ROUTLEDGE HANDBOOK OF CLIMATE CHANGE AND SOCIETY

Second Edition

Edited by Steven R. Brechin and Seungyun Lee

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

Designed cover image: iStock

Second edition published 2025
by Routledge
4 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

and by Routledge
605 Third Avenue, New York, NY 10158

Routledge is an imprint of the Taylor & Francis Group, an informa business

First edition published by Routledge 2010

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-1-032-27071-5 (hbk)
ISBN: 978-1-032-27072-2 (pbk)
ISBN: 978-1-003-29120-6 (ebk)

DOI: 10.4324/9781003291206

Typeset in Sabon LT Pro
by Apex CoVantage, LLC

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POPULATION AND CLIMATE CHANGE

Global Overview

Joel E. Cohen

This chapter surveys the global human population since 1600 and its prospects to 2050 and 2100. It also surveys how the global human population affects climate change and vice versa. It aims to describe and analyze past and projected future trends, rather than to prescribe solutions. It offers "was," "is," and "may be in the future," rather than "ought."

This chapter focuses on births and deaths, which determine global population size. Migration will be discussed separately in Part 5. This chapter also considers other important demographic attributes of human populations including age, sex, education, health, and familial status; the formation of unions, families, and households, and their dissolution; and the spatial distribution of people by geographic regions and size of settlements, from rural to urban.

Among many reviews of the interactions between human populations and climate change are O'Neill, MacKellar, and Lutz (2001, 2004); De Sherbinin et al. (2007); Lutz (2009); Guzmán et al. (2009); Nelson (2010); Cohen (2010); Liddle and Lung (2010); Jiang and Hardee (2011); and Muttarak (2021).

The Global Human Population to 2050

In 1600, Earth had just over half a billion people. By 1800–1825, there were about 1 billion people; by 1927–30, about 2 billion; by 1974, about 4 billion; and by 2022, around 8 billion. The most recent estimated doubling in the 48 years from 1974 to 2022 was the fourth doubling since 1600. It may be the last doubling ever.

From now to 2050, the human population is likely to grow **bigger, more slowly, older,** and **more urban** (UN 2022). Populations of nonhuman animals, plants, and microbes will also change in the coming decades in interactions with human populations. Here I focus on the human population.

Bigger: The medium projections of the UN Population Division in 2022 (2022:i) suggest that "the global population could grow to around 8.5 billion in 2030, 9.7 billion in 2050 and 10.4 billion in 2100," if humans have children, migrate, and die at the rates projected based on statistical models of variation in past rates.

DOI: 10.4324/9781003291206-9

For comparison, in 2009 the UN projected that world population would rise to around 9.1 billion by 2050, lower than the 2022 projection for 2050 by 600 million people. In 2019, the medium scenario of the UN projected that world population would reach 9.7 billion in 2050 and 10.9 billion in 2100. The 2019 medium projection for 2100 exceeds the 2022 projection for 2100 by half a billion people. Demographic projections depend sensitively on future fertility, which no one knows how to predict with precision.

Slower: In 1950, the total fertility rate for the globe slightly exceeded five children per woman per lifetime. The total fertility rate measures the average number of live-born children per woman based on current age-specific rates of fertility, assuming a woman lives through her reproductive years. The total fertility rate fell to fewer than 2.6 children per woman in 2010, that is, by half in sixty years; and to 2.3 children per woman in 2021. More than half the women in the world live in countries where the total fertility rate is below the replacement level (Wilson and Pison 2004; Gietel-Basten and Scherbov 2019). In South Korea, the total fertility rate fell from about 6 children per woman in 1960 to about 0.8 in 2020. The replacement level is between 2.0 and 2.3 children per woman per lifetime in most countries or higher in countries with exceptionally high death rates. The UN projects global fertility of 2.1 live births per woman by 2050.

In 2020, the global population growth rate (the difference between the global birth rate and the global death rate) fell below 1% per year for the first time since 1950 (United Nations Department of Economic and Social Affairs, Population Division 2022:3), partly because of declining fertility and partly because the COVID-19 pandemic increased the global death rate.

This decline in fertility from a peak in the 1960s to now is perhaps the greatest revolution in human history in the behavior of individuals and couples. This enormous change has been under way for centuries in today's rich countries. It is now advancing in many (though not all) poor countries, even in some of the very poorest. 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 2011).

The world's population size grew by 67–80 million people in 2021, according to divergent estimates. Overwhelmingly, these additions were and will be located in the cities of today's poor countries (the "developing regions"). By 2050, the population of today's rich countries (the "developed regions") is projected to be falling while the population of today's poor countries is projected to be growing, and the total is projected to increase by 44 million per year.

Older: For the first time in human history, sometime during the decade 2000–2010, the world had more people 60 or older than children aged 0 to 4. The UN Population Division (2022) projected that the fraction of people 65 years old or older will rise from 10% in 2022 to 16% in 2050, when women 65 plus will outnumber men 65 plus by roughly 11 to 9 globally. By 2050, there will be about as many people 65 plus as under 12, and more than twice as many as children under 5 years old.

More urban: In 1950, 30% of the world's 2.54 billion people lived in urban areas. Starting between 2005 and 2010, for the first time in human history, the world had more urban people than rural. The definition of "urban" varies among countries, so there is uncertainty about the meaning and timing of the cross-over. By 2018, an estimated 55% of the 7.63 billion people, or roughly 4.22 billion people, lived in urban areas. The UN

Population Division (2018) projected in 2018 that 68% of global population would be urban by 2050. Applying that fraction to the UN's projection in 2017 of 9.77 billion people in 2050 gives 6.68 billion urban people. If these projections prove correct, then in the 32 years from 2018 to 2050, the world's urban areas will grow by another 2.46 billion people or, on the average, around 77 million more per year or almost 1.5 million additional city people every week. According to the 2018 projections, Asia and Africa will host almost 90% of this growth. Just three countries will see 35% of this growth: India (with an additional 416 million urban people), China (adding 255 million urban people), and Nigeria (adding 189 million urban people).

Providing urban infrastructure, services, and governance for 1.5 million additional urban people in today's developing countries every week from 2018 to 2050 represents a challenge and an opportunity to build better-designed (Jiang, Young, and Hardee 2008), more energy-efficient (Kelly 2009, 2010), and 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.

By contrast with the rapidly increasing urban population, the rural population was projected in 2018 to decline by 2050 in both more and less developed regions, from a global total of 3.41 billion in 2018 to 3.09 billion in 2050.

The Human Population from 2050 to 2100

Between 2023 and 2050, most births and deaths will occur to people who are now alive. The uncertainty in projecting births and deaths from now to 2050 lies more in the birth rates and death rates than in the sizes of the populations to which those rates apply. By contrast, as the decades pass after 2050, an increasing fraction of births and deaths will occur to people who are not yet born. After 2050, uncertain future rates of birth and death will apply to increasingly uncertain numbers of presently unborn people. The compounded uncertainty of rates and stocks, and the weaknesses of available predictive theories of human fertility, make projections beyond 2050 more uncertain than near-term projections.

To illustrate this uncertainty, I compare three respected projections of the timing and level of peak global human population coming from respected demographers in New York, Vienna, and Seattle. I selected pre-COVID-19 projections from 2018 to 2020 for comparability.

The medium scenario of the 2019 World Population Prospects by the UN Population Division projects global population to continue growing to 10.9 billion in 2100. Below-replacement fertility spreads geographically over time but too slowly to end population growth before 2100. Only the population of sub-Saharan Africa is projected to grow through 2100, while all other regions are declining by 2100. The UN projections are based on a hierarchical Bayesian statistical model of past time series of demographic rates. (For comparison, in 2022 the UN Population Division projected global population to peak around 10.4 billion in the 2080s and to remain around 10.4 billion until 2100, with a 50:50 chance that global population will peak before 2100.)

In the medium scenario of the 2018 projections from the European Commission and the International Institute for Applied Systems Analysis (IIASA) in Vienna, global population peaks around 2080 near 9.8 billion people, then slowly declines to 9.5 billion in 2100. In a second scenario with "rapid social development," specifically a rapid expansion of education, world population is projected to peak around 8.9 billion in 2055–2060 and decline to 7.8 billion by 2100. In a third scenario with "stalled social development," quantified by lower female education and higher fertility rates for each education group, world population passes 10 billion around 2045 and continues growing to 13.4 billion in 2100, a scenario "also likely to be associated with widespread poverty and weak resilience to already unavoidable environmental change" (p. 8). Sub-Saharan Africa's population would grow from around 1 billion in 2018 to 2.2 billion by 2060 under the medium scenario and to 2.7 billion under the stalled social development scenario. These projections are based on the expert judgment of panels of demographers, unlike the time-series analysis of the UN projections and the dynamic modeling of the next projections.

According to the 2020 projections from the Institute for Health Metrics and Evaluation (IHME), University of Washington in Seattle, global population will peak around 2064 near 9.7 billion before declining to 8.8 billion by 2100 (Vollset et al. 2020). In the IHME projections, fertility depends on future commitments to education and available contraception; fertility levels are consistently lower than those of the UN 2018 medium scenario (IHME 2020). The populations of 23 countries—notably Japan, Thailand, Spain, and Ukraine—will be at most half their 2017 size by 2100, while the population of "another 34 countries will probably decline by 25–50%, including China, with a forecasted 48.0% decline." By contrast, Nigeria's population is expected to grow 3.8-fold between 2017 and 2100, though its average fertility rate is expected to drop from 5.1 to 1.7. For context, total fertility of 1.7 children per woman is below replacement level and below that of Sweden in 2017 (1.8 children per woman). Nigeria was the only Sub-Saharan African country to rank among the world's ten most populous countries in 2017. By 2100, the Democratic Republic of the Congo, Ethiopia, and Tanzania are projected to join Nigeria among the ten most populous countries. These country-specific forecasts are subject to even greater uncertainty than global forecasts.

Not one of these three sets of projections models considers possible effects of climate change or pandemics like COVID-19 on future birth, death, and migration rates.

Dyson (2022) is a rare demographer who dares to forecast that climate change will strongly influence global population from 2050 to 2100. Dyson documents increasing trends in atmospheric greenhouse gases and global mean temperatures. He expects the concentration of atmospheric CO_2 to reach 560 parts per million before or by 2100, and global mean surface temperature to increase over pre-industrial levels by 3 to 3.5°C by 2100 unless there is an acceleration in the rise of temperature, in which case the world will get even hotter on average. He outlines a conceptual model that links modern economic and demographic expansion (the Industrial Revolution and the surge in population growth in the eighteenth and nineteenth centuries) to environmental consequences (greenhouse gas emissions and rise in global mean temperatures in the twentieth and twenty-first centuries) with societal and demographic consequences that cause global population decline (increased mortality and lower fertility after 2050). In his words (p. 8):

> [G]eophysical processes have societal effects which operate both internally and internationally. The societal effects include, for example, disruption of food supplies, food price rises, reduced living standards, migration, conflict, and increased sociopolitical instability. Finally, there are demographic effects which, at the global level, work through mortality and fertility.

Contrary to Ghebreyesus (2019), the director general of the World Health Organization, Dyson (2022:9) asserts that "at present there is no clear evidence that global heating is having significant demographic effects at the global level." Regardless of who is right, they both urge consideration of how human populations affect climate changes and how climate changes affect human populations: the topics of the following sections.

When addressing one another, demographers often distinguish projections from forecasts. A projection says: *if* rates of birth, death, and migration are thus and so, *then* populations will change thus and so. A projection is conditional on its assumptions. If the arithmetic of the projection is done correctly, a projection cannot be wrong. By contrast, a forecast says: here is how populations will change. A forecast is an unconditional prediction about the future. A forecast can be, and often is, wrong. While demographers find comfort in distinguishing projections from forecasts, most users of demographic projections interpret them as forecasts.

A core difficulty in making demographic forecasts is that human populations interact with economies, with environments (physical, chemical, and biological), and with cultures (including their histories, languages, religions, institutions, laws, technologies, arts, and values) (Cohen 1995, 2005). Cultures, economies, and environments are at least as difficult to forecast as populations, in part because of limited human understanding and in part because unpredictable human choices influence the future.

How Does and Will Global Human Population Affect Climate Changes?

Humans alter the climate by emitting greenhouse gases (IEA 2022), 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. About 8,000 years ago, Stone Age people burned enough forests and other biomass to account for a rise in carbon dioxide (CO_2) concentrations at that time of about 40 parts per million (Ruddiman 2005). By 5,000 years ago, widespread agriculture including flood irrigation, animal husbandry, and biomass burning accounted for a rise in atmospheric methane concentrations demonstrable 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 (GHGs) including CO_2, methane, and nitrous oxides (Steinfeld et al. 2006; Smith et al. 2007; Pitesky et al. 2009; Wolf et al. 2010). Eleven tons of CO_2 contain three tons (about 27% by weight) of carbon.

While CO_2 is the GHG estimated to have the largest warming effect, the combined warming effects of all GHGs on climate change are measured by a summary index called carbon dioxide equivalent (CO_2e). Between 1850 and 2021, humans' emissions of GHGs increased from 4.0 billion tons CO_2e to 54.6 billion tons CO_2e (13.7-fold) (Jones et al. 2023), while the numbers of people increased from roughly 1.26 billion to nearly 8 billion (6.3-fold). Population growth alone, with constant rates of GHG emissions per person, could not account entirely for the increase in GHG emissions to the atmosphere. But given the historical emissions per person, the growth in total emissions from 1850 to 2021 would have been lower by a factor of 6.3 had the human population not increased by that factor.

Other factors that contributed to increased GHG emissions included increasing energy production per person to drive economic growth, changes in technology (e.g., internal combustion engines, jet engines), tropical deforestation (Houghton 2005), and other land-use changes. The world economy grew sixteen-fold 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.) As the global economy grew sixteen-fold, primary energy production grew about fifteen-fold, 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 (Shi 2003). Following the approach initiated by Dietz and Rosa (1997), Shi (2003) analyzed data from 93 countries on CO_2 emissions from aggregate fossil fuel consumption and cement manufacture as a function of population size, gross domestic product (GDP) per person, 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 93 countries between 1975 and 1996 resembled the whole world over the twentieth century in that their emissions grew faster (by 61%) than their populations (by 43%). CO_2 emissions grew faster than populations in both developed and developing countries. In the high-income countries, emissions grew 27% while populations 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 increase in emissions. Other studies have obtained numerical results that differ in quantitative detail (O'Neill 2010 reviewed the results).

The tautology that GHG emissions depend on population and emissions per person is too simple a way of thinking about them. GHG emissions per person depend on income, technology, demographic factors like household size and composition, city size, population density in built-up areas, institutional and economic factors like the availability of public transport at reasonable cost and convenience (Kenworthy 2003), and a host of behavioral factors like people's propensity to walk, bike, carpool, or drive solo to work. For example, the CO_2 per person emitted by passenger transport is lower in denser cities. The United States has a low urban density (persons per hectare) and very high passenger transport CO_2 per person. In contrast, low-income highly dense Asian urban areas have a low passenger transport CO_2 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 CO_2 per person remains unchanged, the declining urban density may be expected to lead to rising passenger transport CO_2 per person. Whether the relationship will persist depends on technology (the availability of electric vehicles at moderate prices, and electrical generating capacity not dependent on burning fossil fuels) as well as on urban governance (including zoning, control of sprawl, congestion pricing, and provision of public transportation at low enough prices and great enough convenience to induce widespread use).

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).

If world population were at or below 8 billion by 2050 rather than at 9.1 billion, 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.

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.

Households

For understanding how people affect climate, households may be more appropriate units of analysis than individuals "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; Gu, Andreev, and Dupree 2021:610). Compared with households with fewer people, households with more people use less energy per person, on average, and more energy in total (MacKellar et al. 1995; De Sherbinin et al. 2007).

For example, in the US in 1993–94, a household with one person used three times the combined energy (residential energy plus transport energy) *per person* compared to a household with six or more people. However, 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).

The average number of people per household declined worldwide from 1970 to 2000 (Keilman 2003) and has continued to decline since 2000 to a global average around 4 in 2010 (United Nations 2019). While Finland and Germany averaged 2.1 people per household in 2010, Afghanistan averaged 8. 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. "China's household size decreased from 4.7 in 1981 to 3.2 in 2010, and further down to 2.62 in 2020" (Gu et al. 2021:610).

Multiple factors contribute to declining household average sizes: "declining fertility, higher divorce rates, more internal and international migration, and the diminishing norms of co-residence" (Gu et al. 2021:611); also increasing longevity, so the fraction of a lifetime spent without children at home is increasing; later ages of marriage, so people are living singly longer before they marry; better survival from marriage to advanced ages of women compared with men, so that many more women are being widowed; and rising wealth, increasing the feasibility of living independently. The number of households is expected to grow 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 is 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. (1995:861) 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 20 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 US 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), "[s]ince 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 those 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 15 years to 85. Also in the United States in 1983–94, transport energy declined as the age of the household head increased. Similar trends have been demonstrated in China and India, the world's two demographic billionaires (O'Neill and Chen 2002).

How Do and Will Climate Changes Affect Global Human Populations?

Students of human evolution conjecture, based on evidence they consider imperfect, that climatic changes have been major influences on human evolution (NRC 2010). For example, the expansions of grasslands in Africa around three million years ago may have contributed to the evolution of bipedalism, a distinguishing feature of humans. The extremely cold climate of middle Pleistocene Europe may have led to the evolution of the more robust limb bones and shorter forearms of Neanderthals, in contrast to the longer and slenderer limb bones of warm-adapted modern *Homo sapiens*, who first appeared in Africa. The changes in the Classic Mayan civilization of southern Mexico and Central America between 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.

Today climate changes affect infectious diseases (Baker et al. 2022; Bloom, Kuhn, and Prettner 2022; Thomson and Stanberry 2022), coastal cities, agricultural yields (Lobell and Asner 2003; Lobell, Cassman, and Field 2009), agricultural and medical pests, invasive species, biological diversity, phenology (the seasonal timing of the flowering of plants), the ranges of species, forest fires, and many other aspects of the living environment (Walther et al. 2002).

Climate changes will also increase extreme weather events such as 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 per year in 2000–04 (Relman et al. 2008:8). Recent hydro-meteorological disasters in Europe interact with infectious diseases and the COVID-19 pandemic (Mavrouli et al. 2022).

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." 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 2009)*

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 (Mustelin et al. 2010), 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 substantially affect people in the United States (Karl et al. 2009:100). For example, in the twentieth century, the US population grew most rapidly near coasts, in the South, and in and around large cities. The four states with the largest populations in 2022 (California, Texas, Florida, and New York), where 38% of US 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 US 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 US population and US climate indicate that "more Americans will be living in the areas that are most vulnerable to the effects of climate change" (Karl, Melillo, and Peterson 2009:100).

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 underway and coming is unknown.

Conclusion

Four broad dimensions of any complex human problem, including climate change, are the human population, economics, culture, and environment. All four dimensions interact on many time scales. Because of these interactions, the future of the global population depends on demography and on economics, culture, and the environment (including future climate). Projecting the future of population is, therefore, challenging.

From 2022 to 2050, according to current projections, the human population is likely to grow bigger, more slowly, older, and more urban. Household sizes will continue to decline. Most of the additional billions of city dwellers will live in today's developing countries. Global human population growth will end between 2050 and 2100 as most regions decline in population while other regions (notably sub-Saharan Africa) will continue to increase. The date and population size at which the global peak population occurs differ among projections and are unknowable at present.

Humans alter the climate by emitting greenhouse gases, by altering planetary albedo, and by altering atmospheric components. Between 1850 and 2021, humans' emissions of greenhouse gases increased 13.7-fold while the numbers of people increased roughly 6.3-fold. Population growth alone, with constant rates of emissions per person, could not account entirely for the increase in the carbon emissions to the atmosphere but contributed importantly to it. Emissions of greenhouse gases are influenced by the sizes and density of settlements, the sizes of households, and the ages of householders. Between 2022 and 2050, these demographic factors are anticipated to change substantially. 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. Not enough is known to predict quantitatively many details that will matter enormously to future people and other species.

Acknowledgments

Leiwen Jiang provided helpful references on effects of climate change on infectious diseases. Roseanne Benjamin provided help, editorial and otherwise, during this work. Seungyun Lee and Steven R. Brechin edited helpfully.

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