-sea and horizontal drilling, the inflation-adjusted price of crude oil has, notwithstanding periodic volatility, remained virtually stable over the long run. In fact, between the 1950s and the 1990s, the price recorded an inconsequential increase, averaging around 0.3 percent yearly. Similar technological advances can be noted regarding natural gas deposits. Moreover, since natural gas is a geologically *young* resource, worldwide exploration has yielded many successful discoveries. Exploitable coal deposits exist in such vast abundance that declining use, when it occurs, is much more likely to be due to environmental considerations rather than scarcity factors. In short, while history is an imperfect guide to the future, it seems highly probable that energy scarcity will not manifest itself for decades to come.

One caveat deserves to be added to this somewhat optimistic assessment. It has to do with energy security concerns arising from the concentration of petroleum resources in limited parts of the world. Their abundance notwithstanding, access to these resources could be jeopardized by political turmoil or the exercise of market power. That possibility could reinforce the impetus for a more broad-based energy portfolio, including a progressive shift to renewables, and, conceivably, a revived interest in nuclear power to smooth the longer-term energy transition, which both environmental concerns—especially global warming—and rising prices for conventional energy may in time dictate.

Beyond an Aggregative Perspective

Much of the preceding exposition has been framed in highly aggregated or stylized terms. Even if valid for the world as a whole or for broad regions, such generalized treatment says little about the subtleties, exceptions, and counterfactual experience of individual countries. Forming deeper insights on energy use therefore depends on what can be learned from conditions—not merely economic, but institutional and structural—characterizing populations in different countries.

A few examples suggest the type of considerations involved. People in rural areas of many developing countries gather and use energy, often inefficiently, in the form of firewood or dung for meeting basic needs of cooking and heating. Inevitably, this contributes to erosion and loss of soil fertility and, due to poor combustion, to a widespread incidence of indoor air pollution. While poverty is the primary cause of this practice, limited access to information and the absence, or lax enforcement, of property rights—which might limit such exploitation of the commons—are factors as well. Thus, an early-twenty-first century visitor to Bhutan—an extremely low income country by World Bank standards—will note that the country's farmers receive permanent property rights to small woodlots as a source of firewood and to meet other basic needs. This policy provides farmers with both the responsibility and incentive for adopting and maintaining sustainable forest practices. In particular circumstances, therefore, income is not the sole mediator connecting population and energy.

Energy use in densely-populated urban areas, both in developed and developing societies, exhibits its own unique characteristics. Greater density improves the economics of public transport systems, thereby achieving lower energy use per passenger-kilometer of travel in such places. Multi-family housing, another attribute of high population density, allows for more efficient energy use than single-family homes. It is not surprising that, relative to income, energy use in places like New York City or Philadelphia is significantly less than that in Dallas or Phoenix, which have dispersed settlement patterns.

These findings do not imply that crowding is good, for many things enter into decisions about where to live. Indeed, depending on local conditions, including deficient regulatory policies, higher population density can aggravate energy-producing pollution. Mexico City, for example, illustrates how a crowded metropolitan area, traffic congestion, and a substantial volume of industrial activity lacking effective pollution controls all combine with weather inversions to pose serious environmental and public health problems. And, as in numerous other developing-country cities, significant continuation of urban in-migration, coupled with natural population growth, make the search for solutions more challenging. Even in very large cities that have achieved, or are approaching, middle-income rank—for example, Bangkok or Sao Paulo—it is not clear that political processes and governance are as yet up to the task of managing the intertwined challenges of pollution, congestion, and the provision of adequate municipal services. Specifically with respect to energy use, these qualitative dimensions of rising demand, as much as any demographic pressures on resource availability, will require the prime attention of both researchers and policy-makers in the years ahead.

Further Reading

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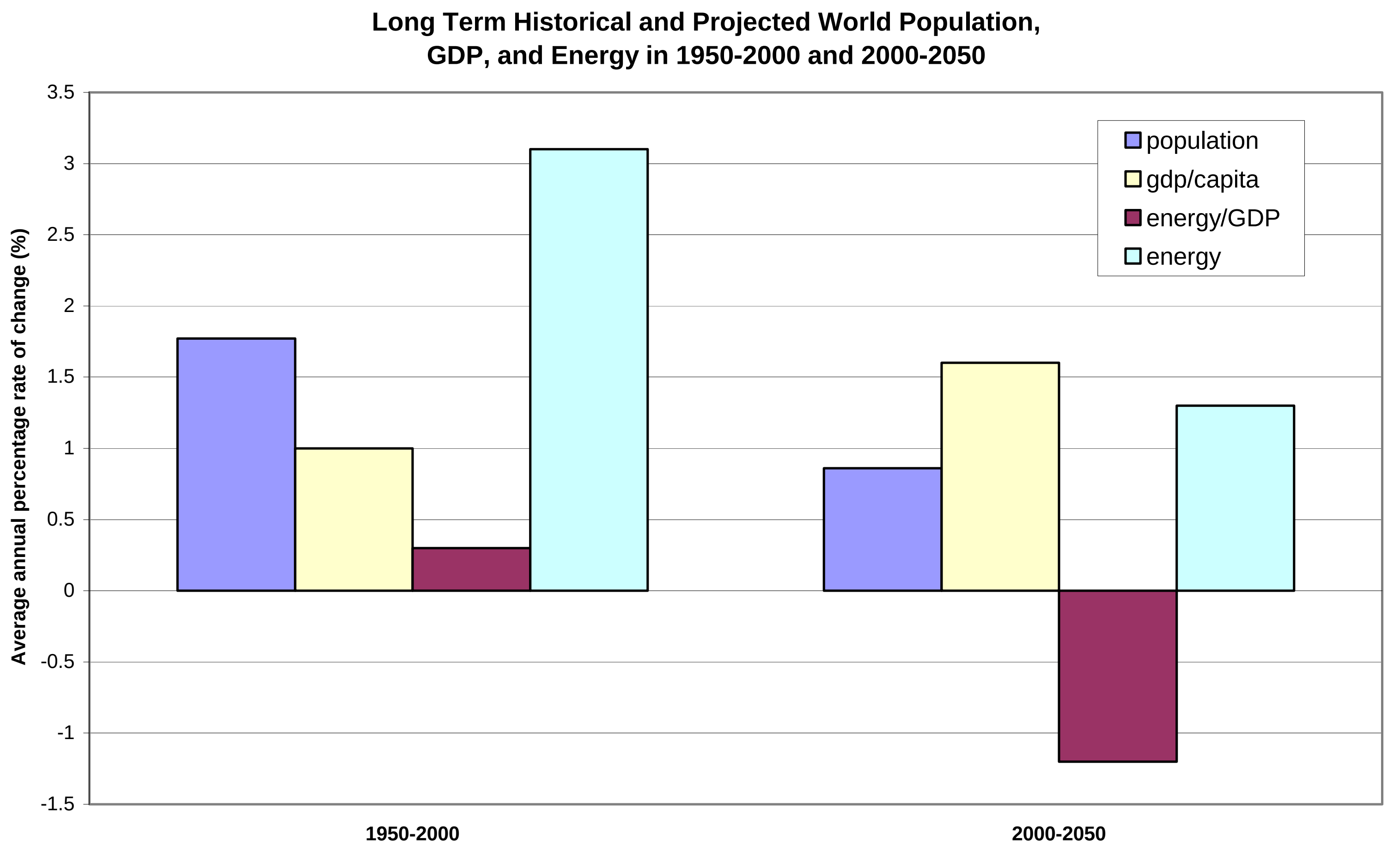
Tables and Figures

Table 1
"DE-COMPOSING" THE POPULATION-ENERGY LINK: MAJOR WORLD REGIONS
(average annual percentage rates of change)

	1990-1999	1999-2020
Population		
Industrial	0.6	0.4
EE/FSU	0.0	0.0
DC	1.7	1.3
World	1.4	1.1
GDP per capita		
Industrial	1.6	2.2
EE/FSU	-3.4	4.3
DC	3.2	3.9
World	1.3	2.8
Energy per unit of GDP		
Industrial	-0.6	-1.4
EE/FSU	-1.1	-2.5
DC	-1.1	-1.4
World	-1.7	-1.6
Energy consumption		
Industrial	1.6	1.2
EE/FSU	-4.5	1.7
DC	3.8	3.8
World	1.1	2.2

Sources and notes: Historic population and energy data and all projections from U.S. Department of Energy, Energy Information Administration, International Energy Outlook 2001 (March 2001), Tables A2, A3, and A16. Historic GDP data from United Nations Development Programme, Human Development Report 2001 (New York/Oxford: Oxford University Press for UNDP, 2001), p. 181. EE/FSU=Eastern Europe and the former Soviet Union; DC=developing countries. "Energy" refers to the sum of the different energy sources, aggregated according to their respective calorific properties. See accompanying text for discussion of the table.

Figure 1



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.