Jefferson W. Tester, David O. Wood, and Nancy A. Ferrari, eds., ENERGY AND THE ENVIRONMENT IN THE 21ST CENTURY (Cambridge, Mass.: The MIT Press, 1991).

Population and the Global Environment

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Introduction

Anthropogenic sources of global environmental change can be traced to three interdependent factors: 1) trends in human activities and policies, such as population growth, economic growth, and the legitimization of activities that generate environmental degradation, 2) technological and industrial development, and 3) prevailing patterns of natural resource use, including energy consumption, deforestation, and land and water use. Technological and industrial contributions to global environmental change are obviously crucial, as are patterns of energy and resource use. The most critical influence on the environment, however, is worldwide demographic change, which generates environmental effects both directly and through its impact on resource use patterns and applications of technology.

The record of population growth is well documented, as are the differentials among states and the implications for per capita claims on the world's resources. The population characteristics of the globe—and of the constituent nations—are among the most robust features of the world we live in. This paper examines the demographic dimension of global change, reviewing the global record, future projections, and implications for modeling global population/environment relationships.

The environmental consequences of population growth are rooted in the fact that every human being requires some minimal amount of basic resources (food, water, air, living space) and that the total resources required by a society increase with population size. The "population nexus" refers to the interactions or dynamic convergence of population, resource needs, and levels of knowledge and technology, including organizational and mechanical skills. Technological change provides new resources (or new uses for existing resources) and may also increase demand for resource uses.

The developmental process is generally one of increased output, enhanced productivity, improved standards of living—and greater environmental degradation. The economic concept of demand is restricted to "willingness to purchase"; the political concept of demand means claims on the political system, claims on governance (including economic, political, social, and other claims or benefits), and claims on environments. The larger the population and the higher the rate of growth, the greater are the social, economic, political, and other demands engendered.

The environmental consequences of population are, therefore, intimately tied to levels of knowledge and skills (technology) and patterns of resource use (especially consumption of energy in all its forms). In the most basic sense numbers do matter, as do the demands generated by populations and their ability to meet those demands. For example, a global population at the technological level of Bangladesh—with per capita carbon emissions at less than 1 percent of the per capita level of the United States—would have a different impact on both the local and global environments than it would at a higher level of industrialization.

Trends in Global Population

Global Record

The global demographic record for the past 250 years is fairly well established, subject only to regional differences and narrow uncertainties in the aggregates. The size of the present population, though not precisely enumerated, is probably between 5.1 and 5.3 billion.

The doubling time for the first billion human beings on earth took 120 years, while the doubling time for the second billion took 47 years. Until recently the trend has been upward; by the late 1960s and early 1970s we observed the first discernible decline in the global rates (departures from the peak of just over 2 percent per year in the 1960s). Since then, the global aggregates have shown a small but downward adjustment. The declines of the 1970s—noteworthy in a historical context—were not sufficient to affect total aggregates since the population still grew at a rate of 220,000 persons per day.

Figure 1 shows the historical record and average growth, in terms of average annual rate as well as overall numbers.

The historical record shows that population growth is intimately related to patterns of energy use and advances in technology and, by extension, to patterns of environmental degradation. The intense interaction among population variables prevents simple assignment of responsibility for global environmental change. Nonetheless, the clear association between the growth of human population and economic activities, on the one hand, and the generation of greenhouse gases (carbon dioxide, methane, nitrous oxide, the chlorofluorocarbons, and others) on the other, illustrates the demographic sources of atmospheric alterations.

Demographic Transition

Populations are generally described in terms of their stage in the "demographic transition." Any given growth rate can be the result of different combinations of births and deaths. The transition refers to adjustments in the birth and death rates and to the theory that describes these adjustments. Specifically, demographic transition means the change from high and proximate levels of mortality and fertility to low levels and rates close to replacement. Demographic transition consists of four stages: 1) high mortality and fertility (life expectancy less than 45 years and total fertility rate (TFR) at six or more), 2) mortality declines earlier than fertility, which is also declining, 3) acceleration of both mortality and fertility declines, and 4) low mortality and low fertility (life expectancy greater than 65 and TFR less than three). Overall, the transition indicates declines in death rates preceding declines in birth rates, and a great variation in the time path of the transition across countries and regions.

While the dynamic processes of the transition are specified in terms of adjustments in fertility and mortality, there is a wide range of views and evidence concerning the determinants of births and deaths. Human beings can die at any age, but fertility, by contrast, is limited to the reproductive age groups. Aggregate changes in global fertility rates—from 4.99 to 3.64 between 1950–55 and 1980–85—mask great variation across regions and countries, as do the forces that shape births and deaths.

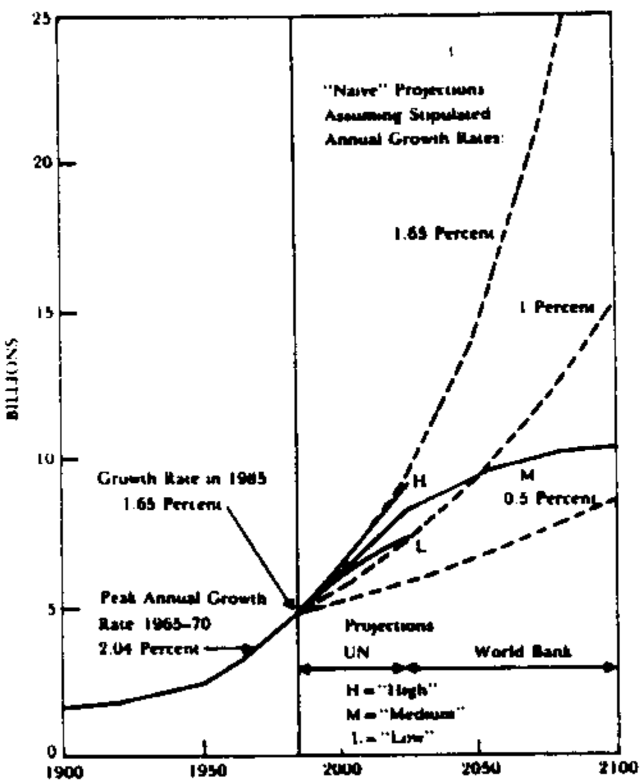

Figure 1. World population growth: 1900–2100 (1900–85: estimates; 1985–2100: projections and extrapolations). Source: Paul Demeny, "The World Demographic Situation," in *World Population and U.S. Policy*, Jane Menken, editor (New York, NY: W. W. Norton, 1986), p. 35.

Differences in Levels and Rates of Growth

Global aggregates obscure significant regional and national differences. The unequal distributions of human population across sovereign states are important in the formulation and design of population policies, since the locus of decisionmaking still resides with states (and state systems).

In 1985, 76 percent of the world's population was classified as "less developed," and its rate of population growth was highest. The less developed countries more than doubled their total population between 1950 and 1985. The importance of China, however, obscures the regional variation among the developing countries. China's 50 percent reduction in fertility rate during this period was due to the combination of strong population control policy (rise in marriage age and one child per family established in 1979) and notable famines. Although the present population level is not much higher than that required for replacement (2.1 births per woman), it takes several decades before fertility decline is reflected in the age structure and in attendant fertility patterns.

The effects of the demographic transition from 1950 to 1985 translate into the average annual population increases shown in Figure 2. Clearly, the *natural* increase in population—the difference between births and deaths—varies extensively across regions. While the global rate of natural increase in 1980–85 stood at 16.6/1000, the highest rate was in South Asia (21.7/1000),

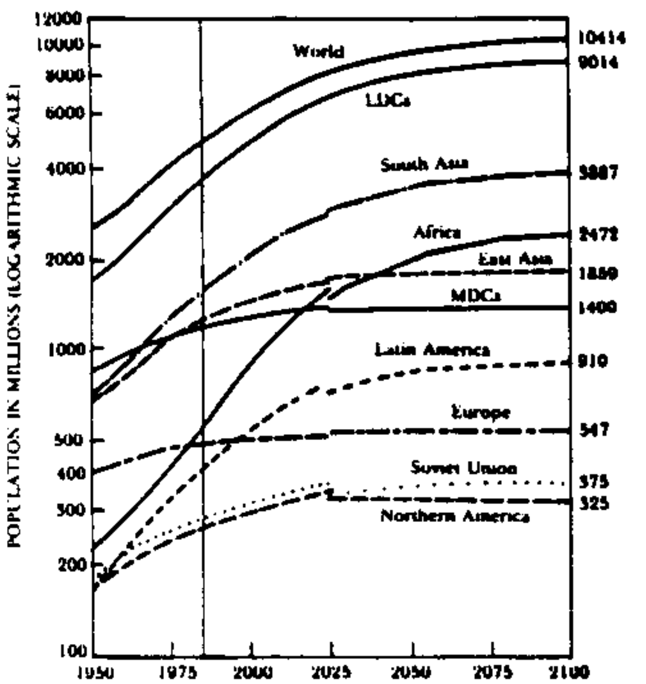

Figure 2. World population growth: 1950–2100 (1950–85: estimates; 1985–2100: projections). Source: Paul Demeny, "The World Demographic Situation," in *World Population and U.S. Policy*, Jane Menken, editor (New York, NY: W. W. Norton, 1986), p. 65.

and the lowest in Europe (3.0/1000). For the less developed countries as a whole, the average rate of natural increase was 20.2/1000.

Composition and Distribution

Demographic changes and variations among countries are due to a combination of socioeconomic conditions, development strategies, and population policy (i.e., toward fertility control, international migration, and provision of health and related services). Select socioeconomic indicators are *inversely* related to fertility (i.e., education, female employment). To the extent that they are the subject of government policy, these indicators can have a profound effect on fertility.

Urbanization

As a global trend, urbanization has been on the rise. It is a powerful determinant of energy use and directly reflects income changes and changes in the composition of the labor force.

Forty-one percent of the global population is urban; with an annual average increase of 2.84 percent, the lesser developed countries have expanded their urban populations fourfold over a 35-year period. In addition, the urban trend has implications for infrastructure demand, the need to expand built environments, and the demand for energy associated with increased conglomeration of populations. In 1950 the 15 largest urban concentrations were located in the developed countries; by 1980, 9 of the 15 most concentrated urban centers of population were in the developing states; 4 of these were in China and India.

International Migration

The movement of people across territorial boundaries is small relative to the total global population. Only 50 million people, or 1 percent of the world's population, are now living in countries in which they were not born. In some cases the number of migrants is large relative to the population in the country of destination (80 percent in the Gulf countries of the Middle East); in others the proportion is small, but the total numbers are high (the US has the largest number of persons born abroad—14 million—but this represents only 6.2 percent of the total population). Regardless of scale or scope, international migration is generally not neutral with respect to economic performance or patterns of resource use. In many regions of the world international migration facilitates or accelerates economic and industrial development and the provision of services. For example, the post–World War II reconstruction program in Europe was greatly aided by immigration from North Africa, Turkey, Yugoslavia, and other areas; the entire oil industry in the Middle East is built on the large-scale migration of foreign workers; agriculture in California draws heavily on Mexican workers; and the list goes on.

Population Policy

Narrowly construed, population policy refers to family planning programs designed to influence fertility rates. More broadly, however, population policy refers to any formal effort to influence the levels, rates, composition, and/or distribution of a society's demographic characteristics. Demographers have generally preferred to adopt the restrictive definition, while planners and designers of social policy have preferred the broader definition. Traditionally, the lines of policy debate have been sharply drawn between those who believe that family planning programs are essential in order to influence fertility rates and those who argue that economic development is both necessary and sufficient for this purpose (and that, at most, fertility control programs may facilitate the decline in the birth rate). The strong interdependence of fertility behavior and socioeconomic development, however, makes it difficult to untangle the effects of family planning programs and evaluate the contending views. Nonetheless, the historical record over the past 20 years provides sufficient evidence to suggest that population control programs do have a significant impact on fertility rates and that demographic and economic processes are so highly interconnected as to seriously question the utility of socioeconomic models that do not explicitly endogenize the demographic processes.

The policy/fertility record is as follows: by 1986, countries accounting for 78 percent of the population of developing nations had adopted policies designed to reduce their fertility rate. The 30 percent decline in fertility in these countries since 1950 was accompanied by a sharp increase in the use of fertility inhibiting technologies. Concurrently, strong modernization programs induced socioeconomic development. The significant intervening variables between socioeconomic development and fertility are not disputed (i.e., age at marriage, income, level of education of women, and employment of females). The availability of fertility control technology adds a powerful impact—a sort of multiplier effect. However, the relationship between fertility and socioeconomic variables, such as employment and education, varies significantly over time and across countries (see, for example, Cochrane, 1986). Furthermore, there are no good quantitative estimates of the specific responsiveness of fertility changes to specific socioeconomic variables (Mauldin, 1989:77). These problems complicate simple causal inferences.

Statistical uncertainties aside, however, the dominant role of the public sector—in setting policies, extending supporting services, and providing fertility control technologies—is crucial; so is the role of international institutions and external sources of both technology and finance. While the manipulability of fertility is clear, the causal sequence and the time frame over which adjustments take place is less clear.

Global Prospects

Projections

The relatively unambiguous demographic record of the past two centuries contrasts sharply with the remarkable diversity in prevailing projections of future trends. While the "dynamics" of aggregate demographic change are determined only by fertility, mortality, and their interactions, the demographic system is not "closed": these individual elements are strongly influenced by technological, social, and other factors. Figure 1 above showed the record of population growth since 1900 and the future projections to 2100—the "naive" as well as the alternative projections. On balance, the most "reasonable" view is that by 2100 the global population may stabilize at 10 billion human beings. But it may also stabilize at 14 billion; and the differential is not insignificant.

Age Distribution

The age structure of the population projected by the UN for 2020 compared to data from 1985 shows that aging will be commensurate with the long-term stabilization of population—when the global population has effectively made its demographic transition (United Nations, 1989:54). An expansion of the age group 60 and over from 8.8 percent to 14.3 percent of the global total will involve important socioeconomic adjustments. The implications for labor, employment, productivity, and the provision of health and other social services, though of increasing concern, have yet to be fully recognized. While the overall dependency rate drops by only 3 percent, the shift away from the cohort 14 years of age or younger implies a gradually declining fertility rate characteristic of stabilization.

Again, global aggregates obscure regional and national differences. For example, while the developing states will retain a youthful distribution of population well into the next century, the industrial states are rapidly aging. Population growth in the United States and the Soviet Union is slowing, both countries are aging, and the effects on the labor force are already apparent (Torrey and Kingkade, 1990).

Doubling Time

Population doubling time given current rates of growth is a stark summary indicator of regional differences. The population of Africa could double in roughly 40 years, while that of Europe may take over 240 years to double (see Figure 3). The global shifts in the distribution of population are obviously not neutral with respect to energy use or other socioeconomic factors.

As indicated in Figure 1, World Bank "medium" projections anticipate a global population of 6.1 billion in the year 2000, rising to 8.2 billion by 2025, and to 10.4 billion by 2100. This growth involves major shifts in the regional distribution of population between now and then but no significant changes subsequently. By 2100 Europe will account for 5.2 percent of the global population (half the 1985 level), North America will account for 3.1 percent (compared to 5.5 percent in 1985), and the less developed regions will account for 87 percent of the world population. The implications for Europe are noteworthy, even graphic: "Europe is literally melting away like snow in the sun from 15 percent of the world population in 1950 to one-third that relative share in 2025" (United Nations, 1989:8).

This view of future population, based on projections such as those of the United Nations, the World

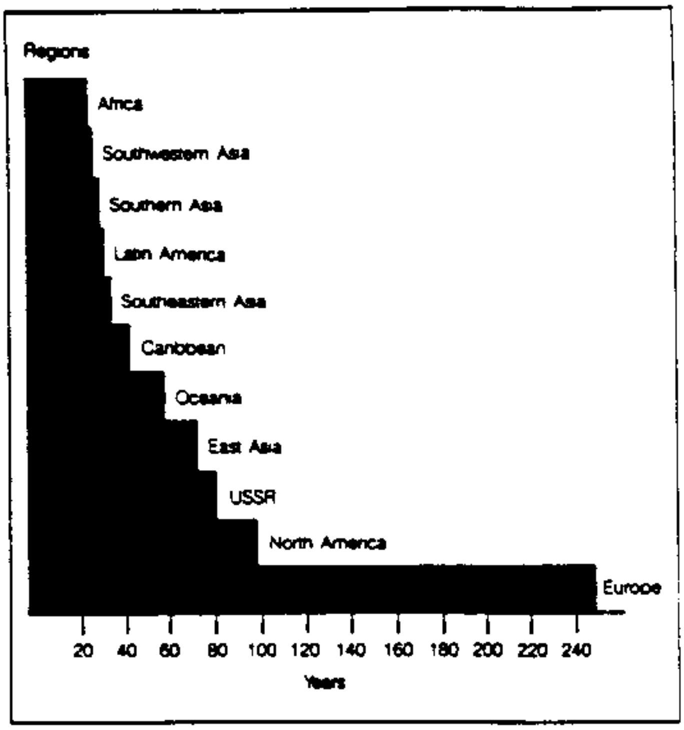

Figure 3. Population doubling times by region, at current rates of growth. Source: World Resources Institute, *World Resources 1987*. (Washington, DC: World Resources Institute, 1987), p. 12.

Bank, and the US Bureau of the Census, is generally used as exogenous input in models of energy and/or environment. This view is built exclusively on the fertility and mortality relationship and makes no provision for the influence of energy and environmental variables or interactions on future population patterns. As such, it is strictly a demographic projection. It does not incorporate population/environment relationships or population/energy use interactions, either directly or indirectly.

Methods: Approaches and Problems

Population projections are based on extrapolations from past trends or on identification of a point in the future at which replacement level fertility will be attained and from which intervening rates of fertility can then be derived by interpolation to the base period. The historical record has informed the theory of demographic transition as well as the determinants of fertility, mortality, and migration. Unfortunately, as Keyfitz notes, there are no clear theoretical explanations from which to derive a behavioral model for future population (Keyfitz, 1983).

Projection Method

The most common method for population projection is known as the "component projection method." It is based on 1) age/sex survival rates to determine survivors in each age group; 2) an age-specific fertility rate applied to the total number of females in each reproductive age group (births are distributed according to the assumed sex ratio at birth; based on survival probabilities, the number of survivors from calculated births is calculated for each time period); and 3) the number of migrants, which is added to or subtracted from the projected additions to population (i.e., survivors) from steps 1 and 2 (IIASA, 1989:16, 41, summarizing conventional procedures). In this sense the projection system draws only on births, deaths, and migration:

$$P_{t+1} = P_t (B_t - D_t + M_t)$$

where P_t = initial population size and structure
B_t = birth rate (fertility)
D_t = death rate (mortality)
M_t = net migration

Sources of error or bias are accordingly contained in estimates of initial population size, age/sex distribution, fertility rates, mortality rates, and migration rates. Among the most common sources of error (or variability) are the growth rate assumptions and the initial estimates of population parameters for developing countries (especially for those large countries—China, India, and others—that have major effects on global demographic trends).

The component method is basically computational rather than behavioral or causal, since it does not determine B_t, D_t, and M_t as functions of socioeconomic or policy variables. Similarity in logic, computation, and initialization is responsible for similarities in projections. Citing Keyfitz (1983), the International Institute for Applied Systems Analysis (IIASA) analysis pointed to the strong possibility that global population projections are not independent, and suggested that agreement therefore should not constitute validation. Differences among projections, determined exclusively by differences in initial condition parameters, cannot be construed as differences in theory or in explanatory power.

The importance of population projections lies not in their precision (or even rough accuracy) but in the sensitivity of socioeconomic, energy, or environmental variables to levels, rates, and distribution of population. Hence, improvements in projections need be delineated only to the extent that they generate discernible effects whose implications may be significant for these systems and/or demographic factors themselves. Among the possible strategies for endogenizing the demographic parameters in population projections are 1) making explicit the relationships of income/fertility and education/fertility, 2) making provisions for the population policy/fertility relationship, and 3) incorporating the migration/ fertility relationship.

Population as a Driving Factor

Population variables and projections are widely used as inputs in energy models and, more recently, in models of CO_2 emissions. Uniformly using population factors (usually size and rate of growth) as inputs "driving" the system assumes that system behavior has no effect on demographic patterns. Energy models and energy/environment models commonly treat population (i.e., size, rate of growth, labor force, labor productivity) as exogenous—influencing but not influenced by the relationships modeled. This practice in essence presumes the complete insensitivity of population to socioeconomic, energy, or other variables in the system modeled. In the short run this is probably a useful approach. Over the longer run, however, population becomes a significant modifier of the natural environment and thus is critical to models of long-term processes (more than 10 years). Endogenizing population is complicated by the lack of a comprehensive theory of population/energy/environment interactions. The processes of growth and development are powerful intervening dynamics shaping both sides of the relationship—demographic and energy/environment. Moreover, the level and type of technology (both organizational and mechanical knowledge and skills) significantly affects growth and development.

Recent reviews of major energy and energy/environment models undertaken by IIASA (1989) and by the Stanford University Energy Modeling Forum (EMF 9 and EMF 11) illustrate the continued practice of using population variables as exogenous factors. The impact of energy on the environment is most readily traced via the fuel mix used to generate energy-based services. Demographic factors enter directly in the demand side; over time shifts in economic and other activities affect fertility, mortality, and migration, which in turn influence the demand for energy almost immediately. The adjustment period may vary across regions and countries as well as over time, but the interactivity can be delineated based on pieces of theory, analysis, projection from demographic and energy/economy analysis, and the nascent energy/environment literature. Clearly, no model can or should do everything; nonetheless, the practice of shaping modeling decisions and defining system boundaries based on past practices may be distorting in a world where the signals are pointing to greater interactions rather than enhanced autonomy of social processes.

The draft report to Congress entitled *Policy Options for Stabilizing Global Climate Change* (Environmental Protection Agency, February 1989) has among its objectives improved definition of the potential effects of global climate change and identification of the options available for influencing the composition of the atmosphere and the rate of alterations. The scenarios examined express population as an exogenous factor. Drawing upon the US Bureau of the Census and World Bank projections, the scenarios differ on the rate at which the global population is projected to stabilize. The major feedback specified is from atmospheric gas concentration and temperature change (inputs) to select emissions forecasting modules (intervening processes). As a strategy shaped by expediency, this approach is certainly reasonable. However, it obscures the variety of demographic processes (and their interconnections) that affect patterns of emissions of the trace gases. It also obscures regional variations in the processes that influence the production of trace gases as the mix of human activities differs at different levels of development. Among the limitations of the study, as identified in the Report, is its failure to address the population and the demographic processes, reflecting the conventional exogenous treatment of population without exploring, or partially testing, the effects of this practice.

Illustrating Recursive Processes

One of the most useful frameworks for exploring CO_2 development options is the Edmonds and Reilly model, which provides five detailed commercial energy/demand/supply and CO_2 balances to 2100 (Edmonds and Reilly, 1983; 1984; 1985). Population and GNP projections drive the energy demand. Technological change affects energy demand, but no feedback effect is set from technological change to GNP, labor, or population. Over the time frame of the model (to 2100), it is reasonable to expect that such feedback effects might provide some useful insights beyond those based on exogenous population projections. This expectation has already been reinforced by sensitivity analysis of this model, showing the salience of labor productivity, change in energy efficiency, and income of less developed countries.

These concerns are relevant to other intertemporal energy/environment models. There is a case for endogenizing demographic factors whenever they are influenced *over time* by the processes modeled, such as energy use, environmental degradation, emissions of trace gases, and so forth. In the short run (five years or less) such interactions may not be significant. However, there are exceptions, most notably deforestation, soil erosion, land degradation, and expansion of noncommercial energy use. Without specifying the time frame, the United Nations Fund for Population Activities (UNFPA) starkly states that population growth alone may account for 80 percent of the loss of forest cover (Sadik, 1990:11). In the longer run (over decades, even a century) there is no historical or empirical basis upon which to presume the separation of demographic from energy or environmental processes. Climate affects water and soil conditions, and shifts in temperature would, in all likelihood, influence sea level, precipitation patterns, and the distribution of land and water resources. Even the brief sketch provided by the UNFPA illustrates the potentially alarming interactions of population and environment (Sadik, 1990: 10–12).

Population, Development, and the Global Environment

The current state of population projection and of demographic theory is not designed to address resource (energy) availability, differentials among populations in levels of economic performance, knowledge and skills, or overall technological capability—or their impacts on fertility and mortality. In large part this is due to the inherent complexity of these issues and the tradition of social inquiry that eschews integrative approaches in favor of detailed foci on particulars, in this case fertility and mortality. Such considerations notwithstanding, the fact remains that these variables are crucial intervening factors shaping the impacts of population on social and natural environments. Thus, demographic factors, however compelling, if considered alone, tell us only a part of the story; the *interactions* among population characteristics, technological change, and patterns of resource use (especially energy) define the nature of the population effects at any point in time. For the globe as a whole as well as for individual states, these interactions shape the effects of humans on both the natural and the social environments.

Differences in Development

Though states all over the world generate many of the same effluents—carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), and others—they tend to do so in different ways and in different amounts, according to size, population, geographical location (climate zone), and level of technology and industrialization. It remains a matter of conjecture whether forms of government and political regimes influence patterns of emissions. Table 1 shows the basic patterns of carbon emissions for the top contributing states.

The most advanced industrial countries, characterized by high levels and rates of technological development combined with access to resources, generate high levels of consumption, high levels of CO_2 emissions, extensive wastes, and high levels of other greenhouse gases, with attendant effects on the natural environment. There are differences among the industrial states, of course, but the basic trends of high per capita emissions rates are broadly similar. The dominant case is the United States, with a GNP per capita of $16,757 and roughly five metric tons of carbon emissions per capita (1986 figures). Despite differences in energy efficiency, the industrial states, by their very nature, rank high on emissions rates per capita compared to the global average.

The developing or industrializing countries are considerably more varied in size, level of economic growth, and level and type of environmental degradation—but they all produce remarkably lower carbon emissions than the global average. At one end of the spectrum are states with large or growing populations and relatively limited basic technology, contributing low carbon emissions per capita. As these countries industrialize, however, their large populations will make them significant contributors. For example, China's emissions per capita are 0.5 metric tons per year, but on the aggregate China is already the world's third largest contributor of global CO_2. Given China's population and its 20 percent share of the global use of coal, its industrialization process will expand its emissions.

At the other end of the spectrum are those states with low density, limited basic technology, and limited resource access. They are typically poor, with close to subsistence levels of development. Chad is a typical case, with a per capita income of $160 and carbon emissions less than 0.5 percent of the US level. These states will not affect global balances markedly in the foreseeable future.

In this context the oil-rich countries of the developing world, with sparse population and a rich resource base, are distinctive because of their rapid rates of environmental degradation and generation of a wide range of effluents. All these states have remarkably high levels of carbon emissions per capita, due in part to petroleum production and in part to rate of industrialization and infrastructure development. Saudi Arabia, for example, produces 2,584 kg of carbon per capita (1986).

Projecting Environmental Impacts

Globally, the industrial states obviously generate more effluents and affect the global balances more than do the developing countries. Over time, however, with greater industrialization worldwide the major sources of emissions and effluents will be significantly more widely distributed than they are at present.

In terms of the global carbon budget, the stabilization level of the future world population (estimated at 10 billion to 14 billion people) will have radically different impacts depending on the level of development worldwide. Depending on whether the global population converges at the level of development of Bangla-

Table 1. Major Contributors of Carbon Emissions to the Atmosphere, 1986.

Total CO_2 Emissions

	Carbon (1) (Thous. mt)	Population (Millions)	Carbon/Pop (Kg)	GNP/Pop ($/pers.)
1 United States	1,201,624	241.6	4,973.61	17,480
2 Soviet Union	1,010,804	281.1	3,595.89	8,384
3 China	554,349	1,054.0	525.95	300
4 Brazil	388,521	138.4	2,807.23	1,810
5 Japan	256,084	121.5	2,107.68	12,840
6 Indonesia	220,127	166.4	1,322.88	490
7 West Germany	186,269	60.9	3,058.60	12,080
8 India	177,326	781.4	226.93	290
9 United Kingdom	166,195	56.7	2,931.13	8,870
10 Colombia	135,831	29.0	4,683.83	1,230
Rest of World	2,918,870	1,986		
Top 10 Share	60%	60%		
World Total	7,216,000	4,917		

CO_2 Emissions from Deforestation

	Carbon (Mill. mt)	Pop (Millions)	Carbon/Pop (Kg)
1 Brazil	336	138.4	2,428
2 Indonesia	192	166.4	1,154
3 Colombia	123	29.0	4,241
4 Ivory Coast	101	10.7	9,439
5 Thailand	95	52.6	1,806
6 Laos	85	3.7	22,973
7 Nigeria	60	103.1	582
8 Philippines	57	57.3	995
9 Burma	51	38.0	1,342
10 Peru	45	19.8	2,273
11 Ecuador	40	9.6	4,167
12 Vietnam	36	63.3	569
13 Zaire	35	31.7	1,104
14 Mexico	33	80.2	411
15 India	33	781.4	42
Rest of World	337	3,729	
Top 15 Share	80%	32%	
Total	1659	4,917	

CO_2 Emissions from Energy Use

	Carbon (Thous. mt)	Pop (Millions)	Carbon/Pop (Kg)
1 United States	1,191,764	241.6	4,933
2 Soviet Union	992,421	281.1	3,530
3 China	532,388	1,054.0	505
4 Japan	246,394	121.5	2,028
5 West Germany	182,666	60.9	2,999
6 United Kingdom	164,373	56.7	2,899
7 India	139,971	781.4	179
8 Poland	122,329	37.5	3,262
9 Canada	103,834	25.6	4,056
10 France	95,162	55.4	1,718
11 South Africa	91,664	32.3	2,838
12 East Germany	90,731	16.6	5,466
13 Italy	90,103	57.2	1,575
14 Mexico	70,787	80.2	883
15 Czechoslovakia	64,430	15.5	4,157
Rest of World	1,194,984	2,000	
Top 15 Share	78%	59%	
Total	5,374,000	4,917	

Sources: Marland et al. (1989); World Bank (1989); Houghton et al. (1987); Central Intelligence Agency (various years).

desh (with near-trivial levels of carbon emissions), or at the level of Iran (the country that demarcates the global median in CO_2 emissions per capita), or at that of Italy (close to the global per capita average), there will be significant differences in the environment.

If we were to imagine a global population today at the level of development of the United States (roughly 5 metric tons of carbon per capita), global emissions would be three-and-one-half times current levels. Table 2 illustrates an alternative future by sketching two cases. Case 1 assumes a future world population of 10 billion persons and shows the projected carbon emissions for the world at the levels of development of various countries, in million tons and as a percent of the 1986 global totals. Case 2 shows what the total emissions would be in 2010 if the world had the population growth rates of these same countries, assuming constant emissions at the per capita world average in 1986.

Case 1 shows that with a future global population of 10 billion at the level of affluence of the United States today, and with present technology, global carbon emissions could be about seven times greater than 1986 levels. Case 2 shows that even if emissions were held constant at the 1986 average per capita level, the population

Table 2. Two Sketches.

	Total Global Carbon In Million Tons For the Year 2010	% of 1986 Global Total
Case 1. Assumes future world population of 10 billion		
Global per capita carbon emissions of:		
Bangladesh (30 kg.)	301	4
India (227 kg.)	2,269	31
China (526 kg.)	5,260	73
Iran (684 kg.)*	6,839	95
Italy (1,659 kg.)**	16,593	230
Japan (2,108 kg.)	21,077	292
Brazil (2,807 kg.)	28,072	389
US (4,974 kg.)	49,736	689
Case 2. Assumes world carbon per capita constant at global average (1,468 kg)		
Global population growth rates of:		
Bangladesh (2.6%)	13,361	185
India (2.2%)	12,165	169
China (1.2%)	9,608	133
Iran (2.8%)	14,000	194
Italy (0.3%)	7,754	107
Japan (0.7%)	8,531	118
Brazil (2.2%)	12,165	169
US (1.0%)	9,162	127

*Iran is at the median of carbon emissions per capita.
**Italy is close to the average global carbon emissions per capita.
Sources: Marland et al. (1989); World Bank (1989).

growth rate alone (under different scenarios) would have a substantial impact on the global level. This can be seen by noting the differential impacts of lower population growth rates (e.g., Italy and Japan) compared to those of higher growth rates (e.g., Bangladesh and Iran).

All of this presumes "no-surprise" futures and the prevalence of current patterns of industrialization and technological development. The cases are therefore only illustrative. They show that demographic factors are indeed compelling but that technological change and patterns of resource use have significant impacts as well. Together they highlight the dilemmas posed by the population nexus.

Challenges to Theory and Policy

Given the impacts of population on the environment and the interactions of population change with socioeconomic development, a central priority must be to improve both theory and policy on population.

The absence of a dynamic "causal" theory of population interactions with socioeconomic conditions may explain the relatively simple treatment of population in energy models, or models of aspects of global environmental change. The omission is serious—not only in terms of direct population effects and feedback but also with respect to the more complex population/resource technology interactions which provide the context and significance of demographic factors in any particular state or social environment.

Contemporary demographic analysis—beyond the demographic transition—needs to address ways in which populations adapt or fail to adapt to their environments (Coleman, 1986:14). Also important is the need to relate more explicitly and precisely the interactions among population, energy, and environment. At least five tasks can be identified:

- Uncoupling processes of demographic responses (fertility, mortality, and migration trends) from those of demographic pressures (size and rates of growth);
- Analyzing the population feedback systems and how they vary in different demographic contexts and with different population nexuses;
- Accounting for the existence of complex demography society linkages, such as warfare, infanticide, natural disasters, and disease, etc., that could substantially alter prevailing patterns of energy/environment interactions;
- Specifying the population/energy/environment interactions for different states at different levels of development;
- Identifying alternative forms of "sustainable" population/environment relationships in different demographic contexts.

Policy

Theory aside, there still remains the crucial issue of managing the global population, taking into account regional and national demographic characteristics, and framing a viable global policy. Population policy, in the broadest sense, has become a highly political issue, necessitating the articulation of underlying norms to help guide policy formulation. Since states at different levels of development generate different energy demand patterns and different forms of effluents—with different implications for the local and the global environment—the norms and principles for policy formation must respond to these differences.

A global approach to policy for managing population parameters can only be based on voluntary compliance internationally; coercion is simply not an option. Five principles, together, frame the basis for compliance.

These are 1) legitimacy: intervention strategies must be viewed as legitimate by all actors; 2) equity: interventions must be fair and appropriate; 3) consensus: policy must be adopted through procedures predicated on volition, not coercion: 4) universality: coverage must be global, encompassing all sovereign states: and 5) efficacy: implementation must be effective and not necessarily efficient.

The fact remains, however, that even if population policy worldwide were strengthened substantially, the most optimistic scenario still projects a future population of at least 10 billion people (rather than 14 billion or higher). In other words, strong population policy will only make the current projection more viable; it cannot shift the trend sufficiently to bring the number down below 10 billion by 2010.

Whatever the long-term management strategies for anthropogenic sources of global environmental change, the population factor is a crucial component. Population policy alone, however effective or comprehensive, is not sufficient to generate the adjustments, but it is necessary. The population nexus as a whole—the interaction of population, resources, and technological change—must become the focus of global policy.

Acknowledgments

I am grateful to Diane Beth Hyman, W. Parker Mauldin, and Jan Sundgren for comments on an earlier version of this paper.

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