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Population and Climate Change¹

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PEOPLE ARE PART OF THE PROBLEM of climate change and part of the solution (O'Neill et al. 2001, 2004; Guzmán et al. 2009; Jiang and Hardee 2009; O'Neill 2010; Nelson 2010). The challenge is to quantify that statement. This article reviews some of what has been learned so far.

Population includes, in addition to the numbers of people, their demographic attributes like age, sex, education, health, and familial status; their demographic processes like birth, death, migration, the formation of unions and families, and their dissolution; and the spatial distribution of people by geographic regions and size of settlements, from rural to urban. I will review what demographers expect of the human population from now to 2050, then describe how people collectively affect climate and how climate affects the human population. The focus will be on the available quantitative information, its implications, and its limitations. Finally, I will offer some recommendations for action.

The interactions between climate and the human population depend on economics and culture (fig. 1). I find it useful to visualize these interactions by means of a regular tetrahedron with a triangular base and a point on top (Cohen 1995, 389). The three corners of the base refer to economics, the environment, and culture. The vertex at the top refers to population. If you are an economist, or anthropologist, or ecologist, please feel free to rotate the tetrahedron to put your field at the top. This image is a graphic reminder that the way the human population interacts with the environment (including climate) is affected by the way they both interact with culture and economics. Equally, the way economics interacts with the environment is affected by the way they both interact with population and culture; and so on. Some examples will arise below.

¹Read 14 November 2008, as part of the symposium "Action Not Words." Copyright © 2010 by Joel E. Cohen.

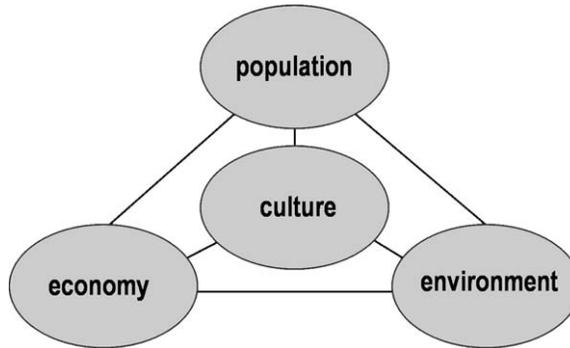


FIGURE 1. Interactions between the human population and the environment, including climate, depend on economics and culture.

Another useful analysis of a climate-related complex human problem, tropical deforestation, identified five “broad underlying driving forces” (Geist and Lambin 2001, 33): POP = human population dynamics, ECON = economic growth or change, commercialization, development, TECH = technological change, INST = policy and institutional factors, or change of political-economy institutions, and CULT = cultural or socio-political factors. POP, ECON, and CULT correspond tidily to population, economics, and culture. TECH falls in the intersection of culture and economics, while INST falls within culture, along with education (Lutz 2009a, 2009b) and governance (Mustelin et al. 2010). Geist and Lambin take account of the environment under “other factors,” including land characteristics (such as soil quality) and biophysical drivers (such as forest fires).

Curiously, Geist and Lambin (2001) do not mention the words “desert” or “desertification” or the phrase “climate change,” which can affect or be affected by tropical deforestation. For example, during the 1990s, emissions of CO₂, methane, nitrous oxide, and other chemically reactive gases from deforestation and subsequent uses of the land accounted for perhaps 25% of anthropogenic emissions of greenhouse gases (Houghton 2005, 13). Keeping in mind the tetrahedron in figure 1 can prevent significant omissions.

A third perspective is expressed by saying that any environmental impact (I) is the product (mathematically and causally) of population (P) times affluence (A, economic product or consumption per person) times the environmental impact per unit of economic activity (T), summarized by the formula $I = PAT$. When this formula was introduced in the early 1970s, T represented technology. Recent interpretations have grown far more sophisticated (Liddle and Lung 2010; O’Neill 2010). For example, Dietz and Rosa (1997) elaborated that T “is determined

by the technology used for the production of goods and services and by the social organization and culture that determine how the technology is mobilized,” while Liddle and Lung (2010) disaggregated P into specific age-groups and specified the proportion of the population living in urban areas.

It is possible to connect $I = PAT$ with the tetrahedron in figure 1 by matching P to population, A to economics, T to both economics and culture, and I to the environment. But there is a big difference. The formula $I = PAT$ and its stochastic generalization, the STIRPAT model (Dietz and Rosa 1997; Liddle and Lung 2010), despite the valuable insights they yield, do not represent the environmental impact on population, economics, and culture. By contrast, the tetrahedron emphasizes bidirectional interactions between any two of these as well as three-way and four-way interactions of population, economics, environment, and culture.

In a useful review of the interactions between human population dynamics and the environment, including (among others) energy and climate change, de Sherbinin et al. (2007) observed, and demonstrated by examples, that “monocausal explanations of environmental change that give a preeminent place to population size and growth suffer from three major deficiencies: They oversimplify a complex reality, they often raise more questions than they answer, and they may in some instances even provide the wrong answers.”

THE HUMAN POPULATION TO 2050

From now to 2050, the human population is likely to grow bigger, more slowly, older, and more urban (Cohen 2005). Populations of non-human animals, plants, and microbes will also change in the coming decades, and their dynamics will affect, and be affected by, human population dynamics in ways not easy to predict. Here I focus on the human population.

Bigger: In 1600, there were just over half a billion people on the planet. When the American Philosophical Society was founded around 1743, there were about 800 million people. The population in 2010 at 6.8 billion is roughly 8.5 times that size. The United Nations Population Division (2009) projected that world population will rise to around 9.1 billion by 2050 if humans have children, migrate, and die at the rates assumed. The projected increase of 3 billion from 2000 (when the world’s population stood at 6.1 billion) to 2050 equals the entire world population in 1960.

Slower: In 1950, the total fertility rate for the entire globe was slightly in excess of 5 children per woman per lifetime. The total fertility

rate measures the average number of children per woman per lifetime based on current rates of fertility. Fertility refers to actual bearing of children, whereas fecundity refers to the biological capacity to bear children. The total fertility rate fell to fewer than 2.6 children per woman in 2010, that is, by half in sixty years. More than half the women in the world now live in countries where the total fertility rate is below the replacement level (Wilson and Pison 2004). The replacement level is between 2.0 and 2.3 children per woman per lifetime depending on death rates.

This decline in fertility is perhaps the greatest revolution in human history in the behavior of individuals and couples. This enormous change has long been under way in today's rich countries. It is now advancing in many (though not all) poor countries, even in some of the very poorest. The demographers of the United Nations Population Division, and many others, anticipate that the global total fertility rate will continue to fall to (or perhaps below) the replacement level by about 2050 (fig. 2). Some demographers believe the global total fertility rate may continue to fall below replacement level and remain there for an unknown time. Others doubt that fertility will fall to the replacement level by 2050 in some countries with high fertility currently, particularly in sub-Saharan Africa (e.g., Jiang and Hardee 2009, 15).

The world's population size was growing by about 79 million people per year in 2010. Overwhelmingly, these additions were and will be located in the cities of today's poor countries (the "developing regions"). The projected annual increase of the global population in 2050, 31 million per year, will be less than half that of today. By the middle of the twenty-first century, the population of today's rich countries (the "developed regions") is projected to be falling by a million people per year, and the population of today's poor countries is projected to be growing by 32 million per year (assuming rates of birth, death, and international migration anticipated by the United Nations Population Division [2009]).

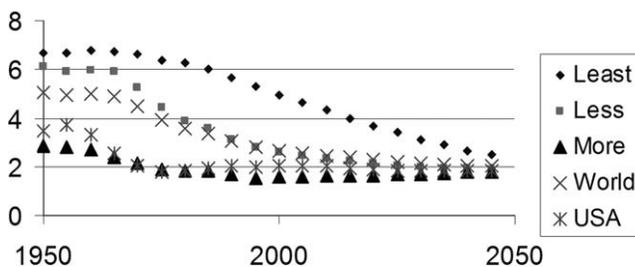


FIGURE 2. Total fertility rates are falling almost everywhere. "Less developed" nations here exclude "least developed" nations. Source of data: United Nations Population Division, World Population Prospects: 2006 revision, medium variant.

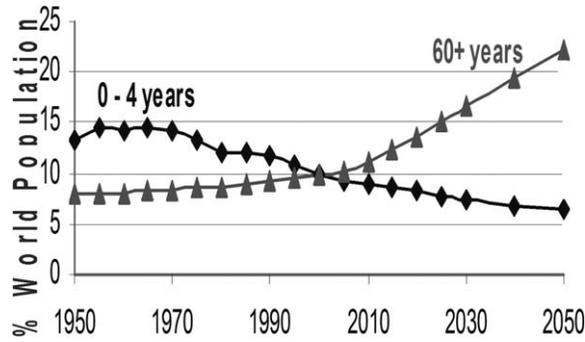


FIGURE 3. For the first time in human history, people aged sixty years and older outnumber children aged zero to four. Source of data: United Nations Population Division estimates and projections, medium variant.

Older: For the first time in human history, since the year 2000 or shortly thereafter, the world has had more people sixty or older than children aged zero to four (fig. 3). It is projected that, by 2050, there will be 3.4 people aged sixty or older for each child aged zero to four.

More urban: Since sometime between 2005 and 2010, for the first time in human history, the world has had more urban people than rural (fig. 4). The definition of “urban” varies among countries, so there is uncertainty about the meaning and timing of the cross-over. Between 2010 and 2050, on the average, the world will have to accommodate around 1.3 million additional city people every week. Is this number plausible? According to the United Nations Population Division (2010), between 2010 and 2050 the world’s urban population will grow from 3.5 billion to 6.3 billion, an increase of 2.8 billion over forty years, or 70 million per year. It is generally conceded that there are just over

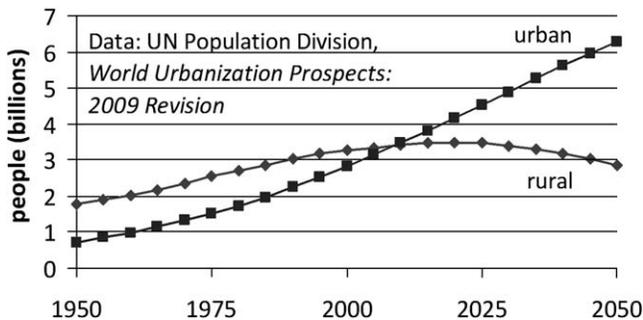


FIGURE 4. From roughly 2007–08 on, the world will have more urban people than rural. Source of estimates and projections: United Nations Population Division, World Urbanization Prospects: The 2009 Revision.

fifty-two weeks in a year. That works out to more than 1.34 million additional urban people per week, on average from 2010 to 2050. Almost 94% of this urban growth (an increase of more than 2.6 billion people) will occur in today's developing countries. Providing urban infrastructure for 1.26 million additional urban people in today's developing countries every week from 2010 to 2050 represents a challenge and an opportunity to build better-designed (Jiang, Young, and Hardee 2008), more energy-efficient (Kelly 2009, 2010), more elder-friendly cities.

The proportion of elderly in the cities of 2050 will be without precedent, and probably beyond present imagination. The rural population is likely to have even higher proportions of elderly, especially in developing countries, because adult migrants from rural areas to cities are disproportionately young adults.

HOW DOES AND WILL THE HUMAN POPULATION AFFECT CLIMATE CHANGES?

Humans alter the climate by emitting greenhouse gases, by altering planetary albedo (the fraction of incoming light that the planet reflects), and by altering atmospheric components, such as ozone and sulfuric acid particles (which affect cloud cover). The albedo is altered by changing the amounts of land covered by forest, snow, ice, desert, asphalt, and concrete.

Human interventions have altered the atmosphere for a long time. Ruddiman (2005) estimated that about 8,000 years ago, Stone Age people burned enough forests and other biomass to account for a rise in CO₂ concentrations at that time of about 40 parts per million. By 5,000 years ago, widespread agriculture including flood irrigation, animal husbandry, and biomass burning accounted for a rise in atmospheric methane concentrations demonstrable at that time from ice cores.

Increasing numbers of people demand increasing amounts of plant and animal foods. Producing those foods contributes significant, though contested, amounts to atmospheric concentrations of greenhouse gases including CO₂, methane, and nitrous oxide (Steinfeld et al. 2006; Smith et al. 2007; Pitesky et al. 2009; Wolf et al. 2010).

I am going to consider only CO₂, the greenhouse gas estimated to have the largest warming effect. It's useful to know that 11 tons of CO₂ contain 3 tons (about 27% by weight) of carbon.

In 1900, humans emitted perhaps half a billion tons of carbon to the atmosphere per year. In 2000, humans emitted 7.3 billion tons a year, by one estimate. The ratio was approximately a fifteenfold increase. The human population of Earth in 1900 was 1.6 billion. The

population in 2000 was 6.1 billion. The population increased by less than a factor of four. A fifteenfold increase in carbon emissions accompanied a less than fourfold increase in numbers of people. Population growth alone, with constant rates of emissions per person, could not account for the increase in the carbon emissions to the atmosphere.

Other factors that contributed to increased carbon emissions included increasing energy production per person to drive economic growth, changes in technology (e.g., internal combustion engines, jet engines), tropical deforestation, and other land-use changes. The world economy grew sixteenfold in the twentieth century, from \$2 trillion to \$32 trillion in 1990 Geary-Khamis dollars. (A 1990 Geary-Khamis dollar is a hypothetical unit of currency with the same purchasing power as one U.S. dollar in the United States in 1990.) So income per person grew about fourfold. As the global economy grew sixteenfold, primary energy production grew about fifteenfold, driven principally by the burning of gas, oil, and coal, though other energy sources contributed.

This global level of analysis is as tantalizing as it is suggestive. It is tantalizing because it does not reveal whether, in one set of countries (e.g., the poor countries), population grew and emissions remained constant while, in another set of countries (e.g., the rich countries), emissions grew and population remained constant, or whether all countries had equal rates of population growth and equal rates of growth of carbon emissions to the atmosphere.

Reality apparently lay somewhere between these extremes of heterogeneity and homogeneity (Shi 2003). Following the approach initiated by Dietz and Rosa (1997), Shi (2003) analyzed data from ninety-three countries on CO₂ emissions (I) from aggregate fossil fuel consumption and cement manufacture as a function of population size (P), gross domestic product (GDP) per person (A), manufacturing output as a percentage of GDP, and services output as a percentage of GDP. The data, from 1975 to 1996, were analyzed for all countries together and separately for high-income countries and “developing” countries (those with incomes in the low, lower-middle, and upper-middle categories of the World Bank).

The ninety-three countries between 1975 and 1996 resembled the whole world over the twentieth century in that their emissions grew faster (by 61%) than their population (by 43%). Carbon dioxide emissions grew faster than population in both developed and developing countries. In the high-income countries, emissions grew 27% while population grew 16%. Hence the ratio of emissions-to-population growth rates was 1.6. In the developing countries, emissions grew 140% (from a base that was much lower than that in the high-income countries) while population grew 49% (from a base that was higher than that in the

high-income countries). For developing countries, the ratio of emissions-to-population growth rates was 2.8 (Shi 2003, 35). Although the population growth of the developing countries was much more rapid than that of the high-income countries (49% compared with 16%), carbon emissions grew still more rapidly compared with population size in the developing countries than in the high-income countries (the ratio of emissions-to-population growth rates was 2.8 compared with 1.6).

In a multiple regression model of log emissions as a function of log population, log GDP per person, log percentage of GDP from manufacturing output, and log percentage of GDP from services output (Shi 2003, 36), each 1% increase in population was associated with a 1.4% increase in emissions; each 1% increase in GDP per person was associated with a 0.8% increase in emissions; each 1% increase in the percentage of GDP from manufacturing output was associated with a 0.1%, but statistically insignificant, increase in emissions; and each 1% increase in the percentage of GDP from services output was associated with a 0.2% *decrease* in emissions. Population growth contributed more (1.4%) and economic growth contributed less (0.8%) than the 1% increase in emissions predicted by the simple model of $I = PAT$. Other studies have obtained numerical results that differ in quantitative detail (O'Neill 2010 reviewed the results).

The tautology that greenhouse gas emissions depend on population and emissions per person is too simple a way of thinking about greenhouse gas emissions. Greenhouse gas emissions per person depend on income, technology, demographic factors like household size, city size, and population density in built-up areas, institutional and economic factors like the availability of public transport at reasonable cost and convenience, and a host of behavioral factors like people's propensity to walk, bike, carpool, or drive solo to work. For example, the CO₂ per person emitted by passenger transport is lower in denser cities (fig. 5). The United States has a low urban density (persons per hectare) and very high passenger transport CO₂ per person. Low-income highly dense Asian urban areas have a low passenger transport CO₂ per person. In recent decades, in all regions of the world, the average population density of built-up areas in cities of all population sizes has been decreasing (Dodman, in Guzmán et al. 2009, 68). If the inverse relationship between urban density and passenger transport CO₂ per person persists unchanged, the declining urban density may be expected to lead to rising passenger transport CO₂ per person. Whether the relationship will persist depends on urban governance, including zoning, control of sprawl, and provision of public transportation at low enough prices and great enough convenience to induce widespread use.

According to numbers credited to the New York Mayor's Office of

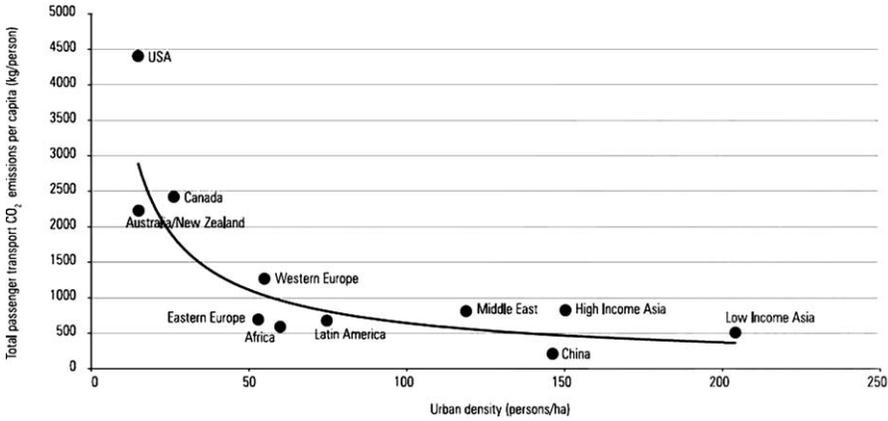


FIGURE 5. Emissions of CO₂ per person for passenger transport per year are lower in denser cities. Source of data: Kenworthy 2003; source of graph: UN-Habitat 2008, 134, figure 3.2.3.

Long-Term Planning and Sustainability (City of New York 2007, 135), all greenhouse gas emissions (not just CO₂) per person in New York City were 29% of the U.S. average (fig. 6). Other greenhouse gases were translated to their “CO₂ equivalent” according to their warming effect in the atmosphere. While the United States averaged 24.5 tons of CO₂ equivalent per year per person, New York City averaged 7.1. London’s average was even lower, at 5.9. Dodman (in Guzmán 2009, 69) cites

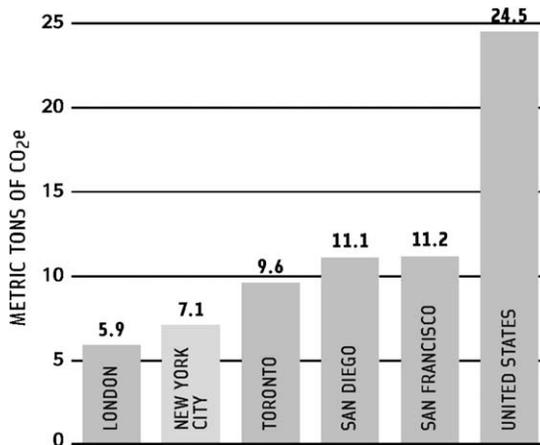


FIGURE 6. Greenhouse gas emissions per person in New York City are 29% of the United States average. CO₂e means CO₂ equivalent: all greenhouse gas emissions are converted to their CO₂ equivalent in their effect on global warming. Source of data and graph: City of New York 2007, 135.

similar comparisons for Britain, Brazil, and Spain. Exactly what the numbers included was not described in detail. Did they include only the emissions within the city, or emissions from the production of all energy directly consumed within the city, even if the energy (e.g., electricity) was generated elsewhere, or did they include the emissions generated elsewhere to produce and transport to the city goods and services other than energy? Were the comparative numbers computed in a consistent way across cities and countries? The large definitional uncertainty of demographic statistics on urban populations also applies to greenhouse gas emissions statistics, especially those for urban or other localized regions.

In China and India, energy consumption per person falls, while money spent per person to pay for energy rises, as one compares rural areas with towns to cities, and the sources of energy change (Pachauri and Jiang 2008, 4030). Biomass combustion (e.g., burning of wood or dung) disappears, while electricity goes from almost nothing to a substantial fraction (Jiang and O'Neill 2004).

In the analyses thus far, the impacts on climate of population have been attributed to the numbers of individuals. This approach fails to capture another relevant demographic factor, households: “. . . it is more appropriate to use the household rather than individuals as the unit of analysis because a large portion of energy consumption related to . . . heating and air conditioning, transportation, and appliance use is shared by household members” (de Sherbinin et al. 2007, 360). Compared with households with fewer people, households with more people have, on average, lower energy use per person and higher energy use in total (MacKellar et al. 1995; de Sherbinin et al. 2007).

For example, in U.S. households in 1993–94, the combined energy use per person (a sum of residential energy and transport energy) for a household with one person was nearly three times the combined energy use per person of a household with six or more people, though the aggregate energy use of a household with six or more people was more than twice that of a household with one person (O'Neill and Chen 2002) (fig. 7).

The average number of people per household declined worldwide from 1970 to 2000 (Keilman 2003). In the more developed regions (Europe, northern America, Japan, Australia, and New Zealand), the average size of a household dropped by about one person from 1950 to 2000. In the less developed regions, average sizes of households fell since 1985 by a bit less than one person. This dramatic change in behavior went with, and was partly, but not entirely, caused by the simultaneous drop in fertility.

In any society at a given time, the average number of people per household equals the number of people divided by the number of

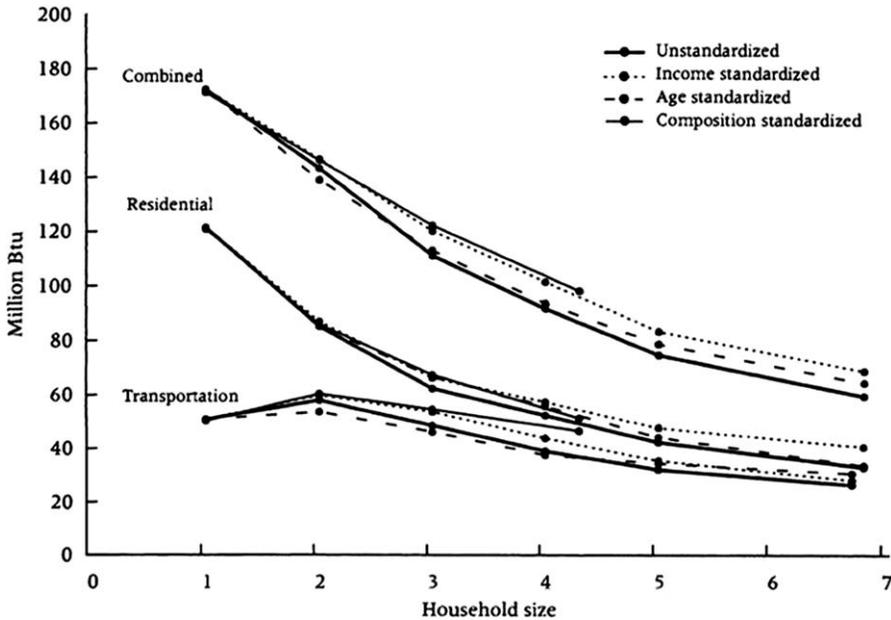


FIGURE 7. Average energy use per person in the United States, 1993–94, was smaller in households with more people. Different lines represent actual and standardized for income, age, and composition 1993–94. Btu = British thermal units. 1 million Btu = 1.05505585×10^9 joules. Source of data and graph: O’Neill and Chen 2002, 68, figure 4.

households. When the number of households increases faster than the number of people (where growth is measured as proportional increase per unit time, e.g., percent per year), the average number of people per household decreases. Demographers expect that households will decrease in size for four reasons (Keilman 2003). One, fertility is falling, so the number of kin, including children, uncles, aunts, and cousins, per household is declining. Two, longevity is increasing, so the fraction of a lifetime spent without children at home is increasing. Three, multiple forces shift more two-adult households to one-adult households: people are living singly longer before they marry; divorce rates are rising; and the better survival from marriage to advanced ages of women compared with men means that many more women are being widowed. Fourth, rising wealth increases the feasibility of living independently. As a consequence of decreasing household size, households are expected to grow in number much faster than the numbers of people. The fall in fertility reduces the number of people in the future, but, for a given number of people, increases the number of households. It’s a complicated interaction.

Forecasts of the future depend on whether the units of analysis are individuals or households (MacKellar et al. 1995, 859). For example, in the more developed regions, the growth rate of energy consumption from 1970 to 1990 was 2.1%. When the accounting was done in terms of individuals, one-third of that growth was due to the growth of population. When the accounting for the same 2.1% was done in terms of households, the growth in the number of households accounted for more than three-quarters of the growth in energy consumption. Using households instead of individuals affected the interpretation of the past and gives very different projections of the future. MacKellar et al. (1995, 863) concluded, and I agree, “. . . it would be unwise to draw far-reaching conclusions about the impact of demographic variables on the environment from one specific choice of model without a substantive justification of that choice.”

MacKellar et al. (1995, 861) decomposed the 2.1% annual growth in energy consumption in the more developed regions between 1970 and 1990 into a sum of four components: 0.7% due to the growth of population (individuals), another 0.7% due to change in age structure, 0.2% due to change in age-specific headship rates (which measured average household sizes as a function of the age of the head of the household), and 0.5% due to other changes. The first two factors, population growth and aging, accounted for two-thirds of the annual growth in energy consumption in the developed regions. By contrast, over the same twenty years, the much greater rate of growth of energy consumption in the less developed regions, 6.7% per year, was largely (4.2%) due to other changes, not to the first three demographic factors.

As this analysis suggested, aging is an important factor in energy demand. The U.S. Consumer Expenditure Survey found that households with an older “householder” or “household head” spent a substantially larger share of income than younger households on utilities, services, and health care, and a substantially smaller share on clothing, motor vehicles, and education. According to Dalton et al. (2008, 652), “Since the most energy intensive goods are utilities and fuels, . . . aggregated consumption in older households is more energy intensive than consumption in younger households.” In their projections of future U.S. carbon emissions to 2050, aging had effects as large as or larger than the effects of technical change in some scenarios.

In the United States in 1987–97, energy consumption for residential purposes increased as the age of the household head increased from fifteen to eighty-five. Also in the United States in the interval 1983–94, transport energy declined as the age of the household head increased (fig. 8). Similar trends have been demonstrated in China and India, the world’s two demographic billionaires (O’Neill and Chen 2002).

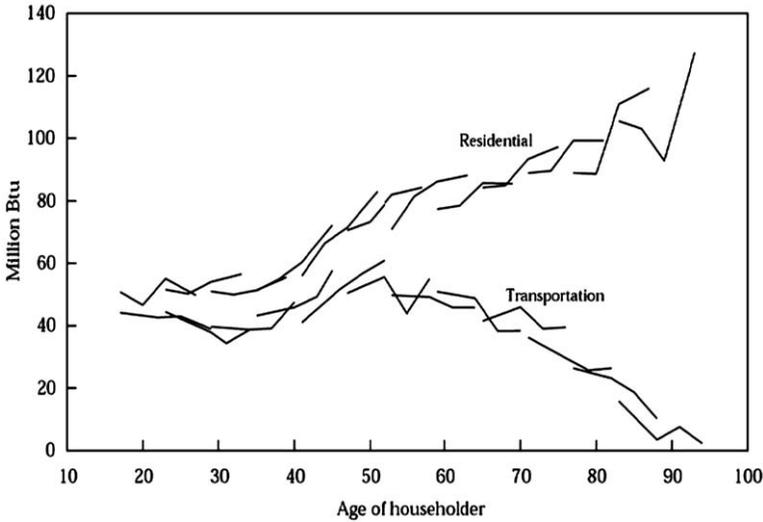


FIGURE 8. In the United States, residential energy use increased with the age of the householder (1987–97), while transport energy use decreased with the age of the householder (1983–94). Btu = British thermal units. Source of data and graph: O’Neill and Chen 2002, 66, figure 2.

HOW DO AND WILL CLIMATE CHANGES AFFECT THE HUMAN POPULATION?

Students of human evolution conjecture, based on evidence they consider imperfect, that climatic changes have been major influences on human evolution (National Research Council 2010). For example, it has been suggested that the expansions of grasslands in Africa around three million years ago contributed to the evolution of bipedalism, a distinguishing feature of humans. It has been proposed that the extremely cold climate of middle Pleistocene Europe led to the evolution of the more robust limb bones and shorter forearms characteristic of Neanderthals, in contrast to the longer and slenderer limb bones of warm-adapted modern *Homo sapiens*, who first appeared in Africa. And it has been argued that the changes in the Classic Mayan civilization of southern Mexico and Central America between AD 750 and 1150, including a 70% reduction in population size, may have resulted from extended droughts in those centuries. These droughts were inferred from sediment cores taken from local lakes, and coincided with dry conditions at those times in other parts of tropical America. Such examples indicate the long history of climatic impacts on human evolution, demography, and civilization.

In the present, climate changes affect infectious diseases, coastal cities, agricultural yields, agricultural and medical pests, invasive spe-

cies, biological diversity, phenology (the seasonal timing of the flowering of plants), the ranges of species, and many other aspects of the living environment.

Climate changes will also increase extreme weather events, a euphemism for hurricanes, droughts, and floods. These “hydro-meteorological disasters” have affected a rapidly growing number of people in developing countries, increasing from perhaps 40 million affected individuals per year in 1975–79 to perhaps 260 million people per year in 2000–04 (Relman et al. 2008, 8).

Sea level rise is likely to affect coastal cities. The area along coastlines that is less than 10 m above sea level covers 2% of the world’s land, but shelters 10% of all people and 13% of urban people (UN-Habitat 2008). For example, in South America, the Caribbean, Africa, and from Turkey to Japan, many coastal cities are less than 10 m above present sea level. As urbanization and numbers of cities on coasts increase while coastal storms become more severe, the numbers of people vulnerable to coastal hazards will rise.

Climate changes will affect people’s health, mortality, and migration directly and, through effects on livelihood, indirectly (Guzmán et al. 2009). Relman et al. (2008, xii) warned, “The warming of the Earth is already contributing to the worldwide burden of disease and premature deaths, and is anticipated to influence the transmission dynamics and geographic distribution of malaria, dengue, tick-borne diseases, cholera, and other diarrheal diseases.” Dyson (2005) warned of the possibility of “several negative changes occurring simultaneously and to cumulative adverse effect.” However, specifying the consequences more precisely is “impossible because simply not enough is known about what exactly will happen in terms of changing biophysical conditions and how the populations of the future will be able to cope with these changes. . . . [A]ssessment of likely future vulnerability is very difficult and probably presents the biggest research gap for assessing the dangers associated with climate change” (Lutz 2009a).

Climate changes will substantially affect people in the United States (Karl et al. 2009, 100). For example, in the twentieth century, the U.S. population grew most rapidly near coasts, in the South, and in and around large cities. The four states with the largest populations (California, Texas, Florida, and New York), where 38% of U.S. population growth occurred in the twentieth century, are vulnerable to rising sea levels, coastal storms, effects of urban heat islands, and droughts. In the Mountain West, the area of the U.S. where the number of people is expected to grow most rapidly from 2000 to 2030, climate changes are projected to exacerbate the frequency and severity of wildfires and shortages of water. In general, projections of future changes in U.S. population

and U.S. climate indicate that “more Americans will be living in the areas that are most vulnerable to the effects of climate change.”

Climate changes will affect poor people more severely than rich, and poor nations more severely than rich. Rich people and nations are better positioned than the poor to bear the costs resulting from climate change. They are also better positioned to develop the technology and to implement the actions necessary to reduce human greenhouse gas emissions. Whether the wealth of even the richest countries will protect them from the consequences of climatic changes already underway is unknowable.

WHAT TO DO

The rich economies of the world could reduce their emissions of greenhouse gases in various ways that have been much discussed (Creys et al. 2007; Granade et al. 2009), e.g., through greater energy efficiency and reduced carbon intensity of energy production. Many such responses do not directly involve the demographic issues described above, and will not be discussed here. I draw attention to three kinds of responses that are related to demographic issues: universal secondary education, voluntary contraception and maternal health services, and smarter urban design and construction. These responses may prevent, reduce, or ameliorate the impacts of climate changes. They are as relevant to rich countries as to poor, though in ways that are as different as are rich countries and poor. They are desirable in their own right because they improve the lives of the people they affect directly and they are desirable for their beneficial effects on the larger society and globe. I would argue that we should, and can afford to, pursue these responses for their own sake, no matter how much they influence climate changes.

The world's population in 2050 will depend sensitively on what we do from now to then. According to the United Nations Population Division (2009), if today's fertility rates remain constant (a scenario that is unlikely, given the past trend of decreasing fertility rates), the world will have 11 billion people in 2050. The U.N. expected the recent decline in fertility to continue, and because of declining fertility, the medium projection for 2050 is 9.1 billion. But if women have, on the average, half a child less per lifetime than assumed in the medium projection, the number of people on the planet will be nearly 8 billion by 2050. If world population were at or below 8 billion by 2050 rather than at 9.1 billion as in the medium projection, carbon emissions would be 1–2 billion tons per year lower by 2054 (O'Neill 2010, 92). This reduction would correspond to one or two of the seven or so “stabilization wedges” estimated by Pacala and Socolow (2004) to be necessary

and sufficient to prevent a doubling of greenhouse gases in the atmosphere (though Pacala and Socolow overlooked the role of the human population). The contribution of slowed population growth to stabilizing the atmosphere would be substantial, though not dominant.

If, between now and 2050, women have, on the average, half a child more than assumed in the U.N.'s medium projection, the projected number in 2050 is 10.5 billion. The difference between the low projection of 8 billion in 2050 and the high projection of 10.5 billion in 2050 is 2.5 billion, which was the total world population in 1950. Putting those two halves of children back together means that a difference of one child per woman between now and 2050 means 2.5 billion more or fewer people by 2050. Almost all of this increase will be in the cities of the developing countries, many of them on coastlines. If O'Neill's (2010) estimate above applies here as well, a difference of one child per woman between now and 2050 entails a difference of roughly 2–4 billion tons per year of carbon emissions by 2054. What we and today's young men and women and today's children, who will become parents before 2050, choose to do between now and 2050 will have an enormous effect.

Murtaugh and Schlax (2009) estimated that “[u]nder current conditions in the United States, for example, each child adds about 9441 metric tons [t] of carbon dioxide to the carbon legacy of an average female, which is 5.7 times her lifetime emissions.” Though the estimated “carbon legacy” of a child in a developing country is much lower (for example, 1384 t in China, 171 t in India, 56 t in Bangladesh), the much higher fertility rates of some of the poorest countries make population growth relevant to climate change in countries both rich and poor.

The case for promoting universal education includes, among many other benefits (cultural, economic, and environmental), its effects on the age of mothers at their first birth, their lifetime fertility, and the survival of their children. The case for universal secondary education rests on thresholds in the duration of education required before some of these benefits are realized.

In Africa, Asia, and Latin America, women with no education are more likely to have children before age twenty than women with some primary education, and women with some primary education are more likely to have children before age twenty than women with some secondary education (United Nations Population Division 2004, table A. II.3, 63) (fig. 9).

Women with more education not only start childbearing later, but have fewer children per lifetime. The average number of children among women who have a given level of education differs from place to place, but in some developing countries, women who complete secondary education have on average at least one child fewer per lifetime than women

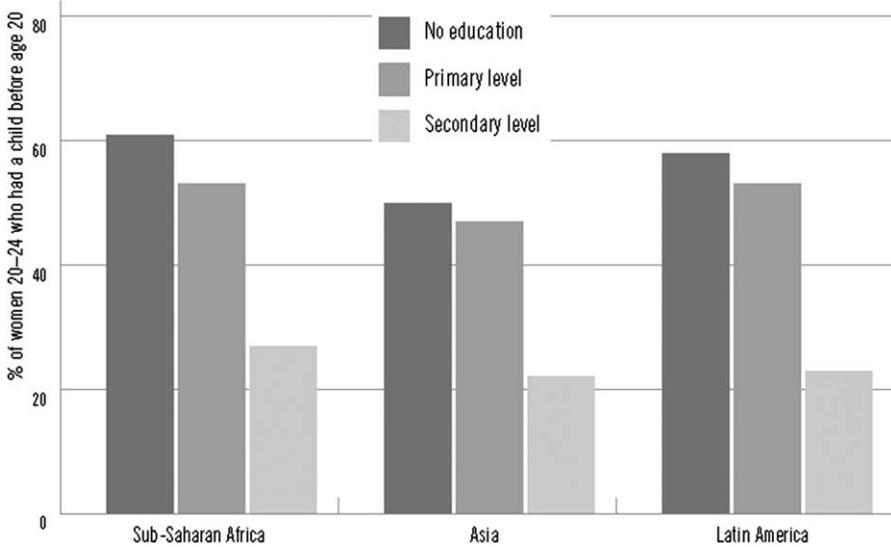


FIGURE 9. Women with less education are more likely to have children before they are twenty years old. Source of data: United Nations Population Division 2004, table A.II.3, 63. Source of graph: Singh et al. 2003, 23, figure 4.1.

who complete only primary education (Murphy and Carr 2007) (fig. 10). KC et al. (2010) compared the total fertility rate of women who had the highest level of education with the total fertility rate of women who had the lowest level of education in each of around a hundred countries from all major regions and levels of development. The most highly educated women in Nordic countries, where fertility was already low, had an average number of children per lifetime that was reduced by about 10% (or less) compared with the fertility of the least educated women. In many developing countries, the reduction in fertility of the most educated women, compared with the least educated women, was 50% or more. As the average fertility in developing countries was much higher, the impact of education on fertility was much higher in those countries as measured both in percentage terms and in absolute numbers of children.

The children of women who have a secondary education survive to the age of five much more frequently than the children of women who have only primary education. The latter children survive much better than the children of women with no education (Hannum and Buchmann 2005, 2006) (fig. 11). Improving the survival of children is an obvious value for its own sake and historically has been a prerequisite for fertility decline, as parents have felt the need for fewer births to assure some surviving children.

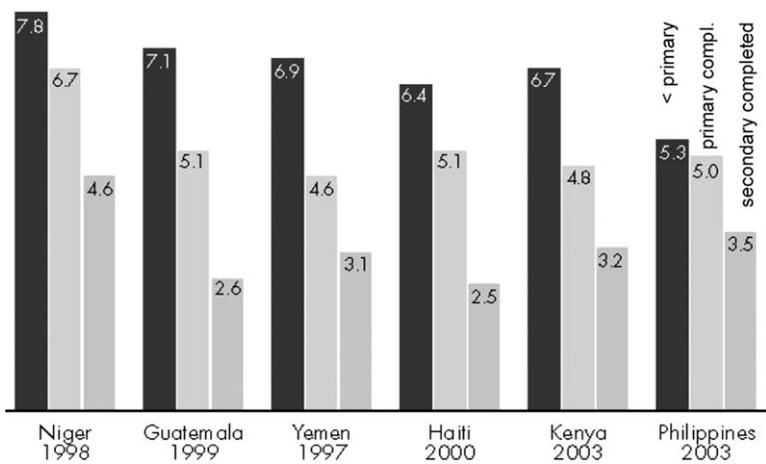


FIGURE 10. In numerous developing countries, the more primary and secondary schooling a woman has completed, the lower the number of children she has. For a given level of schooling, the absolute number of children varies from culture to culture. Source of graph: Murphy and Carr 2007, 2, figure 1.

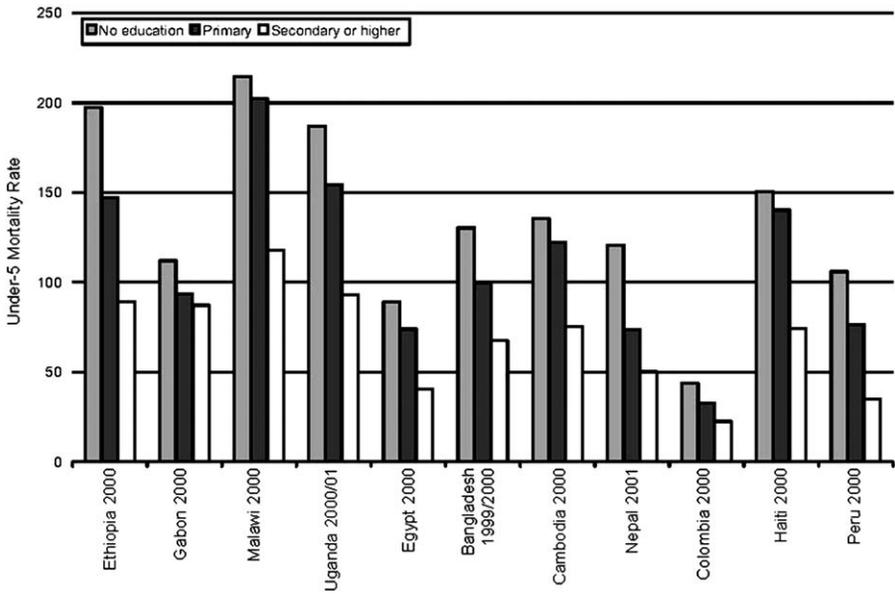


FIGURE 11. Children of better-educated mothers are much more likely to survive to the age of five. Source of graph: Hannum and Buchmann 2005, 342, figure 2; 2006, 511, figure 2, from data of Demographic and Health Surveys.

Of course, these are correlations, not causal proofs. For example, a lack of education among mothers may be associated with the poverty of the family, and poverty may be responsible for the early death of children and a lack of education for their mothers. The interactions between the level of young women's education and their age at first birth, the number of children they bear, and the survival of those children deserve further research. Nevertheless, the correlational evidence is consistent with a plausible argument that more education would affect all three variables favorably from the point of view of the young women, their children, and the larger society. I think the case is strong that we ought to assure a high-quality secondary education to every child in the world. We can afford to do so for less than 1% of the world's annual economic product (Binder 2006), and we cannot afford not to do so (Cohen et al. 2006).

In the conceptual framework suggested by the tetrahedron in figure 1, education falls into the sphere of culture. I would argue that, in addition to its inherent value, universal primary and secondary education may be the cheapest, most effective way to influence favorably the other vertices of the tetrahedron: population, through reduced fertility, better health, and better survival; economics, through improved productivity and technological capacity; and the environment, including climate, through more educated demands on the resources of the planet. Lutz (2009a, 2009b) has emphasized the potential of education to increase people's capacity to adapt to climate changes and to develop technologies that could lessen them.

However, education cannot realize its vast potential without food, peace, energy, law, health, and freedom. Hardly any complex human problem has a unidimensional solution. If climate changes make it more difficult to feed children and their families (e.g., Lobell and Asner 2003; Lobell et al. 2009), it will be more difficult also to educate those children.

Increasing the availability of voluntary contraception and maternal health services is a second needed action. In 2008, some 215 million women who wanted to avoid a pregnancy were not using modern, effective contraception, 75 million pregnancies were unintended, and about 20 million women had unsafe abortions (Singh et al. 2009, 4). Providing modern contraception to women who need it and maternal and newborn health services would reduce unintended pregnancies to an estimated 22 million per year and unsafe abortions to perhaps 5.5 million per year (assuming abortion laws remained unchanged), as well as offering numerous other health, social, and economic benefits. Meeting the unmet need for modern contraception in developing countries would cost an estimated \$3.6 billion in 2008 U.S. dollars, on top of the

\$3.1 billion being spent to serve those who are currently using modern methods. The total cost, \$6.7 billion, works out, by sheer coincidence, to about one dollar per year for every person in the world. For comparison, the gross world product in 2008 was somewhere between eight and ten thousand dollars per person, depending on how other countries' economic activity was converted to U.S. dollars.

Unintended pregnancies and the need for effective, modern contraception and maternal health services are not limited to developing countries. In 2001, in the United States, an estimated 49% of pregnancies were unintended, and 5.1% of women aged 15–44 had an unintended pregnancy, with substantially higher rates among unmarried cohabiting women, minority women, women who had not completed high school, and low-income women (subgroups that overlap) (Finer and Henshaw 2006). The world, and the United States, can afford the small cost to make every newborn a healthy, wanted child (within the limits of biological variability).

As I pointed out above, more than half the world's people now live in cities, and the world will have to provide urban infrastructure to accommodate roughly 1.3 million additional city-dwellers every week for the next forty years. People in cities consume energy for transport, buildings, industry, and services. According to UN-Habitat (2008, 164), “much of the current urban building stock in Europe was designed and constructed when energy was cheap and global warming was unheard of.” In the U.K., buildings account for about 45% of all energy consumption, and homes for 27% (Kelly 2009; 2010, 1084). Kelly (2010) argued that, in the U.K., 70% of the buildings in 2050 will be buildings that exist today; therefore, in addition to building more energy-efficient new buildings, it is also imperative to improve the energy-efficiency of existing buildings.

New technologies can reduce energy consumption while providing the same level of comfort and service. Technologies currently commercially available include efficient lighting and daylighting, efficient electrical appliances, improved insulation, and passive and active solar design for heating and cooling. Technologies projected to be commercialized before 2030 include integrated intelligent meters that provide feedback and control, and solar photovoltaics. We ought to put the best available technologies to work, because we're going to have billions more people consuming energy in cities.

In their foreword to the collection of studies of population dynamics and climate change edited by Guzmán et al. (2009, vi), Werner Haug and Gordon McGranahan wrote, “The defining challenge of the 21st century is to combine a rapid reduction in poverty and inequality with a rapid reduction in global greenhouse gas emissions.” Both prongs of

the challenge would benefit from the three lines of action I propose, namely, universal secondary education, voluntary contraception and maternal health services, and smarter urban design and construction.

SUMMARY

To review, the four broad dimensions of any complex human problem, including climate change, are the human population, economics, culture, and environment. These dimensions interact with one another in all directions and on many time-scales. From 2010 to 2050, the human population is likely to grow bigger, more slowly, older, and more urban. It is projected that by 2050 more than 2.6 billion people (almost 94% of global urban growth) will be added to the urban population in today's developing countries. That works out to 1.26 million additional urban people in today's developing countries every week from 2010 to 2050.

Humans alter the climate by emitting greenhouse gases, by altering planetary albedo, and by altering atmospheric components. Between 1900 and 2000, humans' emissions of carbon into the atmosphere increased fifteenfold, while the numbers of people increased less than fourfold. Population growth alone, with constant rates of emissions per person, could not account for the increase in the carbon emissions to the atmosphere. The world economy grew sixteenfold in the twentieth century, accompanied by enormous increases in the burning of gas, oil, and coal. In the last quarter of the twentieth century, population grew much faster in developing countries than in high-income countries, and, compared with population growth, the growth of carbon emissions to the atmosphere was even faster in developing countries than in high-income countries. The ratio of emissions-to-population growth rates was 2.8 in developing countries compared with 1.6 in high-income countries. Emissions of CO₂ and other greenhouse gases are influenced by the sizes and density of settlements, the sizes of households, and the ages of householders. Between 2010 and 2050, these demographic factors are anticipated to change substantially. Therefore demography will play a substantial role in the dynamics of climate changes.

Climate changes affect many aspects of the living environment, including human settlements, food production, and diseases. These changes will affect poor people more severely than rich, and poor nations more severely than rich. Yet not enough is known to predict quantitatively many details that will matter enormously to future people and other species.

Three kinds of responses are related to demographic issues that affect climate changes: universal secondary education, voluntary contraception and maternal health services, and smarter urban design and

construction. These responses may prevent, reduce, or ameliorate the impacts of climate changes. They are as relevant to rich countries as to poor, though in ways that are as different as are rich countries and poor. They are desirable in their own right because they improve the lives of the people they affect directly; and they are desirable for their beneficial effects on the larger society and globe. They are effective responses to the twin challenges of reducing poverty and reducing greenhouse gas emissions.

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