

June 2009

Projecting Population, Projecting Climate Change

Population in IPCC Scenarios

Malea Hoepf Young
Kathleen Mogelgaard
Karen Hardee

Projecting Population, Projecting Climate Change

Population in IPCC Scenarios

PAI WORKING PAPER WP09-02

INTRODUCTION

While population is widely recognized as one of the driving forces behind the growth of greenhouse gas emissions, this paper shows that it is not adequately accounted for in the emissions scenarios produced in the Special Report on Emissions Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC). The paper examines the assumptions about fertility, mortality and migration that are built into the low, medium and high variations of the population projections used in scenarios of emissions growth. The SRES shows the implications of changes in population size on emissions, but fails to account for other demographic trends such as urbanization, age structure, and household composition. As a result, the SRES likely underestimates demographic impacts on emissions growth. Furthermore, the fertility decline assumptions contained in population projections in the SRES may be over-emphasized given recent declines in political and financial support for policies strongly tied to fertility decline, such as education and equality for women and access to reproductive health and family planning services. The paper concludes that a deeper and more nuanced understanding of the emissions implications of population size, age structure, household size, and urbanization should be incorporated into climate change scenarios that provide the basis for policy decision-making and strategy development for climate change mitigation and adaptation.

“By 2100, the world will have changed in ways difficult to imagine—as difficult as it would have been at the end of the 19th century to imagine the changes of the 100 years since.” *The Special Report on Emissions Scenarios* (Nakićenović et al. 2000)

Climate change is one of the most serious challenges human society will confront in the coming decades, and throughout the course of the next century. Human production of greenhouse gas emissions (GHGs), largely through the burning of fossil fuels, is expected to warm the earth’s surface. This will lead to rising sea levels, changes in patterns of precipitation, heat waves, drought, flooding, and increasingly damaging storm surges. All of these have potentially severe consequences for both humans and ecosystems.

The full range of climate change impacts over the course of the next century is difficult to ascertain, both because of uncertainty surrounding how the earth’s complex physical and environmental systems will change, and how much total emissions will grow. Changes in emissions and subsequent environmental impacts will be affected by future development patterns around the world. The climate science community attempts to understand the range of uncertainty of climate change impacts by developing scenarios—such as those included in the Intergovernmental Panel on Climate Change’s (IPCC) Special Report on Emissions Scenarios (SRES)—exploring the range of factors that influence emissions. These scenarios are then used to drive climate models that show a range of projected change and impacts.

Scientists generally accept that population size influences global GHG emissions, although the role of demographics is complex and involves significant uncertainty. This paper identifies important points

at which demographic factors underlie the climate science community’s projections of future climate change.



The paper describes the development of the IPCC’s scenarios, explores the population projections that were used, and explains the assumptions behind those projections. The paper concludes that the assumptions made about falling fertility and slowed population growth may be over-emphasized, and that by not taking into account important demographic variables beyond population size, the scenarios have underestimated potential demographic impacts on greenhouse gas emissions growth.

Understanding the strengths and weaknesses of the SRES can help shed light on strategies for effectively addressing climate change, as its scenarios have been used for much of the major climate research up to the present, the results of which have been and will continue to be widely used by policymakers. The IPCC’s next assessment, due in 2014, will employ a new process of scenario development, and this paper briefly describes that process, now in its incipient stages. Because all population projections used in the SRES include in their assumptions large declines in fertility over the next century, The paper concludes by addressing the role population policies might play in the context of comprehensive solutions to climate change.

THE IPCC AND ITS ASSESSMENT REPORTS: DEVELOPMENT AND USE

“This report reinforces our understanding that the main driving forces of future greenhouse gas trajectories will continue to be demographic change, social and economic development, and the rate and direction

Scientists generally accept that population size influences global GHG emissions, although the role of demographics is complex and involves significant uncertainty.

of technological change.” *The Special Report on Emissions Scenarios* (Nakićenović et al. 2000)

In the late 1980s, the UN’s World Meteorological Organization and the United Nations Environmental Program established the Intergovernmental Panel on Climate Change (IPCC). It was created to assess and synthesize the state of scientific thinking on human-induced climate change. Initially tasked with gathering climate change evidence into its First Assessment Report, published in 1990, the IPCC remains the key organization in coordinating research efforts and compiling results, as well as translating evidence for non-scientific communities, particularly policymakers. Today, the IPCC’s assessment process involves over 2,500 scientists from over 150 countries, with the majority drawn from the natural sciences. The IPCC has three standing working groups that contribute reports to the IPCC’s periodic assessments:

- Working Group I assesses the physical science of climate systems and climate change and produces the report, *The Physical Basis for Climate Change*;
- Working Group II assesses the vulnerability of societies and natural systems to climate change impacts and produces the report, *Impacts, Adaptation and Vulnerability*
- Working Group III assesses options to mitigate climate change, and produces the report, *Mitigation of Climate Change*.

A special task force of the IPCC works on National Greenhouse Gas Inventories (IPCC 2004).

The Assessment Reports produced by the IPCC have been extremely important to both the research and policymaking communities, providing increasingly detailed information on all aspects of future climate change. The First Assessment Report was published in 1990 and formed the basis for the negotia-

tion of the 1992 United Nations Framework Convention on Climate Change (UNFCCC), the treaty that provides the current policy framework for addressing climate change. The First Assessment Report also identified gaps in understanding and future research needs, and it underlined the need for reports geared towards policymakers to bridge the gap between the policy and climate science communities. The Second Assessment Report, published in 1995, provided input for the negotiations of the Kyoto Protocol in 1997. The Kyoto Protocol is an addition to the UNFCCC treaty, and is a legally binding agreement to reduce GHG emissions in industrialized countries. The gathered research stated that “the balance of evidence suggests a discernible human influence on global climate,” a finding that was further enforced in the Third Assessment Report published in 2001 (IPCC 1995, IPCC 2001).

The Fourth Assessment Report was released in 2007. In addition to providing stronger scientific evidence that climate change is occurring and that it is caused by human activities, the report also included a section entitled “Historical Overview of Climate Change Science,” which stated that in recent decades research in climate change has accelerated dramatically and developed new methodology and tools such as complex modeling. While climate change science literature had barely emerged before 1951, it tripled between 1965 and 1997 (Le Treut et al. 2007).

This proliferation of research has occurred as models of the earth’s processes have become increasingly complex, with new factors included. Faster computer speeds allow scientists to increase the number, complexity, and resolution of the models. As this information is compiled, the result is a more complete picture of a range of possible climate futures. Using this range of possible climate futures, scientists can

project impacts of climate change on natural and human systems, examine the resilience of these systems, and develop plans to address both the causes and consequences of climate change. The basis for all of this research is the IPCC's emissions scenarios (Le Treut et al. 2007).

THE IPCC'S EMISSIONS SCENARIOS

“Scenarios are images of the future, or alternative futures. They are neither predictions or forecasts. Rather, each scenario is one alternative image of how the future might unfold... they enhance our understanding of how systems behave, evolve, and interact... given the uncertainties in both emissions models and our understanding of key driving forces, scenarios are an appropriate tool for summarizing both current understanding and current uncertainties.” *The Special Report on Emissions Scenarios* (Nakićenović et al. 2000)

Emissions scenarios project alternative paths of greenhouse gas emissions into the future. Like other aspects of climate science, emissions scenarios have become much more sophisticated over time, and employ increasingly complex patterns of socio-economic, demographic, and technological change throughout the world. The IPCC has produced three sets of scenarios: the 1990 Scientific Assessment (SA90) with four scenarios, the IPCC Scenarios 1992 (IS92) with six scenarios, and the 2000 SRES with 40 quantitative scenarios, grouped into four families, each with a qualitative narrative storyline describing possible futures and combinations of driving forces (Nakićenović et al. 2000). In the past, the IPCC completed its scenarios, converted the resulting GHG emissions to levels of radiative forcing,¹ and gave these results to climate model-

ers. Modelers then delivered their results to the impacts assessment and vulnerability community, who use this information as the basis for their research. The next round of scenario development, which will contribute to the Fifth Assessment Report expected in 2014, will take advantage of a different approach. Scenario development and climate modeling will occur simultaneously and use set levels of radiative forcing, resulting from representative concentration pathways (RCPs) of GHG emissions.

The IS92 scenarios formed the basis of the second assessment report in 1995. However, after that report and a 1994 evaluation, the IPCC announced that because of the community's increased understanding of energy supply and non-CO₂ GHG emissions, and because of a need to explore different development pathways that show a narrowing gap between industrialized and developing countries, it was appropriate to create a new set of scenarios (Houghton et al. 1994). Begun in 1996 by a group of six modeling teams, the Special Report on Emissions Scenarios (SRES) was published in 2000, and presents projections of future emissions that could result from different pathways of demographic, socio-economic and technological development. The authors analyzed existing scenarios in the published literature, including their major characteristics, driving forces, and relationships. The scenarios represent the range of scenarios in the literature, excluding outlier and “disaster” scenarios. While the scenarios explicitly project a world without climate change mitigation policies, authors were asked to identify policies that could affect GHG emissions, such as efforts to reduce sulfur dioxide in response to poor air quality and acid rain. Most of the scenarios do anticipate change to cleaner technologies (Nakićenović et al. 2000).

Each storyline in the SRES tells a story of a potential future world.

The 2000 SRES scenarios cover a relatively long time period, from 1990 to 2100, in order to express the long-term nature of climate change, but the authors acknowledged the uncertainties involved in projections over such a lengthy period. The scenarios address uncertainties about the future by locating the scenarios within “storylines,” which make certain assumptions about the trajectories of three broad categories of human activity, termed “drivers.” The drivers include population dynamics (based on three different projections of population growth), economic development, and technological change. Unlike the IS92 scenarios, the SRES scenarios showed projections of change in human societies, not just changes in the resulting greenhouse gas emissions (GHG). The authors developed four narrative storylines to describe a variety of possible futures, and quantified the storylines using integrated assessment models. While the scenarios were developed under the auspices of the IPCC (a unique instance in which the IPCC played a role in conducting rather than synthesizing research), the scenarios and their assumptions underwent an extensive open review process and several revisions. The resulting scenarios created the emissions levels that form a basis for models of climate change (Nakićenović et al. 2000).

The SRES outlines 40 scenarios of future GHG emissions²—both globally and for a group of four regions. As noted earlier, there are four qualitative storylines telling a different story about the world’s future development. Under each storyline, there is a family of quantitative scenarios showing the GHG emissions resulting from a combination of drivers compatible with the storyline. Within the 40 scenarios, the authors chose an illustrative marker scenario as most representative of each storyline. While these scenarios have received the most scrutiny and are the most frequently used, they are no more

or less credible than the other scenarios (Nakićenović et al. 2000).

The SRES was explicit about the limitations and appropriate uses of the 40 scenarios, stating that they are not policy recommendations, none are more or less likely than the others, and none should be construed as means or medians (the choice of an even number of scenarios was meant to avoid a single scenario being construed as a central or “best guess” projection). The authors advised that it was important for those who use the scenarios for modeling or other purposes to utilize more than one family to reflect the range of uncertainty surrounding the drivers and emissions outcomes (Nakićenović et al. 2000).

The SRES scenarios represent an improvement over the IS92 scenarios because of improved baseline measurements of emissions, and more types of GHGs included in the analysis. The SRES also includes projections of economic change and development throughout the world, and rates of technological change. The resulting scenarios explore a higher bound of emissions than the IS92 scenarios, but did not extend the lower bound. Also in contrast to the IS92 scenarios, the SRES includes some families in which the gap in per capita income between more and less developed countries narrows over time, and overall, assumes a more affluent world in the future than exists today (Nakićenović et al. 2000).

The SRES was a critical step forward in the development of climate models that take into account human population growth and activities, and continues to be very important in the climate community. Research based on the SRES will be used until the IPCC’s Fifth Assessment Report in 2014 for major policy decisions and other research; thus is it important to understand the scenarios and their assumptions.

They connect changes in the number of people in the world and the way that they live to how much they emit, and subsequently, through the work of climate modelers, to how their actions impact global climate change.

TABLE 1: THE FOUR SRES FAMILIES OF SCENARIOS

Scenario Family	Population projection used	Population in 2050 (billions)	Population in 2100 (billions)	Economic growth/technological change assumptions	CO2 emissions in marker scenario in 2100 (GtC/year) ³	Temp change (degrees Celsius) by 2090-2099 ⁴
A1	IIASA 1996 – low variant (revised)	8.7	7.1	Very rapid economic growth; rapid introduction of more efficient technologies	13.83	A1B: + 2.8 A1T: + 2.4 A1FI: + 4.0
A2	IIASA 1996 – high variant	11.2	15	Per capita economic growth and technological change slower and more fragmented	28.19	+ 3.4
B1	IIASA 1996 – low variant (revised)	8.7	7.1	Rapid change in economic structures toward service and information economy; clean and efficient technologies	4.04	+ 1.8
B2	UN 1998 – long-range medium projection	9.3	10.4	Intermediate levels of economic development; less rapid and more diverse technological change	13.32	+ 2.4

Sources: Nakićenović et al. 2000; Le Treut et al. 2007.

THE SRES STORYLINES

Each storyline in the SRES tells a story of a potential future world. The SRES scenarios have both qualitative and quantitative aspects—a narrative storyline with associated quantitative information. They connect changes in the number of people in the world and the way that they live to how much they emit, and subsequently, through the work of climate modelers, to how their actions impact global climate change.

There are four storylines and associated families of scenarios: A1, A2, B1, and B2. The “A” scenarios place more emphasis on economic growth, while the “B” scenarios place more emphasis on environmental protection. The “1” scenarios assume greater globalization, while the “2” scenarios show a more regional, less connected world (for a comparison of the major characteristics of the families, see Table 1). Several trends span multiple storylines. All scenarios show a world that becomes more affluent than

it is today: by 2100 world GDP estimates range from 10 to 26 times higher than 1990. Along with greater affluence, many scenarios assume greater equality between today’s developed and developing countries. Forest area continues to decrease in most scenarios, but this trend eventually reverses (Nakićenović et al. 2000; Van Vuuren and O’Neill 2006)

Characteristics of the SRES Storylines and Families of Scenarios

The A1 storyline and family of scenarios is characterized by a low population trajectory and rapid economic growth. This storyline uses the International Institute for Applied Systems Analysis (IIASA) 1996 low variant projection of world population,⁵ which projects a world of 8.7 billion people by 2050, which then declines to 7 billion by 2100. Alongside assumptions about continued low fertility in parts of the world such as Europe, this projection also assumes dramatic declines in fertility in areas where fertility is

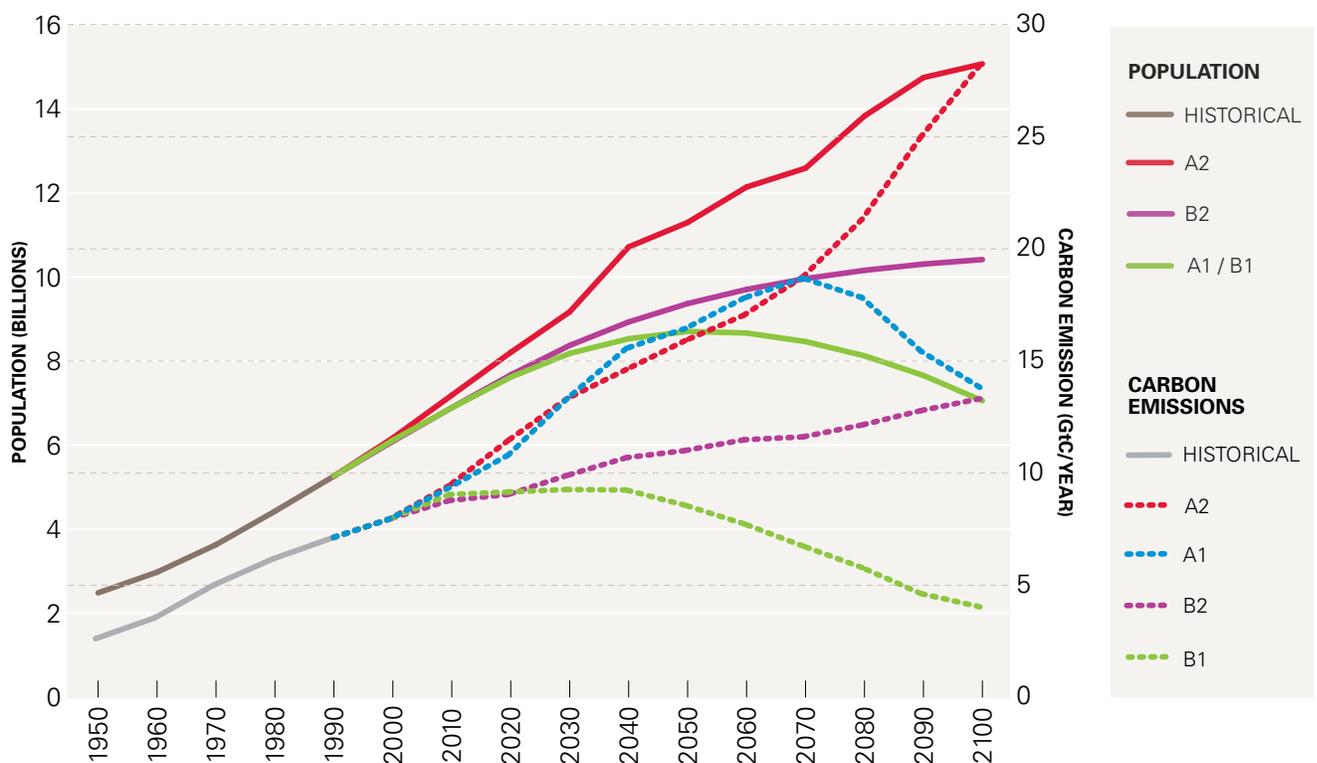
currently high. For example, in sub-Saharan Africa, fertility would fall from 5.9 in 2000 to 1.8 in 2050 (Lutz 1996). Additionally, the A1 storyline projects the development and adoption of new, more efficient technologies. It also describes a world with greater cultural and social interaction, and a reduction in the gap between incomes in developed and developing countries.

The A1 storyline is unique in that it was chosen to examine different future paths of energy use. Within the A1 family of scenarios, there are three groups of scenarios—A1FI, A1T, and A1B—with similar development pathways, but very different projected energy use. The A1FI scenarios are fossil fuel intensive, the A1T scenarios are non-fossil fuel intensive, while the A1B group is balanced across sources. The emissions projection results from these groups show

the importance of technological change in pathways of future emissions. Controlling for demographic and socioeconomic factors, different patterns of technology and resource use can result in very different levels of emissions. The fossil-intensive A1F1 scenario leads to some of the highest CO₂ emissions of all the scenarios, while the alternative-energy emphasis of the A1T results in some of the lowest.

In contrast, storyline A2 assumes a more heterogeneous world, with regional differences in development, slower and more fragmented economic growth, and slower technological change. This storyline also assumes higher population growth (IIASA's high variant), with global population reaching 15 billion by 2100—over twice the projection of the A1 storyline. Under this scenario, total fertility rates—the number of children the

FIGURE 1: POPULATION CHANGES AND CARBON EMISSIONS UNDER DIFFERENT IPCC SRES SCENARIOS



Source: Jiang and Hardee 2009.

average woman has in her lifetime—decline in various regions, but global fertility remains above replacement level⁶ by the end of the century, following the IIASA high variant projection. Furthermore, the A2 storyline has largely negative environmental implications. This is the only scenario in which forest cover continues to decline through 2100, and the associated CO₂ emissions from this change continue to grow. Further, the high population growth is paired with slower increases in agricultural productivity than in other scenarios, leading to higher nitrous oxide and methane emissions from land use, as opposed to the A1 and B1 storylines, which see limited amounts of these emissions. The shift in energy under A2 is marked by transition away from oil and gas, and back to coal as an energy source, with a moderate increase in non-fossil energy sources. The resulting emissions under this storyline span from medium to high, although not as high as the A1F1, fossil fuel-intensive scenario, mainly because there is much slower economic growth in the A2 storyline (Nakićenović et al. 2000).

Storyline B1 describes a world in which income gaps between rich and poor countries are reduced, with rapid economic change and shifts to an information and service economy. This storyline uses the same population projection as A1 (IIASA's low variant), projecting 8.7 billion people by 2050 and a decline to 7 billion by 2100. In this storyline, there is extensive use of clean and resource-efficient technology, with widespread exchange of technology across regions, and an improvement in economic equity around the world. Under this scenario, CO₂ emissions from loss of forest cover decrease at the fastest rate among the four families of scenarios, as population declines and agricultural productivity increases. A large share of energy comes from renewable and nuclear sources. The range of carbon emissions from

this storyline spans the lowest end of the range of SRES scenarios.

Finally, storyline B2 illustrates a world that develops localized solutions to sustainability, while experiencing a continuously growing population (although at a slower rate than A2) and intermediate development and technological change. Its results are based on the 1998 long-range UN medium fertility variant population projection, which results in 10.4 billion people by 2100. This storyline describes a more equitable world with more environmental protection, but with solutions generated at the regional and local levels. Under this scenario, about half of the world's energy comes from non-fossil fuels, with the remaining half split between coal, oil and gas. The corresponding emissions levels under this scenario span an intermediate range by 2100.

Emissions from the SRES Scenario Families

As noted throughout, the scenarios cover a wide and overlapping range of emissions, widening over time with increased uncertainty in the long term. The range of total GHG emissions in the SRES reflects the range in the published literature (excluding outlying “disaster” scenarios). By 2100, estimates of total cumulative CO₂ emissions range from 700 to 2540 gigatons. The scenarios also show that different development paths can result in similar GHG emission levels, and different driving forces (demographic, development, and technological change) can result in very different emissions levels. Thus, the range of emissions levels overlap significantly between families and, importantly, no single driver is a determining factor of emissions, as they all have very different outcomes in different combinations of other drivers. For example, regional per capita income convergence (e.g., more equitable economic development) can lead to high or

low emissions. Also, in the A1 storyline, economic and demographic changes were held constant, but different shifts in technology resulted in very different emissions outcomes among the scenarios in this family. Thus, all driving forces should be considered when developing mitigation strategies.

POPULATION PROJECTIONS AND THE SRES

“Population projections are arguably the backbone of GHG emissions scenarios.” *The Special Report on Emissions Scenarios* (Nakićenović et al. 2000)

As noted in Table 1, and illustrated in Figure 1, the SRES scenarios utilize three population projections: the 1998 UN long-range projection, and IIASA low fertility and low mortality variant, and the IIASA high fertility, high mortality variant. Their assumptions are important to understand, and are detailed below.

IIASA Projections: Storylines A1, A2, and B1

The IIASA variants were chosen as the high and low population projections for the SRES in part because they are probabilistic, in that they assign a probability distribution to cover the range of current knowledge of uncertainty around future world population growth. The intervals of the full population projection are between 6.7 and 15.6 billion by 2100, representing 90 percent of the range of uncertainty in the literature (between the 5th and 95th percentile).⁷ This range was developed by inviting experts on the factors contributing to population growth (fertility, mortality, and migration) to provide high and low estimates for each of these factors for 2030-2035. The factors were then extended to 2080-2085 and held constant until the end of the century. The IIASA projections are composed of all possible combinations

of low, central, and high estimates of these three factors, resulting in 27 projections for 13 world regions. Emphasis is given to those combinations that are most intuitive, i.e., high mortality and high fertility, and low mortality and low fertility, in the two IIASA projections used in the SRES. These are also referred to as slow and rapid demographic transition variants. Just as in the UN medium projection used in the B2 storyline, both of these projections show a world population that will grow substantially, will age substantially, and will be increasingly concentrated in today's developing countries (Lutz 1996).

In IIASA's low variant projections, global average fertility rates fall from 2.81 in 1995-2000 to 1.39 in 2100. This drop is most dramatic in sub-Saharan Africa, where fertility rates fall from 5.87 to 1.44 over this period (Lutz 1996). For use in the SRES storylines A1 and B1, IIASA modified their projection in this category slightly. Rather than the population estimates of 8.5 billion in 2050 and 6.5 billion in 2100, the projections are slightly higher at 8.7 in 2050 and 7.1 in 2100. This adjustment was made to project more rapidly decreasing mortality rates in developing regions that better correspond with the narrative storyline describing more rapid economic growth in industrialized and developing countries alike (IIASA 2007). However, in the original population projection (before it was altered for use in the SRES), increases in life expectancy under this scenario were still dramatic, increasing from 65.4 years in 2000 to 84.3 years in 2100.

The A2 storyline, marked by slower and more fragmented economic growth and technological change, has the highest population projection. This upper bound was created by IIASA's high fertility, high mortality scenario. Under this scenario, fertility rates remain above replacement, at 2.86 in 2050, and 2.40 in 2100. The result is a world of 15 billion people by the end of the century.

Life expectancy remains low, at 64.0 years, increasing less than a year over the course of the 21st century. The gap in life expectancy between industrialized and developing regions under this scenario is more than 14 years larger in this than in the low fertility, low mortality scenario described above (a gap of 14.6 years vs. 11.2 years).

UN Medium Projection—Storyline B2

Storyline B2 (marked by localized solutions to sustainability) utilizes the 1998 long-range UN medium fertility variant projection. Under this projection, fertility stabilizes at replacement level (2.1) and global population grows from 5.7 billion in 1995 to 9.4 billion in 2050 and 10.4 billion in 2100. Population continues to grow before stabilizing at fewer than 11 billion people by 2200. The SRES authors chose this projection because of its widespread use and its assumption of replacement level fertility. It is also remarkably close to the IIASA central fertility and mortality scenario of 10.35 billion people in 2100, despite using significantly different methodologies (UN Population Division 1998; Lutz 1996).

The 1998 UN long-range population projections were based on the UN's 1996 near-term population projections, which extended to 2050, and follow the same assumptions. The 1996 projections were developed with improved information on fertility patterns (particularly in sub-Saharan Africa), and also extend the upper bounds of life expectancy to 82.5 years for men and 87.5 years for women. The end result is a lower total population figure than that used in the IS92 scenarios that preceded the SRES (Nakićenović 1997; UN Population Division 1998).⁸ This population projection assumes an increase in population size in all areas of the world except Europe, which would decline in size by 18 percent over the next 155 years. Popu-

lation size is projected to grow worldwide even though the projection shows that all regions converge to just above replacement level fertility by 2050, and fall to replacement of 2.1 births per woman shortly thereafter. This assumes both a dramatic drop in fertility in the less developed regions— particularly Africa— and increases in fertility rates in North America, Europe, and China that have not yet been observed (fertility rates are currently 4.7 for Africa, and 2, 1.5, and 1.7 for North America, Europe, and China, respectively) (UN Population Division 2007). Slight adjustments are made in replacement level fertility to match the projected increases in life expectancy over the long term, so that replacement level fertility comes closer to 2.0 than 2.1 (UN Population Division 1998).

Aside from fertility, the other factors contributing to population growth and change are mortality and migration patterns. In the population projection used for B2, mortality is projected to decline in all regions, with life expectancy projected to accelerate faster in the areas currently experiencing higher mortality. Thus the gap in life expectancy between more and less developed countries narrows from 13 years in 1995 to less than four years by 2150, and global life expectancy increases worldwide by 21 years, from 62.2 years and 66.5 years for men and women, respectively, in 1995, to 83.4 years for men and 88.2 years for women in 2150. While migration plays a role in population size and structure at the regional level, none of the 1998 projections assume net migration for the regions after 2025, because, as the UN report states, “international migration patterns are highly unpredictable in the long run” (UN Population Division 1998, 10).

The dramatic changes in fertility observed in the medium variant of the UN population projection lead to dramatic population aging worldwide by 2150, with the median age of the world's population rising from 25.4 in

Since the publication of the SRES in 2000, the UN has updated and refined their long-range population projections, with significant implications for projected population outcomes.

1995 to 36.5 in 2100. In turn, the share of global population under age 15 will decline from 31.3 percent of the world's population in 1995 to 20.5 percent in 2100. The proportion of the population over 65 and over 80 will also increase. While this significant shift in population composition is likely to have implications for energy use, these implications were not considered in the development of the SRES.

Updates to the UN and IIASA Projections

Since the publication of the SRES in 2000, the UN has updated and refined their long-range population projections, with significant implications for projected population outcomes. The most recent version of the UN's long-range population projections was published in 2004, and includes some notable changes in methodology and results. World population under the medium projection reaches 8.9 billion in 2050, peaks at 9.2 billion in 2075, and falls to 9.1 in 2100. This is significantly lower than the 1998 projection included in the B2 storyline, in which global population reaches 9.3 billion in 2050 and 10.4 in 2100. The changes resulted from improved baseline information from more and better national census data than were previously available. The projections also changed assumptions about fertility, assuming that fertility will fall below replacement levels, and then increase again to stabilize at replacement. Although the updated 2004 projection does not project all countries to reach or go below replacement levels by 2050, it does assume that once fertility rates reach four to five births per woman in current high fertility countries, the decline in fertility accelerates. As a group, less developed countries are projected to undergo the most dramatic demographic changes, with fertility falling from 3.1 currently to 2.04 (below replacement) by 2050. Each country is expected to converge below replacement

fertility at a rate of 1.85 children per woman for a period of around 100 years, before rising again to replacement levels (UN Population Division 2004).

In terms of the other factors in population growth, the UN's 2004 long-range population projection revision extends projections of migration out to 2050, rather than to 2025, but migration falls to zero after that point. During the period when it is incorporated into the projections, migration prevents a more rapid decline in population growth rates in developed countries because they are projected to continue to receive immigrants from other countries. Life expectancy does not have an upper bound in the new projections, with a range between 87 and 106 years in 2300 (because mortality rates have already declined significantly in all regions, increases in life expectancy contribute far less to population growth than fertility rates) (UN Population Division 2004).

Like the UN, IIASA has since updated their population projections, and has shown lower population growth under all scenarios in the medium and long term. The confidence interval for population in 2100 in the new population projection spans 6.2 to 11.1 billion, significantly lower than the projections used in the SRES, suggesting that the 15 billion estimates used in the A2 scenario, representing more than a doubling of today's population, has a less than 2% likelihood of occurring (Van Vuuren and O'Neill 2006). While all of these trends have potential implications for GHG emissions trends, these refined population projections are not currently reflected in the SRES.

DEMOGRAPHY AND THE SRES SCENARIOS

“Broadly speaking, demographic change, changes in economic output, and changes in the GHG intensity of the global economy are the forces that drive GHG emissions. Each of these is, in turn, influenced by a number of important indirect variables.” *Population, Greenhouse Gas Emissions, and Climate Change* (O’Neill et al. 2004)

In its discussion of the main driving forces of climate change, the SRES explains the scenarios’ conceptions of population, but the authors are careful to avoid suggesting a linear relationship between population and emissions, emphasizing that relationships among drivers of GHG emissions are very complex. The report states that the relationships can be expressed as the **I=PAT** Identity, in which:

$$\text{Impact} = \text{Population} \times \text{Affluence} \\ \times \text{Technology}$$

This implies that the level of emissions results from the size of population, multiplied by affluence and the level of technology (Nakićenović et al. 2000). This conceptualization has been used to describe the impact of human activities on a range of environmental issues (O’Neill et al. 2004).

When examining climate change, a variation on the I=PAT Identity, known as the Kaya Identity, is often used. **The Kaya Identity** is expressed as:

$$\text{CO}_2 \text{ emissions} = \text{Population} \times (\text{GDP/Population}) \\ \times (\text{Energy/GDP}) \times (\text{CO}_2/\text{Energy})$$

In the Kaya Identity equation, annual CO₂ emissions are the product of population, per capita income (or per capita econom-

ic production), the amount of energy used per unit of economic production (energy intensity), and the amount of CO₂ emitted per unit of energy produced (carbon intensity). Many other factors influence these determinants, such as the stage of industrialization (service-oriented economies tend to have lower energy intensity). Their multiplicative relationship means that changes in one variable are amplified or mitigated by the others (e.g., population increase in a country of high per capita GDP would have a greater impact than that in a country with low GDP) (O’Neill et al. 2004).

While the Kaya Identity underpins the treatment of population in the process of scenario development in the SRES, the authors of the SRES acknowledge that total population size has less direct relation to emissions than other demographic units, such as households. However, the authors of the SRES faced the limitation that nearly all the integrated assessment models in the literature used to develop the scenarios are based on population size at the regional level, thus precluding scenarios based on factors.

The trend in changing household size is closely tied to population aging. As populations age, the number of people per household tends to fall, which results in a loss in economies of scale in energy use. Household size shrinks as older people tend to live alone, or as couples live in households longer without children. Due to aging, under both the medium and low population projections used in the SRES, the number of households will grow faster than population in developing and developed countries alike, although this may unfold differently in developing countries where multigenerational households are still common. Because of this, the SRES authors note that the rapid aging expected in the next century could significantly increase CO₂ emissions more than currently accounted for in the SRES,

The trend in changing household size is closely tied to population aging. As populations age, the number of people per household tends to fall, which results in a loss in economies of scale in energy use.

but say that at the time of the report's publication, uncertainties surrounded this effect (Nakićenović et al. 2000).

The SRES also discussed the potential effect of urbanization on emissions. The report stated that urbanization is likely to increase emissions, mainly through a function of increased income, as the promise of higher income drives rural-urban migration, higher incomes result in more fossil fuel use in households, and transportation use increases. However, neither the effect of urbanization nor population aging is explicitly addressed in the SRES scenarios.

O'Neill and colleagues addressed some of these issues subsequent to the publication of the SRES, noting that the SRES analysis could have explored population and emissions relationships by holding other drivers constant and examining the outcomes, as was done for energy under the A1 scenario. In 2004, O'Neill, MacKellar and Lutz conducted a simple sensitivity analysis, using the 1996 IASA projections and IS92 scenarios, examining the model's sensitivity to changes in population. In their analysis, the authors found that total emissions in the medium term (to 2050) are much more sensitive to changes in per capita emissions than to differences in population size (using the central vs. the low population projections). The results found a significantly larger difference between a scenario of central and low per capita emissions than between central and low population projections. However, in 2100, the opposite occurs; the difference is much more pronounced in scenarios with different populations. When a central per capita emissions scenario was assumed, a low population projection led to 37 percent less total emissions than the central population scenario.

O'Neill, MacKellar and Lutz also conducted sensitivity analyses for aging and household

size on emissions scenarios. Assuming that household emissions grow at the same rate as per capita emissions, under a scenario of central population growth and emissions, emissions are 25 percent higher in 2100 in a model using households as its demographic unit than those using population size alone. The 25 percent difference between the two makes it important for modelers to include households in their analyses (O'Neill et al. 2004).

POPULATION IN POST-SRES SCENARIOS AND THE REPRESENTATIVE CONCENTRATION PATHWAYS PROCESS

The SRES scenarios were published in 2000 and were based on data from the mid-1990s. Because these scenarios were used for the IPCC Fourth Assessment Report, published in 2007, it is important to assess their performance against updated historical data and against emissions scenarios published since 2000. The IPCC's Working Group on Mitigation—Working Group III—conducted such a review in its Working Group Report for the Fourth Assessment Report. This review documents the scenarios published in the literature since the publication of the SRES and compares the new scenarios with those used in the SRES. The report found that the emissions ranges identified in the post-SRES scenarios did not vary significantly from the SRES ranges. While the Working Group Report notes that population projections have been lowered since the publication of the SRES, they conclude that many of the new scenarios still use more dated population projections. Review of the literature also found that while lower population levels are generally associated with lower emissions, scenarios that do incorporate the new population figures had largely unchanged emissions results, because changes in other contributors to emissions, such as economic

growth and energy use patterns, offset the effects of lower population figures (Fisher et al. 2007). The report drew heavily on a review by Van Vuuren and O'Neill, who found that most of the SRES data ranges remain credible, and thus a large-scale update of the scenarios was not necessary in the near term. They emphasized, however, that new scenarios should consider lower population growth—using smaller population size at the low end of the range of estimates, as well as a smaller population size under the high population projection. Particularly at the highest ends, the authors conclude that the high population estimate included in the SRES “strains credibility,” falling as it does outside the 90 percent confidence interval of future population (Van Vuuren and O'Neill, 2006).

While the SRES scenarios have been found to be relatively robust, as mentioned earlier they are being replaced by new scenarios that are currently under development. The new scenarios have important differences, both in their structure and development process. Requests from policymakers have led to the inclusion of scenarios that assume climate mitigation efforts, including one that reflects very stringent emissions reductions. Also, the IPCC will be less involved in scenario development, acting instead as a catalyst for their creation. The new round will be centered on four Representative Concentration Pathways (RCPs) drawn from the published literature. The name is meant to emphasize that it is not only the point of stabilization of GHG concentration that matters, but also the path a country or the world takes to get to a stabilization point (O'Neill, Jiang and Pitcher, 2008).

Beginning with a given starting point-of radiative forcing, the RCPs will also allow integrated assessment modelers to develop scenarios of future emissions at the same time climate modelers will use the RCPs to

develop their scenarios of atmosphere, climate, and related changes, such as sea level rise and ocean acidification. This is an important change from the sequential procession from scenario development to climate modeling and then to adaptation and impacts assessment used in previous assessment reports. This extra time also allows climate modelers to make projections out to both the near (2035) and long terms (2300). At the same time, integrated assessment modelers will develop RCPs into a suite of scenarios that include a range of technological and policy options. The scenario development and impact assessment, adaptation and vulnerability communities can work together to develop narrative storylines, before all the various pieces are ultimately integrated and aligned for the publication of the IPCC's Fifth Assessment Report in 2014 (Moss et al. 2008). This new phase of development is an important opportunity to include improved consideration of demographic and population variables discussed in the SRES and subsequent research, including household level analysis, and consideration of aging and urbanization on regional and global emissions pathways.

POPULATION POLICY AND CLIMATE CHANGE

While the IPCC includes population in its scenario development, and thus in its projections of climate change, population is not fully integrated into several key areas of IPCC work.

While the SRES assumes a future without policies intended to mitigate climate change, such as emissions reductions under the Kyoto Protocol, it does include a review of “non-climate” policies that impact emissions, such as those influencing economic development, technological innovation, energy, agriculture, transportation, and infrastructure. This review includes a brief discus-

The linkages between population and emissions are complex but real.

sion of population policies. The SRES notes that studies support the notion that reduced population growth significantly abates GHG emissions, and that therefore, policies influencing fertility, mortality and migration rates could have a significant impact on future emissions. At the same time, SRES authors note, policies relating to health, education, and gender equality can also influence economic growth, consumption, and per capita emissions, with the overall effects likely to vary from country to country. At the end of this brief section of the report, SRES authors assert that while policies that reduce fertility may have significant effects on climate change, implementation of such policies was unrelated to concerns about climate change at that time (Nakićenović et al. 2000).

In a 1997 commentary, Bongaarts, O'Neill and Gaffin note that the Second Assessment Report, published in 1995, did not mention population in its mitigation strategies, and devoted little attention to the role of demographic and population growth on emissions. The commentary discusses three common misconceptions that fuel this resistance to considering population as a part of climate change mitigation. The first was the belief that "the real problem is consumption, not population," emphasizing that the main cause of climate change was high levels of historic emissions from the developed countries, and not the result of population growth or over-consumption in the developing world. The second was the belief that "not much can be done about population," ignoring the effect of population policies on fertility reduction over the past decades. The third was that "strengthening population polices is likely to lead to coercion." The authors presented a rebuttal, stating that emissions from developing countries will surpass those of developed countries in the medium term, such that rapid population growth as well as over-consumption issues

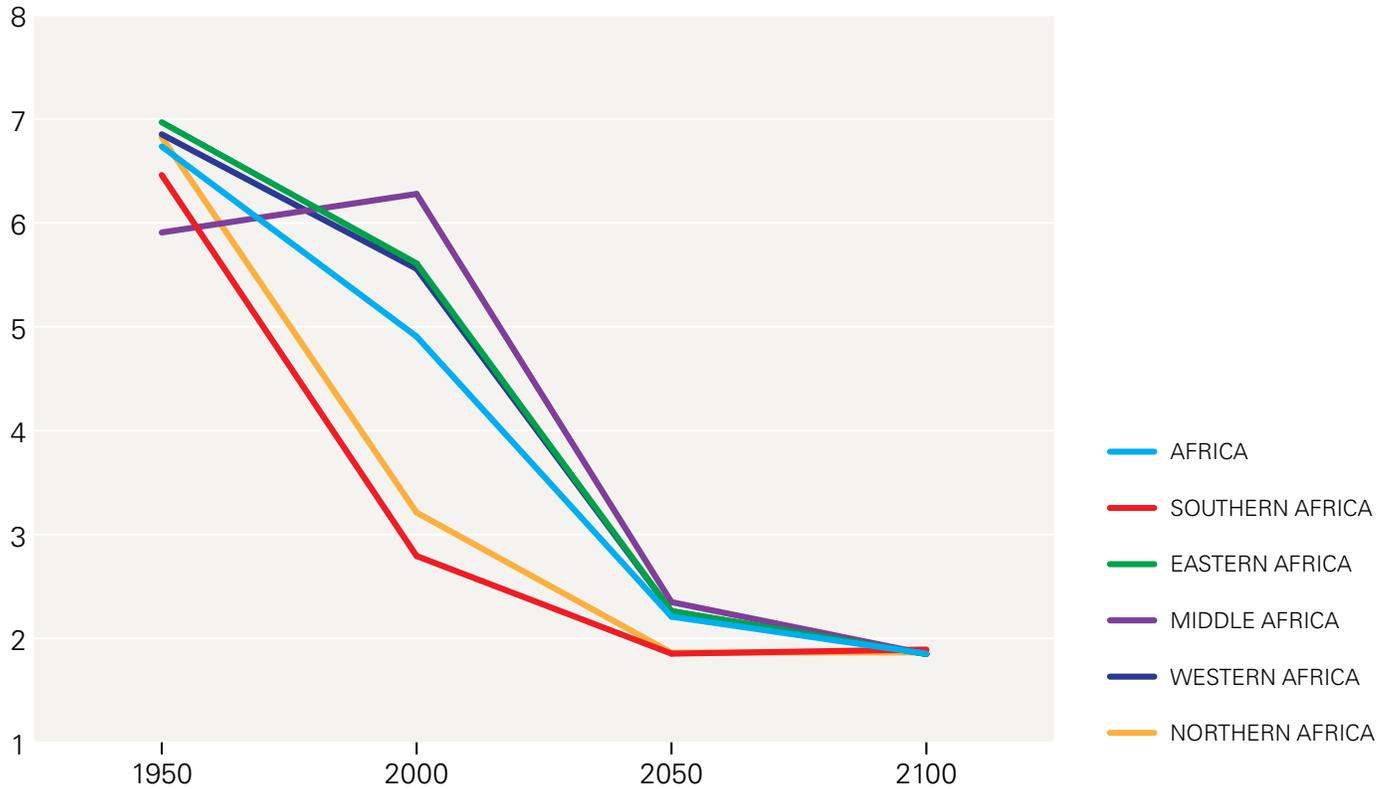
must be addressed. They also argued that slowed population growth can have a beneficial impact on emissions in the long run, and make emissions targets easier to reach. They counter the coercion argument with the fact that there is existing high unmet need for family planning and high rates of unintended pregnancy in developed and developing countries alike (Bongaarts et al. 1997).

Despite these arguments, the 2007 Fourth Assessment Report also does not include population policies in its recommendations for mitigation (Fisher et al. 2007), just as the Kyoto Protocol, adopted in 1997, did not include consideration of population issues. The absence of population in critical climate change dialogues is possibly influenced by continuing controversy over family planning and reproductive health issues, as the conservative political environment—particularly in the U.S.—conflates family planning policies with abortion (de Sherbinin et al. 2007). Further, population related policies have not been examined as an adaptation strategy despite the contribution these policies can make to reducing many environmental stresses, such as those on water, land, and forests, in addition to improving health and reducing poverty.

ASSUMPTIONS IN POPULATION PROJECTIONS: ARE THEY REALISTIC?

There are many policies that influence GHG emissions more directly than those surrounding population. However, given that they are still acknowledged as important, and are cost-effective and beneficial in their own right, it is important to consider population in combination with other GHG mitigation interventions. The linkages between population and emissions are complex but real. The vast gap in consumption, energy use, and per capita emissions between the more and less developed countries man-

FIGURE 2: FERTILITY RATES IN AFRICA: 2004 UN LONG-RANGE PROJECTIONS



Source: United Nations Department of Economic and Social Affairs Population Division. 2007. *World Population Prospects: the 2006 Revision*.

dates commitments on the part of industrialized nations to reduce their emissions in order to mitigate global warming, which will have a disproportionate impact on the world’s poorest countries, and on disadvantaged groups within those countries. However, it is also useful to revisit some of the assumptions made in population projections like those used in the SRES. In their projections of a world with falling fertility and slowed population growth, the projections forecast some dramatic changes that might not be realistic. **To focus on the most recent UN long-range population projection, fertility in Africa is projected to fall 50 percent from 2000 levels by 2050, after falling only 26 percent since 1950** (see Figure 1) (UN Population Division 2004)

In Uganda, where 41 percent of married women have an unmet need for family planning, in which they wish to space or limit their childbearing, but are not using contraception (Uganda Bureau of Statistics and Macro International Inc. 2007), the UN projects a fall in fertility from 6.95 in 2000 to 2.78 in 2050—a nearly 60 percent drop—after falling only four percent since 1960 (UN Population Division 2007). A recent study has shown that “in sub-Saharan African countries, the average pace of decline in fertility was lower around 2000 than in the mid-1990s and that more than half the countries in transition in this region have stalled” (Bongaarts 2008). This is not to say that the dramatic fertility declines assumed in population projections are impossible, but they are

It is also useful to revisit some of the assumptions made in population projections like those used in the SRES. In their projections of a world with falling fertility and slowed population growth, the projections forecast some dramatic changes that might not be realistic.

Given the GHG emissions implications of population policies, they warrant further consideration as the international community strives to develop of a comprehensive set of effective solutions to climate change challenges.

unlikely to occur in the absence of sound policies supporting education and equality for women, and, importantly, political and economic support for the reproductive health services—including family planning supplies and services—necessary for families to have the number of healthy children that they desire.

O'Neill, MacKellar, and Lutz's conclusions regarding the benefits of including population-related policies in both mitigating emissions and facilitating adaptation to likely climate change impacts note that there are other more direct measures to address climate change mitigation through reduction in GHG emissions and land use change. However,

slower population growth will generally lead to lower emissions and allow developing countries to better adapt to climate change (O'Neill et al. 2004). Slower population growth, they note, will make the other policies less burdensome to implement and make emissions reductions easier to attain. Further, policies that influence fertility, such as women's education and access to reproductive health and family planning services, have their own inherent benefits, making them no-regrets strategies. However, such policies are currently underfunded worldwide (O'Neill et al. 2004).

CONCLUSION

Like many factors contributing to climate change, population is one part of a great, complex climate system. This paper has demonstrated that the influences of demographic factors on emissions are significant, and not adequately accounted for in the IPCC's emissions scenarios. A deeper and more nuanced understanding of the emissions implications of population size, age structure, household size, and urbanization should be better incorporated into climate change scenarios that provide the basis for policy decision-making and strategy development for climate change mitigation and adaptation.

Furthermore, the fertility decline assumptions contained in long-range population projections that are incorporated into climate change scenarios may be overly optimistic given recent declines in political and financial support for policies strongly tied to fertility decline, such as education and equality for women and access to reproductive health and family planning services. Given the GHG emissions implications of population policies, they warrant further consideration as the international community strives to develop of a comprehensive set of effective solutions to climate change challenges.

ENDNOTES

- 1 Radiative forcing is a measure of the influence that a climatic factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system. The term radiative forcing is also used as an index of the influence a factor has as a potential climate change mechanism (Nodvin and Vranes 2007).
- 2 GHG and sulfur emissions accounted for in the SRES include CO₂, CH₄, N₂O, HFCs, PFCs, SF₆, HCFCs, CFCs, and SO₂, CO, NO_x and non-methane volatile organic compounds
- 3 GtC stands for gigatons of carbon
- 4 The numbers in this column represent multi-model mean SAT warming. Please see Le Treut et al. 2007 for complete temperature range information.
- 5 The assumptions of this and other population projections are discussed in detail in the next section.
- 6 The fertility rate at which population growth stabilizes is approximately 2.1 children per woman.
- 7 It is important to note that the confidence interval is not an assignment of likelihood for a given population, but rather an expression of the range of uncertainty surrounding future growth.
- 8 The IS92 scenarios used the World Bank's 1991 projection (the World Bank had ceased publication of its population projections by 1994, the time the SRES scenarios were developed), and the UN 1992 medium high and medium low projections. Thus, the range in the IS92 had both higher estimates at the high and medium end, as well as slightly lower population estimates in the low projection.

REFERENCES

- Bongaarts, J, B O'Neill and S Gaffin. 1997. "Global Warming Policy: Population Left Out in the Cold." *Environment* 39(9):40-41.
- de Sherbinin, A, DCarr, S Cassels and L Jiang. 2007. "Population and Environment." *Annual Review of Environmental Resources* 32:345-373.
- Fisher, B S, N Nakićenović, K Alfsen, J Corfee Morlot, F de la Chesnaye, J-Ch Hourcade, K Jiang, M Kainuma, E La Rovere, A Matysek, A Rana, K Riahi, R Richels, S Rose, D van Vuuren, R Warren. 2007. "Issues related to mitigation in the long term context." In B Metz, O R Davidson, P R Bosch, R Dave and L A Meyer (Eds.). *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.
- Houghton, JT, L G Meira Fliho, J Bruce, H Lee, B A Callander, E Haites, N Harris, and K Maskell. 1994. *Climate Change 1994: Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Scenarios*. Cambridge, UK: Cambridge University Press.
- International Institute for Applied Systems Analysis (IIASA) World Population Program. 2007. "Population Projections for the IPCC Special Report on Emission Scenarios (1996)." <http://www.iiasa.ac.at/Research/POP/IPCC/index.html>. Accessed 10 November 2008.
- Intergovernmental Panel on Climate Change (IPCC). 2004. "Sixteen Years of Scientific Assessment in Support of the Climate Convention." Geneva: IPCC.
- Intergovernmental Panel on Climate Change (IPCC). 2001. *Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.
- Intergovernmental Panel on Climate Change (IPCC). 1995. *IPCC Second Assessment: Climate Change 1995*. Geneva: IPCC.
- Jiang, L and K Hardee. 2009. *How Do Recent Population Trends Matter to Climate Change?* Washington DC: Population Action International.
- Le Treut, H, R Somerville, U Cubasch, Y Ding, C Mauritzen, A Mokssit, T Peterson and M Prather. 2007. "Historical Overview of Climate Change." In Solomon, S, D Qin, M Manning, Z Chen, M Marquis, K B Averyt, M Tignor and

- H L Miller (Eds.). *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.
- Lutz, W (Ed.). 1996. *The Future Population of the World: What Can We Assume Today?* London: Earthscan Publications Ltd.
- Moss, R, M Babiker, S Brinkman, E Calvo, T Carter, J Edmonds, I Elgizouli, S Emori, L Erda, K Hibbard, R Jones, M Kainuma, J Kelleher, J F Lamarque, M Manning, B Matthews, J Meehl, L Meyer, J Mitchell, N Nakićenović, B O'Neill, R Pichs, K Riahi, S Rose, P Runci, R Stouffer, D van Vuuren, J Weyant, T Wilbanks, J P van Ypersele and M Zurek. 2008. *Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies*. Geneva: Intergovernmental Panel on Climate Change.
- Nakićenović, N, J Alcamo, G Davis, B de Vries, J Fenhann, S Gaffin, K Gregory, A Grubler, T Y Jung, T Kram, E L La Rovere, L Michaelis, S Mori, T Morita, W Pepper, H Pitcher, L Price, K Riahi, A Roehrl, H-H Rogner, A Sankovski, M Schlesinger, P Shukla, S Smith, R Swart, S van Rooijen, N Victor and Z Dadi. 2000. *Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.
- Nodvin, S C and K Vranes. 2007. "Radiative forcing." In C J Cleveland (Ed.). *Encyclopedia of Earth*. Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment. http://www.eoearth.org/article/Radiative_forcing. Accessed February 3, 2009.
- O'Neill, B, L Jiang and H Pitcher. Personal communication. 28 August 2008.
- O'Neill, B, F L MacKellar, and W Lutz. 2004. "Population, Greenhouse Gas Emissions, and Climate Change." In Lutz, W, W C Sanderson and S Scherbov (Eds.). *The End of Population Growth in the 21st Century: New Challenges for Human Capital Formation and Sustainable Development*. London: IIASA and Earthscan, Pp. 283-314.
- Uganda Bureau of Statistics (UBOS) and Macro International Inc. 2007. *Uganda Demographic and Health Survey 2006*. Calverton, Maryland, USA: UBOS and Macro International Inc.
- United Nations Population Division. 2007. *World Population Prospects: the 2006 Revision*. New York: United Nations.
- Van Vuuren, D and B O'Neill. 2006. "The Consistency of IPCC's SRES Scenarios to Recent Literature and Recent Projections." *Climatic Change* 75:9-46.

ACKNOWLEDGMENTS

This paper greatly benefited from reviews from Dr. John Bongaarts, Population Council, Dr. Geoffrey Dabelko, Woodrow Wilson International Center for Scholars, and Dr. Peter Frumhoff, Union of Concerned Scientists. At PAI, the authors appreciate review from Amy Coen, Leiwen Jiang, Kimberly Rovin, and Elizabeth Leahy Madsen and editorial assistance from Kristine Berzins.

AUTHORS

Malea Hoepf Young was a Research Associate at Population Action International through December 2008.

Kathleen Mogelgaard is Senior Program Manager of Population and Climate Change at Population Action International.

Karen Hardee is Vice President of Research at Population Action International.

© 2009 Population Action International

1300 19th Street NW, Second Floor | Washington, DC 20036 USA | +1-202-557-3400
e-mail: research@popact.org | www.populationaction.org