April 2009

How Do Recent **Population Trends** Matter to **Climate Change**?

Leiwen Jiang and Karen Hardee

Population Action
INTERNATIONAL
HEALTHY FAMILIES HEALTHY PLANET

POPULATION ACTION INTERNATIONAL

uses research and advocacy to improve access to family planning and reproductive health care across the world so women and families can prosper and live in balance with the earth. By ensuring couples are able to determine the size of their families, poverty and the depletion of natural resources are reduced, improving the lives of millions across the world.

How Do Recent **Population Trends** Matter to **Climate Change**?

INTRODUCTION

Although integrated assessment models (IAM) of the Intergovernmental Panel on Climate Change (IPCC) consider population, along with economic growth and technological change, as one of the root causes of greenhouse gas emissions, how population dynamics affect climate change is still under debate. While policy debates around climate change engender lively discussion on a number of factors, population is rarely mentioned. Studies in the past decade have added significantly to understanding the mechanisms and complexity of population and climate interactions. In addition to the growth of total population size, research shows that changes in population composition (i.e. age, urban-rural residence, and household structure) generate substantial effects on the climate system. Moreover, studies by the impact, vulnerability and adaptation (IAV) community also reveal that population dynamics are critical in the near term for building climate change resilience and within adaptation strategies. This paper explores how global population dynamics affect carbon emissions and climate systems, how recent demographic trends matter to worldwide efforts to adapt to climate change, and how population policies could make differences for climate change mitigation and adaptation.

In the past two decades, increasing scientific evidence from the Intergovernmental Panel on Climate Change (IPPC), the world's leading body on climate change that includes over 2500 scientists from 150 countries, indicates that global warming is occurring, mostly due to greenhouse gas emissions that are related to human activity. That global warming is unequivocal is nearly certain (98% confidence level) (Houghton, Callander and Varney 1992). Furthermore, most of the warming is very likely due to greenhouse gas emissions—with a confidence level of greater than 90% (Parry et al. 2007). The IPCC Fourth Assessment Report provides for the first time concrete observations of the effects of climate change on human society. The report, produced in 2007, indicates that global warming and its subsequent adverse impacts present a grave challenge for humanity.

Making a clear and direct linkage between population change and climate change is complex because the effects of human activity on emissions are the product of a range of driving forces, including economic growth, technological changes, and population growth. Likewise, human vulnerability to climate change impacts is a complex concept, and the scope and scale of those impacts will be influenced by a wide range of factors, including not only demographic changes, but also geography, infrastructure, access to various forms of capital, and social and cultural factors. While the relationships between population and the climate system are complicated, recent research has greatly improved our understanding of population-climate interactions. Increasing evidence suggests that the recent climate models have an important limitation in the demographic component which may have resulted in underestimating the impacts of population on climate change. Furthermore, population factors have yet to be fully incorporated into adaptation strategies.

Based on existing scientific evidence, this paper explores (1) how population changes affect the growth of global greenhouse gas emissions and resulting climate change; (2) how anticipated population trends affect future adaptive strategies for coping with the impacts of climate variation and change; and (3) how population policy responses could make a difference for climate change mitigation and adaptation.

POPULATION TRENDS AS A MAJOR DRIVING FORCE OF EMISSIONS GROWTH

Historical relationship between population growth and greenhouse gas emissions growth

Historical statistics reveal that population growth parallels increases in economic growth, energy consumption and greenhouse gas emissions. During the 200 years between 1800 and 2000, energy use increased 35 fold, carbon emissions increased 20 fold, and the world's population grew by a factor of 6 (Table 1). Meanwhile, global income (Gross Domestic Product) increased 70 times (Naki´cenovi´c et al. 2007). While it is clear that technological changes have substantially improved energy efficiency and reduced carbon intensity during the past 200 years, there continues to be debate about whether population growth or increasing consumption levels have contributed relatively more to greenhouse gas emissions (Dietz, 2007; Ehrlich, 1971; Meyerson, 1998; Parikh, 1994).

Making a clear and direct linkage between population change and climate change is complex because the effects of human activity on emissions are the product of a range of driving forces, including economic growth, technological changes, and population growth.

Table 1. Changes in global population, economy, energy, and CO2 emissions

	1800	2000	FACTOR
Population (billion)	1	6	x6
GDP (PPP trillion 1990 US$)	0.5	36	x70
Primary Energy (EJ)	12	440	x35
CO2 Emissions (GtC)	0.3	6.4	x20

Source: Nakićenović et al. 2007.

There continues to be debate about whether population growth or increasing consumption levels have contributed relatively more to greenhouse gas emissions.

Table 2. Net impact of population growth on carbon emissions

Study	% increase in carbon emissions per 1% increase in population
Dietz and Rosa 1997	1.15
Shi 2003	1.43
York, Rosa and Dietz 2003	0.98
Rosa, York and Dietz 2004	1.02
Cole and Neumayer 2004	0.98

Based on the assumption that economic development, technological change and population growth jointly determine energy consumption and carbon emissions, a number of statistical analyses have been conducted to explore the net effect of population growth. Using multinational time series data from several decades, these studies reveal that, after controlling for other variables (mainly economic growth and technology related to energy efficiency and carbon intensity), a one percent increase in population is generally associated with a one percent increase in carbon emissions (O'Neill 2009) (Table 2).

The findings from statistical analysis of historical data have been used to inform the projections of future climate change, including those of many models incorporated into IPCC reports.

POPULATION IN IPCC CLIMATE MODELS

The 2000 IPCC Special Report on Emission Scenarios (SRES) identifies population growth, economic growth, technological change, and changes in patterns of energy and land use as the major driving forces of the growth in greenhouse gas emissions. Figure 1 depicts these root causes and the four families of scenarios from the SRES that represent future changes in those factors. The two 'A' scenarios of the top limbs of the "climate scenario" tree assume high economic growth, while the two 'B' scenarios of the bottom limbs imply a more environmentally-friendly development pattern. The two '1' scenarios on the left limbs assume a more globalized or converged world, while the two '2' scenarios on the right limbs assume less global cooperation, less technology transfer, and little support provided by rich countries to the global poor. The major characteristics of the four families of scenarios are summarized in Table 3. As far as population is concerned, the A1 and B1 scenarios assume low population growth, B2 assumes medium population growth, and A2 assumes high population growth (see Hoepf Young, Mogelgaard and Hardee 2009 for a more detailed explanation of population projections and climate models).

Based on these scenarios, **the projections produced by various climate models suggest a mixed relationship between population growth and carbon emissions in future decades** (Figure 2). On the one hand, there is a generally positive relationship for most of the cases—carbon emissions will be low under the slow population growth scenario (B1) and high under the fast population growth scenario (A2), and will fall somewhere in the middle under the medium population growth scenario (B2). On the other hand, however, in two scenarios with the same population (A1 and B1), A1 produces much higher emissions than B1, due to the fact that A1 assumes the highest level of economic growth and rapid technological changes in energy efficiency,[1] while the economic growth pattern in B1 is not as rapid and is more environmentally-friendly.[2] Moreover, although A1 has lower population growth than A2, the emissions level in A1 is similar to or even higher than A2 before the year 2070.

Therefore, according to the output of these models, higher population growth means more greenhouse gas emissions; with the same population growth, different economic and technological patterns produce very different emission outcomes; and under certain circumstances, the effects of economic growth and technological changes tend to be more substantial than population growth on future carbon emissions for at least several decades (O'Neill 2009).

IMPROVING UNDERSTANDING OF DEMOGRAPHIC IMPACTS ON EMISSIONS

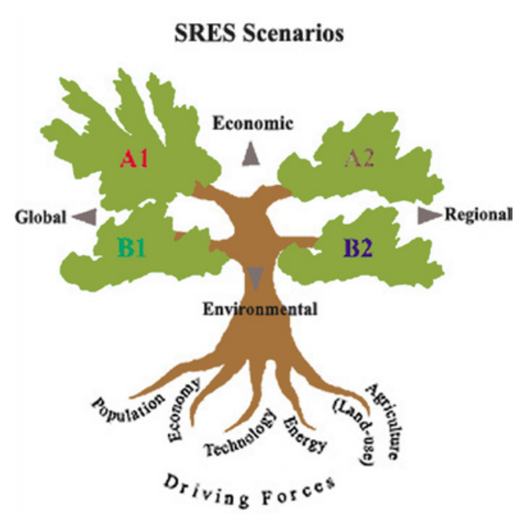
In almost all climate models, population size is the only demographic variable considered. The assumption behind this treatment of the demographic component is that each individual in a population shares the same productive and consumptive behavior, an assumption that is inaccurate and misleading. Consumptive and productive patterns among various population groups differ, and as the proportion of various groups in a population change, the amounts of greenhouse gases that the population emits also changes.

In almost all climate models, population size is the only demographic variable considered. The assumption behind this treatment of the demographic component is that each individual in a population shares the same productive and consumptive behavior, an assumption that is inaccurate and misleading.

Table 3. Main assumptions of the four families of SRES scenarios

	A1	A2	B1	B2
Population Growth	Low	High	Low	Medium
GDP Growth	Very High	Medium	High	Medium
Technological Change	Rapid	Slow	Medium	Medium
Energy Use	Very High	High	Low	Medium
Land- Use Changes	Low / Medium	Medium / High	High	Medium

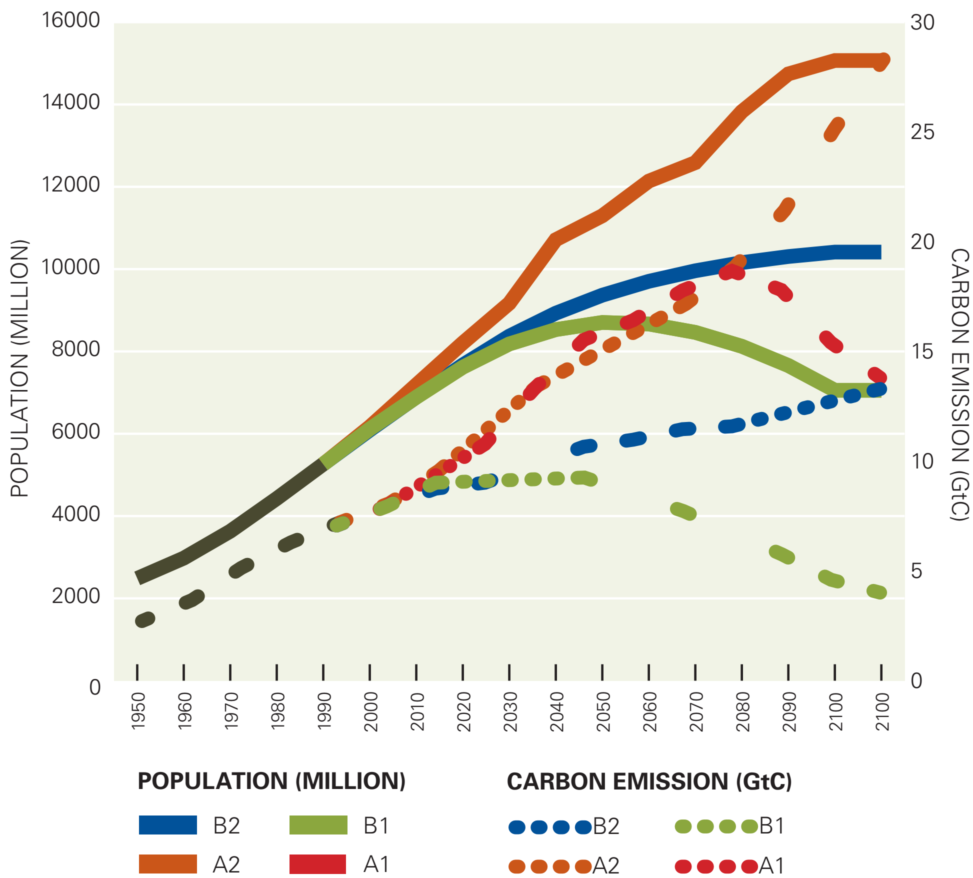
Figure 1. Schematic illustration of the IPCC Special Report on EmissionS Scenarios



Source: Nakićenović et al. 2000.

Addressing both issues is important, and neither can be ignored to truly understand the extent of demographic impacts on future greenhouse gas emissions and climate change.

Figure 2 .Population changes and carbon emissions under IPCC SRES scenarios



Key: The Population over the A1 scenario does not appear in the figure because it is exactly the same as that for Population B1.

Data Sources: Figure is based on the output of the climate model MESSAGE by the International Institute for Applied System Analysis (IIASA).

In order to more accurately account for demographic impact on future climate change, a growing number of studies have been conducted to address two important and related issues: (1) whether significantly different consumption and emission behaviors exist among population groups with various characteristics (Cole and Neumayer 2004; Cramer 1998; Dietz 2007; Jiang 1999; Jones 1989; Liu et al. 2003; Parikh and Shukla 1995; Prskawetz et al. 2004; Van Diepen 1994); and (2) whether the proportion of population groups with significantly different consumption and emission behaviors will change significantly in the future (Jiang and O'Neill 2007; Lutz 2001; Mackellar et al. 1995; Prskawetz et al. 2004; Zeng et al. 2008). To address the first issue, analyses have been conducted based on historical statistics to identify the significant consumption and emission behavior that exists among **people in developed vs. developing countries**, populations living in small vs. large households, residents of rural vs. urban areas, and young groups vs. elderly populations. To address the second issue, population and household projections have been carried out to explore the major demographic trends that may coincide with the changes in the shares of population groups representing significantly different consumption patterns.

Addressing both issues is important, and neither can be ignored to truly understand the extent of demographic impacts on future greenhouse gas emissions and climate change. For instance, it would not be necessary to consider the impact of urbanization if there are not big differences in productive and consumptive behaviors between rural and urban populations. It would be sufficient to use only the national average per capita emissions. Furthermore, even if significant differences in consumptive and productive behavior are found between rural and urban populations, it would still not be necessary to consider the urban-rural dichotomy in the analysis if future change in the proportion of rural and urban population is not significant.

For illustrative purposes, we use the case of a hypothetical community with a population of 100,000, with 50% living in urban areas. Per capita greenhouse gas emissions for the urban and rural populations are 20 and 10 units respectively, and this difference will remain constant for the future (Table 4). Accordingly, the average per capita emission of the community is 15 units, which gives a total emission of 1,500,000 units for the baseline year. Fifty years later, if the population size doubles (reaches 200,000) and there are not any changes in the proportion of the population that is urbanized, the average per capita emissions will remain 15 units. The total emission will go up to 3,000,000 units because of the increase in total population size. Under this circumstance, one would not need to account for urban-rural difference in the demographic component of climate models. **However, if substantial urbanization occurs and the community becomes compeletely urbanized 50 years later, the average per capita emissions will increase to 20 units.** Therefore, the total emissions will be 4,000,000 units after considering the rural-urban difference, which will be significantly higher than the 3,000,000 units seen when the rural-urban difference is not considered.

Studies conducted over more than two decades, based on historical statistics and household survey data, have revealed **a number of important demographic characteristics that are associated with different patterns of energy consumption, including age structure, household size, and rural-urban division** (Clark and Deurloo 2006; Jiang and O'Neill 2004; Jones 1989;

Table 4. examples of carbon emissions under different urbanization scenarios

	Urbanization	Population (X1000)			Per Capita Emissions			Total Emissions
		Urban	Rural	Total	Urban	Rural	Average	
Baseline	50%	50	50	100	20	10	15	1,500,000
50 Years Later	50%	100	100	200	20	10	15	3,000,000
	100%	200	0	200	20	10	20	4,000,000

O'Neill and Chen 2002; Pachauri 2004; Pachauri and Jiang 2008; Parikh and Shukla 1995; Prskawetz, Jiang and O'Neill 2004; van Diepen 2000; Yamasaki and Tominaga 1997). Projections of future population/household changes also suggest that total population size, aging, urbanization and declining average household size will be important demographic trends in the coming decades.

The United Nations' recent population projections indicate that, while global population will grow, **all population growth will occur in the developing world** (Table 5). **The world will also become more urban, with the proportion of urban population increasing from 48% in 2005 to about 70% in 2050. In the coming decades, almost all world population growth will occur in the urban areas of developing countries. Population aging will happen in both developed and developing nations**, with the proportion of the elderly (aged 60+) worldwide increasing from 10% in 2005 to 22% in 2050 (UNPD 2007). Furthermore, household projections for major developed and developing countries also show that an increasing proportion of these populations will **be living in smaller households** (Dalton et al. 2008; Jiang and O'Neill 2007; Zeng et al. 2008).

Using integrated assessment modeling approaches, research has focused on exploring the importance of population compositional changes on carbon emissions. In these integrated assessment models, the interactions of economic growth, technological changes and population dynamics are systematically taken into account. This type of modeling shows that beyond changes in total population size,

Projections of future population/household changes also suggest that total population size, aging, urbanization and declining average household size will be important demographic trends in the coming decades.

Table 5. Important global demographic trends 2005-2500

	2005	2050
Population Size (Billion)	6.7	9.2
Developed	1.2	1.2
Developing	5.5	8.0
Urban (Billion) (%)	3.3 (48%)	6.4 (70%)
Developed	1.0	1.1
Developing	2.3	5.3
Elderly (60+ Billion) (%)	0.67 (10%)	2.0 (22%)
Developed	0.24	0.4
Developing	0.43	1.6

Data Sources: UNPD. UN Population Prospects 2006 Revision; UN Urbanization Prospects 2007 Revision factors of population aging, urbanization, and household shrinking are major demographic trends that should be explicitly accounted for in projections of future climate change (Dalton et al. 2007; Dalton et al. 2008). Changes in total population size and household shrinking can have significant impacts on emissions in both developed and developing countries; considering the effects of population compositional changes, aging is a more important demographic factor related to carbon emissions in the developed world while urbanization is more significant in developing countries.

THE IMPACT OF HOUSEHOLD SHRINKING

An increasing number of studies have shown that households, instead of individuals in a population, should be used as the variable for analyzing demographic impact on emissions, as households are the units of consumption, and possibly also the units of **production in developing societies** (Jiang 1999; Liu et al. 2003; Mackellar et al. 1995; O'Neill and Chen 2002; Prskawetz, Jiang and O'Neill 2004; van Diepen 2000).

For instance, a study of the energy consumption from 1970-1990 in developed countries shows that, using either number of households or population size as the demographic unit of analysis leads to substantially different conclusions about the demographic impact on energy use. In this study, the total increase of energy consumption, 97.4 MTOE,[3] is decomposed into demographic effects and economic-technological effects. If one uses population size as the demographic variable in the analysis, demographic factors account for **only one-third** of the total increase in energy consumption. However, if one uses the number of households as the demographic variable, demographic factors **contribute to 76%** of the total increase (Mackellar et al. 1995). This large difference is mainly due to the impacts of household compositional changes, in which the proportion of smaller households to the total number of households has expanded, and subsequently increases in the number of households has been much faster than increases in population size. Owing to the loss of economies of scale, the per capita energy consumption **of smaller households is significantly higher than that of larger households. As a result, total energy consumption has increased significantly even though the population growth rate has slowed**.

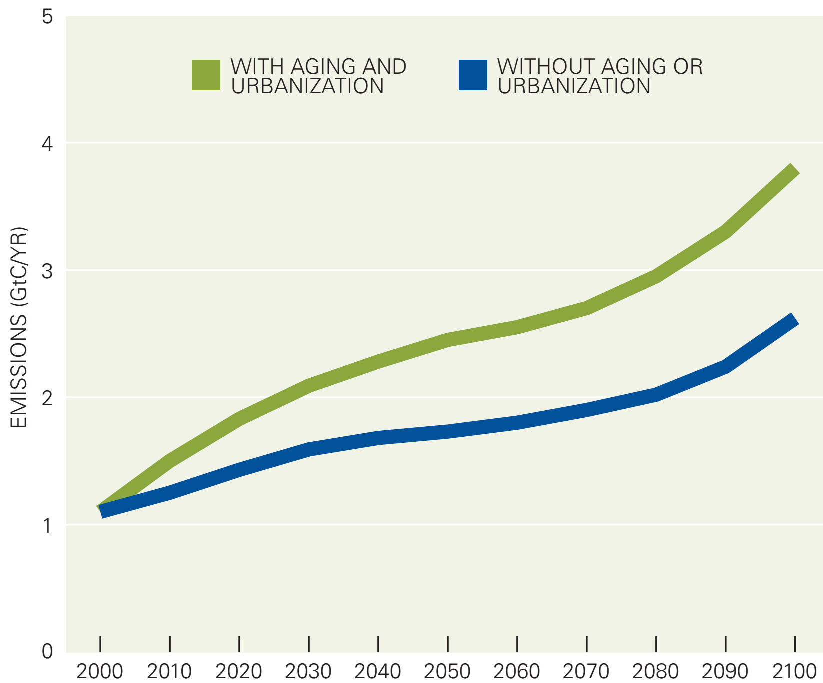
AGING AND URBANIZATION IMPACTS ON EMISSIONS IN CHINA

Considering the effects of population aging and urbanization, projections of future carbon emissions in China show that the country's annual carbon emissions will increase from 1.2 GtC[4] in 2000 to 3.8 GtC by the end of the century (Figure 3) (Dalton et al. 2007). This estimate of carbon emissions is 45% higher in 2100 than projections that do not incorporate aging and urbanization. While urbanization drives emissions up in China due to higher per capita fossil fuel consumption in urban areas, aging will contribute to higher emissions up to year 2030 and then to lower emissions thereafter, as the proportion of the labor force population declines.

A study of the energy consumption from 1970-1990 in developed countries shows that, using either number of households or population size as the demographic unit of analysis leads to substantially different conclusions about the demographic impact on energy use.

The impact of population compositional change (aging in this case) on the climate system could be more significant than that of technological changes up to year 2085—the emissions level will be higher in the case of considering only technological change than in the case of considering only aging before 2085

Figure 3. Impacts of urbanization and aging on carbon emissions in China



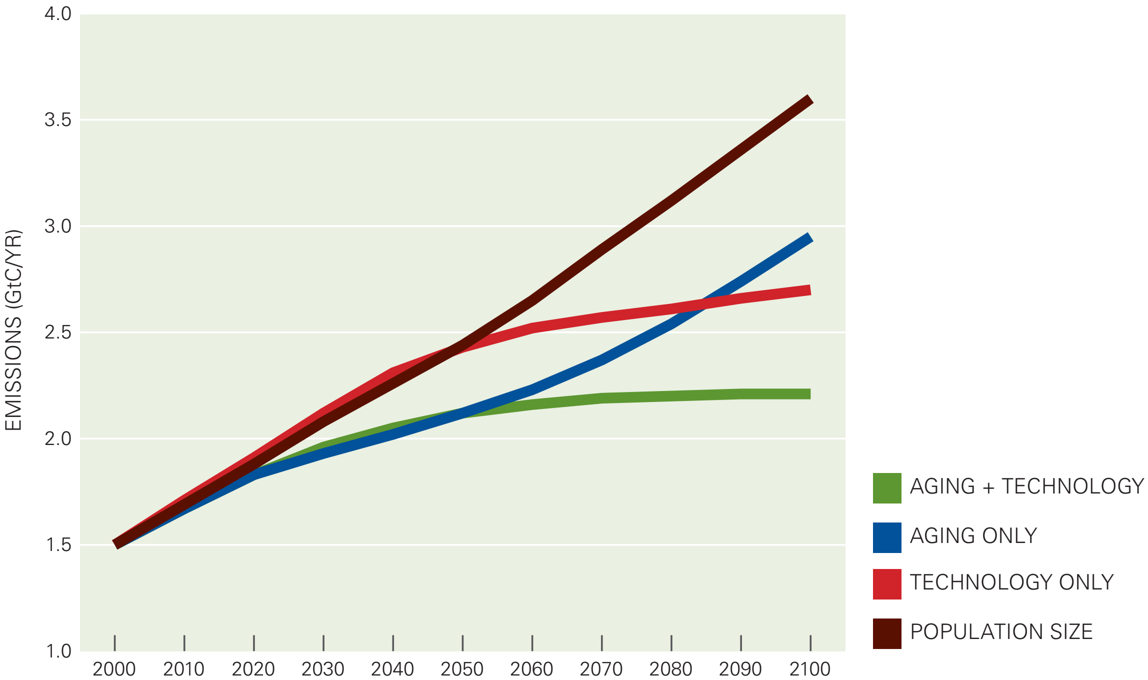
AGING AND TECHNOLOGICAL CHANGE IMPACTS ON EMISSIONS IN THE U.S.

Similar analysis for the U.S., shown in Figure 4, suggests that under certain circumstances, the impact of population **compositional changes (mainly aging) on carbon emissions is even larger than that of technological changes** (technology related to energy intensity and carbon intensity) (Dalton et al. 2007). Sensitivity analyses were used to understand the relative importance of aging and technological changes for future carbon emissions.

These analyses test the different emission paths under four cases. In the first case, no technological change or aging is considered—in other words, population size is used as the only demographic variable in the model. This analysis showed that total emissions will increase **from 1.5 GtC in 2000 to 3.6 GtC in 2100**. In the second case, both technological change and aging are considered in the model, and this analysis results in the lowest increase in annual carbon emissions—up to about 2 GtC by the end of century. The model is then used to test the relative importance of aging and technological changes by considering other two cases: one that considers only aging, and another that considers only technological change.

These analyses reveal that while population aging generally drives emissions down, technological changes contribute to slightly higher emissions in the first half of the century, due to the fact that technological advancement will increase energy efficiency and reduce costs, **encouraging more energy consumption**. This positive relationship between technological change and carbon emissions will remain unchanged

Figure 4. Impacts of aging and technology on carbon emissions in the US



up to 2050 until further improvement in technology is achieved, which induces substantial reduction in the intensities of energy consumption and carbon emissions and eventually drives total emissions down to a level lower than in the first case that considers only aging. Further, under certain circumstances, the impact of population compositional change (aging in this case) on the climate system could be more significant than that of technological changes up to year 2085—the emissions level will be higher in the case of considering only technological change than in the case of considering only aging before 2085.

This section has shown that it is important to understand the impacts of both an increase of population size as well as changes in demographic composition in addressing climate change.

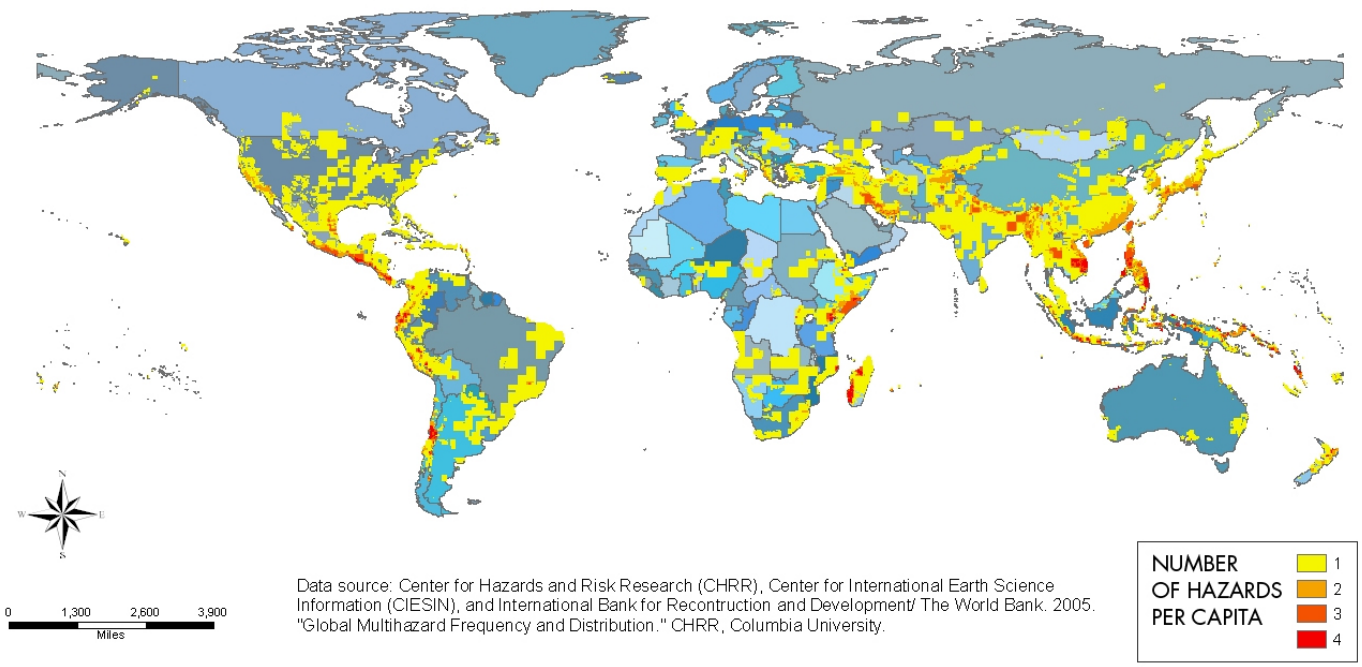
Analysis has shown that different consumption and emission behaviors exist among population groups by various characteristics and that the proportion of population groups with different consumption and emission behaviors will change significantly in the future. The next section addresses the relationship between demographic trends and adaptation to climate change.

ANTICIPATED POPULATION TRENDS AND ADAPTATION TO THE IMPACTS OF CLIMATE VARIATION AND CHANGE.

Potential effects of climate change on population

While mitigation may be the best means of avoiding risks related to climate change, the world cannot rely solely on mitigation to ease the effects of climate change on people. All existing projections under

Figure 5. global distribution of climate-related hazard hotspots



Data source: Center for Hazards and Risk Research (CHRR), Center for International Earth Science Information (CIESIN), and International Bank for Recontruction and Development/ The World Bank. 2005. "Global Multihazard Frequency and Distribution." CHRR, Columbia University.

While mitigation may be the best means of avoiding risks related to climate change, the world cannot rely solely on mitigation to ease the effects of climate change on people.

the IPCC framework show that global greenhouse gas emissions in all scenarios will continue to increase at least up to the year 2020. Due to the persistence of carbon in the atmosphere, global warming is inevitable under any scenario in the coming decades (IPCC 2007). Therefore, climate change is leading to large-scale irreversible effects, whose likelihood, magnitude and timing is observed to be both increasing and accelerating. Many consequences of global warming once thought to be controversial are now being observed (IPCC 2007). Seemingly small values of warming (1 to 2.5 degree Celsius) are expected to produce net benefits in the short-term in some regions and for some activities (e.g. agricultural and transportation) and net costs for others. However, greater warming in the long run would produce net costs in all regions and affect increasing numbers of people. Moreover, the poorest countries and population groups will bear the brunt of changes related to climate change; attention to adaptation strategies will be critical for these countries. Attention to demographic factors, including fertility rates, population growth rates, urbanization and encroachment of populations into ecologically marginal areas, will strengthen understanding of vulnerability and approaches to adaptation.

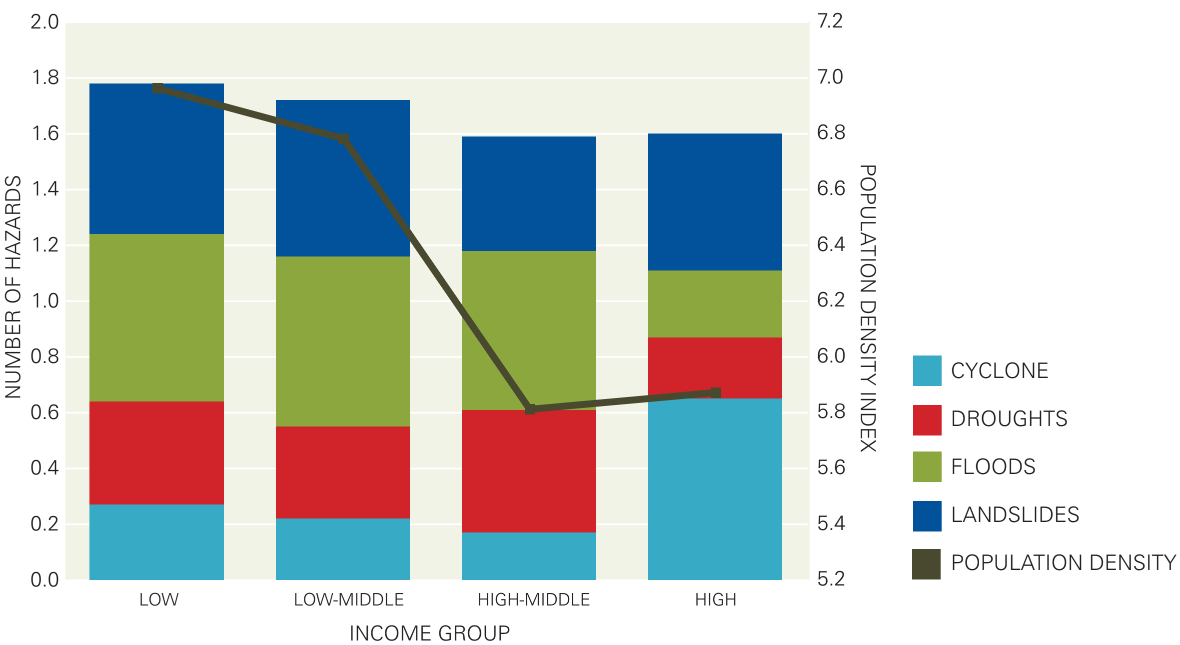
UNEVENLY DISTRIBUTED EFFECTS OF CLIMATE CHANGE

While the whole world is being increasingly affected by global warming, the impact of climate change on the human population is not evenly distributed across regions. Spatial analysis of the current hotspots of climate-related hazards (cyclones, droughts, floods, and landslides) shows that those hazards largely concentrate in certain areas, leaving the rest of the world relatively risk-free (Figure 5).[5] The poor are at significantly higher risk of most climate-related hazards. Spatial analysis of hazard distribution indicates that low income populations have been affected by more types of climate-related hazards than those of high or middle-high income populations (Figure 6). While poor people are more likely affected by droughts, floods and landslides, the prevailing hazards for the rich are cyclones. Moreover, future climate change will continuously and increasingly hit poor and vulnerable populations the hardest. **It is projected that those living in sub-Saharan Africa and South Asia will suffer the most, while some people living in high latitudes will not have any impacts or even benefit from climate change for at least some time (IPCC 2007).**

This analysis also shows that areas of low income or **low-middle income have significantly higher population densities** than those in high or middle-high income areas (Figure 6). In 2005, the average population density in developing countries was 66 people/km2, which is more than double the figure in developed regions (27 people/km2). Under high population pressure, a large share of the population in the developing world is already living in marginalized areas, which are susceptible to climate variation and extreme weather events. For instance, around **one-sixth of the world's population is living in arid**

Moreover, the poorest countries and population groups will bear the brunt of changes related to climate change; attention to adaptation strategies will be critical for these countries.

Figure 6. Climate-related hazards and population density by income level



Note: (1) The unit of analysis is a grid cell with the world divided into a 2.8 x 2.8 grid. (2) Income level is derived based on per capita GDP of each grid and grouped into income quartile. A low income area could be in a relatively rich country, while a high income area could be in a relatively poor country. (3) 'Number of hazards' is based on the proportion of areas of each income group suffering from each type of hazard. The sum of proportions of all four types of hazards indicates the average number of hazards suffered by people by income level. (4) Each grid is assigned a group value for population density, according to its population density, from 1 (the lowest density) to 10 (the highest density). 'Population density index' is the average population density group value of all the grids in each income group.

Source: Center for Hazards and Risk Research (CHRR), Center for International Earth Science Information (CIESIN), and International Bank for Recontruction and Development/The World Bank 2005 "Global Multihazard Frequency and Distribution." CHRR, Columbia University.

Coupled with high fertility rates and rapid population growth rates that outpace the ability of countries to provide services including schooling, employment opportunities, and infrastructure, poor people are becoming even more vulnerable to changes in climate. Future global warming will exacerbate their vulnerability.

and semi-arid regions; more than 250 million people are directly affected by desertification, while another one billion are at risk (World Bank 1999). The world's major arid regions are in the developing world, where the population growth rate is high, and socio-development levels are low (UNDP 1999).

Poor and vulnerable populations are those living in places exposed to climate risks, heavily dependent on climate for survival, and who have fewer resources to cope with the adverse impacts of climate change. Coupled with high fertility rates and rapid population growth rates that outpace the ability of countries to provide services including schooling, employment opportunities, and infrastructure, poor people are becoming even more vulnerable to changes in climate. Future global warming will exacerbate their vulnerability. For example, 70 percent of the African population relies on rain-fed agriculture for their livelihoods, and a slight shift in rainfall patterns or temperature can be disastrous (Pinstrup-Aderesen 2002). A 1° C temperature rise may not seem much to Europeans, who enjoy relatively abundant water resources, and can easily adapt to the changes through import or preventive agricultural or bioengineering projects. However, few African countries have the resources to prepare for climate change, and **the effect of a 1° C temperature rise can mean significantly lower food production and increasing poverty, and increased felling of trees to make charcoal, leading to soil loss and further desertification**. Generational subdividing of increasingly small agricultural plots among large numbers of children drives already vulnerable populations into increasingly marginalized land. **Agricultural production loss in rural areas of the least developed countries, combined with rapid population growth, results in an increasing flow of rural migrants into urban areas of coastal areas,** which are largely flood-prone low elevation zones. This movement from rural areas will put a growing number of urban populations at risk (McGranahan 2007). The populations of **many countries in Africa will double within the next 40 years, and some countries with chronic food insecurity, including Ethiopia, will double in closer to 25 years** (Worku 2007; UNPD 2007). Countries that cannot cope with current population sizes will be severely strained to cope in such a short time span with populations double their current size.

Even relatively small differences in projected population growth trends—such as the upward adjustment of 300 million in the most recent medium population projections for 2050 (discussed in more detail below)—are significant when it becomes clear that the majority of the projected population growth is likely to occur in areas of the world that are already beginning to experience climate change impacts, and that the growth is likely to be concentrated among population groups—poor, urban, and coastal—that are already highly vulnerable to climate change impacts.

MAJOR ADVERSE EFFECTS OF GLOBAL WARMING ON PEOPLE

The five major adverse effects of global warming on population include heat waves, water stress, sea-level rise and extreme weather, agricultural production loss and spreading vectors of various diseases.

1 **Heat waves:** The most direct effect of climate change on humans is likely to be the impacts of higher temperatures. Researchers report that, with 90% confidence, past human influence on

climate was responsible for at least half the risk of heat waves (Stott, Stone and Allen 2004). Rising temperatures could lead to increases in cardiovascular disease. Hotter temperatures increase the concentration of ozone at ground level which damages lung tissues and adversely affects people with asthma and other lung diseases (McMichael et al. 2003). Additionally, heat waves may contribute to increased mortality. For example, the European heat wave of 2003 caused 22,080–44,000 excess deaths (Kosatsky 2005; Schar and Jendritzky 2004). Rising temperatures in winter may reduce death from cold in Europe (Keatinge et al. 2000; Kovats 2008; Palutikof, Subak and Agnew 1997). At the same time, twice as many people die from heat as from cold each year in the United States (US-EPA http://www.epa.gov/climatechange/effects/health.html).

2 **Water stress:** Changes in temperature have substantial impacts on precipitation patterns. In the past century, although annual precipitation has increased in large areas of the Northern Hemisphere, it has noticeably declined in subtropical southern Asia, and particularly sub-Saharan Africa.

Five billion people—more than half of the world's population—are expected to live in water-stressed countries by 2050 even without factoring in climate change (World Resource Institute 2000; Military Advisory Board 2007). Anticipated changes in climate will exacerbate the problem of water shortages in those areas. Moreover, the retreat of glaciers due to global warming has both direct impacts including landslides, flash floods and glacial lake overflow, and also indirect effects such as increases in the annual variation of water flows in rivers. With more than one-sixth of the global population relying on glaciers and melting of seasonal snow packs for their water supply, the consequences of these hydrological changes for future water availability are likely to be severe (Barnett, Adam and Lettenmaier 2005).

By the end of the century, an estimated 40 percent of the world's population could be affected by loss of snow and glaciers in the mountains of Asia (UNEP 2007). Of particular importance are the Hindu Kush and Himalayan glacial melts which comprise the principal dry-season water source of many of the major rivers of Central, South, East and Southeast Asia. According to the UN climate report, the Himalayan glaciers could disappear in 50 years due to global warming. During these decades, approximately 2.4 billion people living in the drainage basin of the Himalayan rivers in India, China, Pakistan, Bangladesh, Nepal and Myanmar could experience floods followed by droughts (UNEP 2007).

3 **Sea-level rise and extreme weather:** Melting of glaciers and ice sheets and thermal expansion due to global warming has caused sea-level rise. Since 1900, the sea-level has risen at an average 1.7 mm/year; since 1993, the annual rising rate has increased to about 3 mm. Future global warming means sea-level rise projections in the IPCC's SRES ranges from 22 centimeters to 38 centimeters between 1990 and the 2080s, at about 4 mm/year (Bindoff et al. 2007). Far faster sea-level rise (more than a meter per century) could result from accelerated melting of the Greenland ice sheet and the collapse of the West Antarctic ice sheet, which is not well accounted for in the IPCC analyses and projections (Hansen et al. 2007). Partial loss of ice sheets on

Generational subdividing of increasingly small agricultural plots among large numbers of children drives already vulnerable populations into increasingly marginalized land.

fertility rates in the least developed countries remain much higher than in Europe and, more recently, East Asia. The annual reduction in the total fertility rate (TFR) in the regions with the highest population growth rate.

polar land could imply meters of sea-level rise, causing major changes in coastlines and inundation of low-lying areas, with the greatest effects in river deltas and low-lying lands. Such changes are projected to occur over millennia, but more rapid sea-level rise on century time scales cannot be excluded (Nicholls et al. 2007). Sea-level rise is also projected to increase salt-water intrusion into groundwater and cause other environmental damage in low elevation coastal zones (LECZ) (Vellinga 1989).

Moreover, global warming is also responsible for increasing natural disasters caused by extreme weather such as tropical storms and Atlantic hurricanes. Although it is not conclusive yet as to whether global warming can be blamed for the increase in the frequencies of these extreme weather events, it is much more evident that high CO_2 concentration and warmer sea surface temperatures contribute to more intensive cyclones (Emanuel 2005; Emanuel 2008; Hoyos et al. 2006; Knutson 2008; Knutson 2004; Kovats 2008; Pearce 2005). Future warming will lead to an upward trend in destructive tropical cyclones and tidal waves, particularly in the low elevation coastal zone.

The impact of extreme weather and sea-level rise is particularly significant due to the concentration of population and economic activities on and near coastlines. Human settlement has long been drawn to coastal areas, which provide many resources and trading opportunities but also expose residents to various hazards (Pielke et al. 2008). Overall, the low elevation coastal zone covers two percent of the world's land area, but contains 10 percent of global population. Moreover, least developed countries have a higher share of population (14%), particularly urban population (21%), living in coastal zones, compared to developed countries which have only 10 percent of their total population and 11 percent of their urban population living in coastal areas (McGranahan, Balk and Anderson 2007). Taking into account an increasing coastal population, sea-level rise and extreme weather will affect an estimated 20 percent of the population in developing countries and lead to a substantial increase in economic losses in the 21st century (McGranahan, Balk and Anderson 2007). Nicholls (2004) has estimated that in the absence of any other changes, a sea-level rise of 38 cm would increase by five-fold the number of people flooded by storm surges.

4 Agricultural production loss: Temperature increases and increases in atmospheric CO_2 levels may enhance agricultural productivity in mid- and high latitudes, but will surely hurt agriculture in the tropics and subtropics, where crops already exist at the top of their temperature range (IPCC 2007). While global agricultural production appears stable, regional differences in crop production are likely to grow over time and lead to a significant polarization effect, with continuous crop production increase in developed countries but decrease in the developing world. Under all of the IPCC SRES scenarios, if climate change effects dominate, world crop yields are likely to be more negatively affected (9% to 22% reduction by 2080 relative to current crop production level) (Parry et al. 2004). Under the UN medium population projection, with substantial agricultural production loss and an increase in the prices of crops due to climate changes, an additional 90 to more than 125 million people by 2080 in the poor nations will be at risk of hunger (Parry, Rosenzweig and Livermore 2005).

5 **Spreading vector-borne diseases:** Global warming may extend the zones that are favorable for vectors conveying infectious disease such as malaria and dengue fever (Reiter et al. 2004; Rogers and Randolph 2000; Simon et al. 2002). In the richer countries the consequences may be felt more in economic than health terms, due to disease control measures such as vaccination, draining swamps and pesticide use. However, spreading vectors may lead to higher incidence of these diseases in less developed nations. The World Health Organization, using standardized methods to quantify global and regional health consequences of climate change, indicates that in 2000, globally 154,000 deaths (or 0.3% of total deaths) and 5.5 million disability-adjusted life years (DALYs) (or 0.5% of all DALYs) lost are attributed to climate changes (McMichael et al. 2003; McMichael et al. 2004). Compared to the numbers in 2000, future health impacts attributed to climate change (DALYs and deaths due to malnutrition, diarrhea, malaria, and floods) are projected to approximately double by 2020. The number of deaths due to climate change by 2030 will increase 3 percent for diarrhea diseases, 5 percent for malaria diseases, and 10 percent for malnutrition (Campbell-Lendrum et al. 2005).

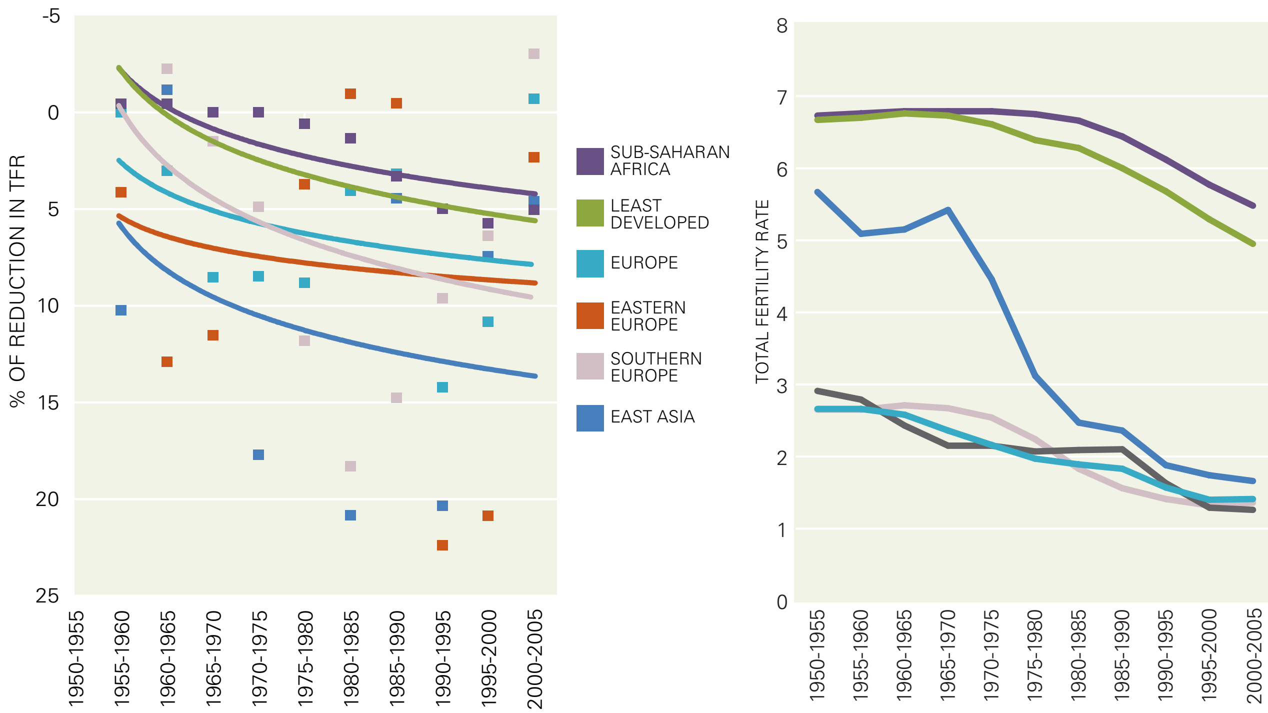
ANTICIPATED POPULATION GROWTH PUTS AN INCREASING NUMBER OF PEOPLE AT RISK IN MUCH OF THE DEVELOPING WORLD

Traditionally, demographers assume that all countries of the world, after completing the process of demographic transition, will converge demographically. This vision is typically reflected in the long-held United Nations population projections (UNPD 2007), in which all countries of the world are assumed to converge to replacement level fertility of 2.1 children per woman and even to the same low level of mortality.

As a result, demographic differentials around the world are supposed to disappear. In reality, however, demographic trends in the past decades have shown little convergence, and anticipated population growth will not help to reduce the degree of uneven population distribution across developed and less developed regions in coming decades.

During the past five decades, all regions of the world have experienced fertility decline, although as the panel on the right in Figure 7 shows, fertility rates in the least developed countries remain much higher than in Europe and, more recently, East Asia. The annual reduction in the total fertility rate (TFR) in the regions with the highest population growth rate (i.e. the least developed regions, particularly sub-Saharan Africa) is considerably slower than the regions with the lowest fertility in Europe (particularly Eastern and Southern Europe), and East Asia (left panel in Figure 7). Demographic trends show that we are living in an increasingly demographically divergent world (Dorius 2008; Kent 2005, Bloom, Canning and Sevilla 2008), in which the gaps between high and low fertility regions are enlarged. While some European countries have already experienced population decline,

Figure 7. Uneven fertility changes across regions



Note: The chart on the left is a scatter plot of the percentage of TFR reduction of each period and the trend lines for each region.

Data source: derived from the UN Population Division databank.

population in the less developed regions continues to grow.

Continuously high fertility levels in the least developed countries will cause further rapid population growth in those regions, where people do not have adequate resources and are therefore at high risk of the adverse effect of climate changes.

IMPLICATIONS OF POLICY RESPONSES FOR POPULATION PROJECTIONS

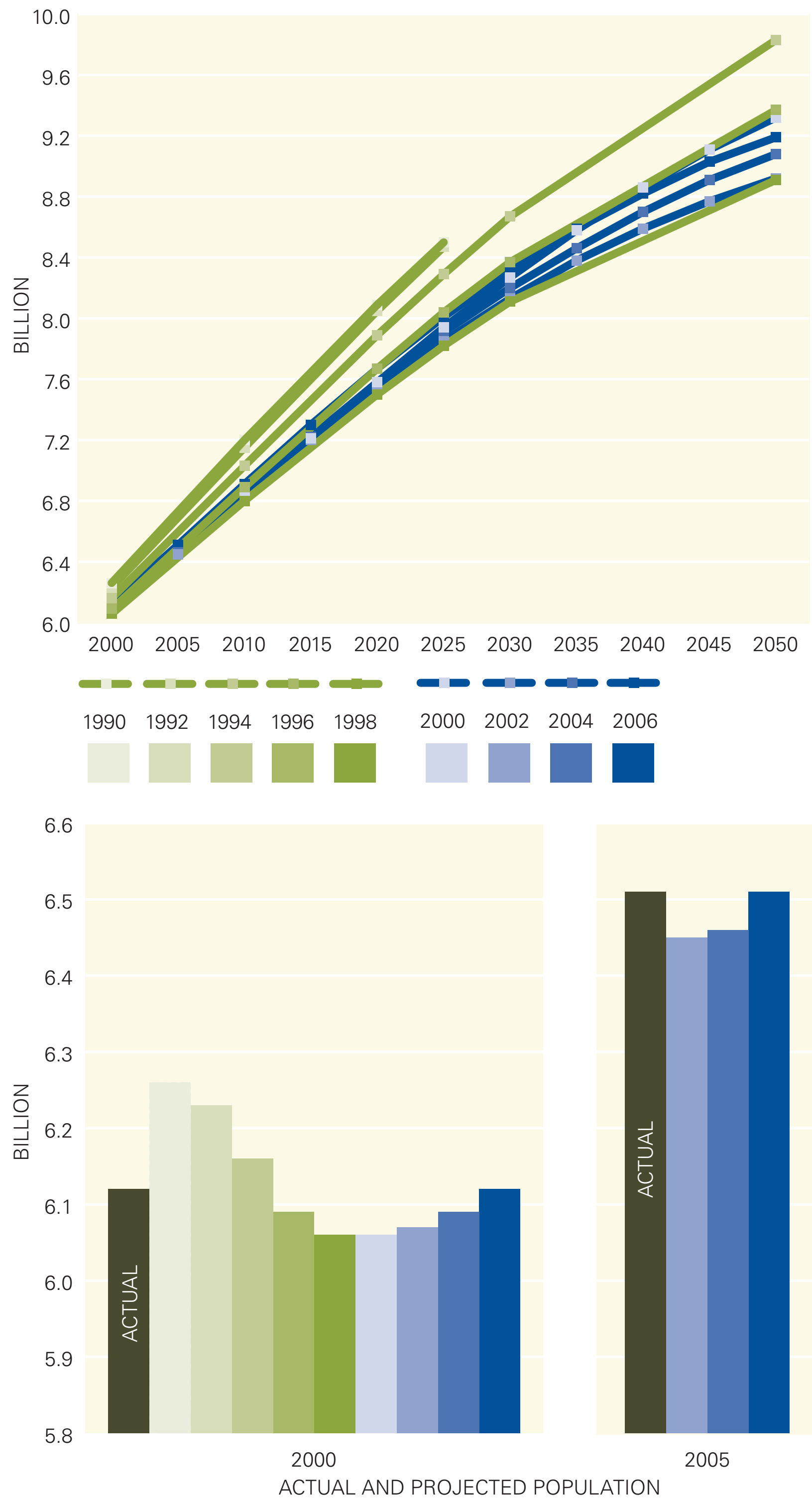
Given that population and a range of demographic factors are important to both mitigation and adaptation to climate change, how important are population policies? An analysis of the practices of population projections conducted by the UN Population Division over the last half century is instructive in showing the effects of policy attention to demographic trends.

In the 1960s, world attention to rapid population growth resulted in international efforts to promote smaller family size through the use of voluntary family planning and other development efforts. More recently, attention once paid to demographic trends and resources allocated for family planning have both waned, and the effects of these fluctuations in policy attention are borne out in the UN population projections.

Since 1950, the UN Population Division has undertaken 20 runs of population projection/estimates, which assess the changes in population size, age and sex composition for both the world and individual countries/regions. During the 1970s and 1980s, all UN population projection revisions were systematically and considerably over-predicting global population growth. The over-projection was due to the fact that rapid fertility decline in the developing world, largely driven by effective family planning and reproductive health programs since the 1960s,[6] was unexpected and unaccounted for by the population forecasters. With an increased understanding of the extent of fertility decline in the past decades, the UN Population Division adjusted downward its medium population projection for 2000 from 6.26 billion in the 1990 Revision to 6.06 billion in the 1998 Revision; similarly, the medium population projection for 2050 was also adjusted downward from 9.8 billion in the 1994 Revision to 8.9 billion in the 1998 Revision (Figure 8).

These adjustments were based primarily on the assumption that the expansion of contraception and family planning services in developing nations from the 1960s to the 1980s would continue to drive fertility levels down further (Lutz et al. 2007). **These assumptions did not hold true**. The most recent worldwide population censuses and surveys reveal that the actual population sizes of the world in 2000 and 2005 were significantly higher than what was predicted in the UN medium population projection in the late 1990s and the early part of this century (the small chart in Figure 8), **largely due to a decline in attention to family planning and reproductive health programs and services in the recent decade**[7] (Cleland and Bernstein 2006; Speidel and Grossman 2007). Acknowledging the stagnant fertility in regions of high population growth, including Africa, the Middle East, South Asia, and the Caribbean (Bongaarts 2008), the UN gradually adjusted upward the medium population for 2050 in the most recent projections, from 8.9 billion in the 1998 Revision to 9.2 billion in the 2006 Revision.

Figure 8. UN Medium Population Projections since 1990



Source: United Nations, World Population Prospects (various issues), Population Division, Department of Economic and Social Affairs, New York

Family planning and reproductive health could help least developed and developing countries to speed up their demographic transition, enabling them to achieve demographic windows of opportunity which may contribute to rapid economic growth

One may argue that the differences between a population size of 8.9 billion and 9.2 billion over a period of 50 years is not significant at a global level. **Indeed, it would not make much difference if the extra population growth would be evenly allocated across regions. However, as above-mentioned, the global picture of relatively stable population growth hides very important regional shifts**: the rapid population growth in sub-Saharan Africa was largely offset by the much lower population growth rate than previously anticipated in Eastern Europe and China. Under the UN medium population projection, without immigrants from developing countries, the population of the more developed regions is expected to decline by 2.3 million annually after 2010. In contrast, the population of the 50 least developed countries will likely more than double (passing from 0.8 billion in 2007 to 1.7 billion in 2050), while growth in the rest of the developing world is also projected to be robust (rising from 4.6 billion to 6.2 billion in the same period) (UNPD 2007).

Changes in policy attention to population stabilization, along with weakened health care and family planning services in the past decades, have resulted in substantial changes in our vision of the demographic future. Family planning and reproductive health, delivered according to the international consensus forged at the International Conference on Population and Development (ICPD) in 1994 in Cairo (UNFPA 2008), have significant implications for future population dynamics, particularly for the global poor who already have higher population density, and are susceptible to or unable to cope with the adverse impacts of climate change. Family planning and reproductive health could help least developed and developing countries to speed up their demographic transition, enabling them to achieve demographic windows of opportunity which may contribute to rapid economic growth—a phenomenon observed in East Asia and other parts of the world (Ross 2004). More than 120 million women say they would prefer to avoid a pregnancy, but are not using any form of contraception (Singh et al. 2003). If women who rely on traditional methods of family planning are included in the estimate of unmet need, the figure rises to 201 million women. In sub-Saharan Africa, one in four married women have an unmet need for contraception (Sedge et al. 2007).

In addition to family planning and reproductive health services, the ICPD Programme of Action also called for implementing a range of programming, including promoting gender equity, to facilitate the demographic transition as soon as possible in countries where there is an imbalance between demographic growth rates and social, economic and environmental goals, while respecting human rights. Slowing population growth could help slow the growth of greenhouse gas emissions, and could help countries buy time to promote education, advance technological progress, achieve rapid economic growth, and increase their resilience and capacity to adapt to climate change and to meet the Millennium Development Goals (USAID Health Policy Initiatives, 2006).

SUMMARY

Strong evidence exists showing that demographic change is closely associated with greenhouse gas emissions, and that population dynamics will play a key role in attempts to mitigate and adapt to the effects of changes in the climate system in the future. It is clear that analyzing the compositional change of populations, specifically the age composition, the distribution of people in urban and rural areas, and household size and composition, is very important for understanding future needs and potential for mitigating carbon emissions and climate change. The analysis presented in this paper shows that by including only population size as the demographic variable in climate models, the contribution of "population" to climate change has been underestimated.

Similarly, understanding demographic trends, including fertility, population growth, urbanization, migration from environmentally depleted areas, and growing population density in marginal and vulnerable areas, is also crucial for the world to adapt to and cope with the adverse impacts of current and projected climate change.

Sir Nicholas Stern (2006) states that climate change threatens to cause the greatest and widest ranging market failure ever seen. He warns that one percent of global GDP must be invested in order to mitigate climate change, and that failure to do so could risk a recession worth up to 20 percent of global GDP. Moreover, the adverse effects of climate change cannot be bound within any administrative boundaries. Climate change poses a grave challenge for the whole world and has wide ranging implications for human well-being as well as for security (Campell 2007; Military Advisory Board 2007), including the risk of armed conflict over resources and large-scale migrations of population within nations and across national borders. The IPCC estimates that 150 million environmental refugees will exist in 2050, due mainly to the effects of coastal flooding, shoreline erosion and agricultural disruption (McCarthy et al. 2001).

A range of development policies are urgently needed to address this situation, including renewed commitment to meeting the globally agreed Millennium Development Goals (MDGs). Investments in family planning and reproductive health, girls education, economic opportunities and empowering of women, and in youth could help least developed and developing countries to speed up their demographic transition, enabling them to achieve demographic windows of opportunity which may contribute to economic growth and a greater capacity to cope with climate change impacts. Population dynamics should not continue to be ignored in climate change adaptation strategies, and effective measures must meet the needs of the world's most vulnerable citizens, including the needs of women.

Combating climate change calls for the spirit of environmental stewardship and international cooperation on a range of emissions reduction and adaptation approaches. These approaches will benefit from greater attention to population dynamics, including growth, household structure, urbanization and aging. Population policies and programs that promote universal access to voluntary contraception, when linked with broader efforts to address a range of demographic factors and meet development and poverty reduction objectives, such as the MDGs, will help lead to a more sustainable demographic future that will play a crucial role in climate change mitigation and adaptation.

ENDNOTES

1 While it improves energy efficiency, rapid technological change under the A1 scenario encourages higher energy consumption, along with rapid economic growth. As a result, carbon emissions in A1 are the highest among the four scenarios for much of the 21st century, and will not change until further, substantial technological advancement late in the century drives emissions downward.

2 B1 includes the least fossil fuel combustion, a high proportion of renewable energy use, and the most rapid improvement in land use changes.

3 Million tons of oil equivalent

4 Gigaton of carbon

5 Data used in this analysis is 'Global Multihazard Frequency and Distribution' developed by Columbia University Center for Hazards and Risk Research (CHRR), International Bank for Reconstruction and Development/The World Bank, and Columbia University Center for International Earth Science Information Network (CIESIN). It is a 2.5 by 2.5 minute grid presenting a simple multihazard index solely on summated single-hazard decile values. This dataset also includes variables of population, gross domestic product (GDP) and transportation infrastructure.

6 Family planning programs were responsible for at least 40% of the fertility decline in developing countries from the 1960s through the end of 1980s (Vlassoff, 2004).

7 A less significant factor contributing to higher population growth than that previously projected in sub-Saharan Africa is because of the downward revision of HIV/AIDs prevalence in many African countries, thanks to the aggressive

REFERENCES

Barnett, T.P., J.C. Adam, and D.P. Lettenmaier. 2005. "Potential impacts of a warming climate on water availability in snow-dominated regions." *Nature* 438:303-309.

Bindoff, N.L., J. Willegrand, V. Artale, A. Cazenave, S. Gregory, K. Hanawa, C. Le Quere, S. Levitus, Y. Nojiri, C.K. Shum, L.D. Talley, and A. Unnikrishnan. 2007. "Observations: Oceanic climate change and sea level." *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller. Cambridge, UK: Cambridge University Press.

Bloom, David E., David Canning and Jaypee Sevilla. 2008. *The Demographic Dividend. A New Perspective on the Economic Consequences of Population Change.* Santa Monica, CA: RAND.

Bongaarts, J. 2008. "Fertility Transitions in Developing Countries: Progress or Stagnation?" *Studies in Family Planning.* 39(2): 105-110

Campbell-Lendrum, Diarmid, Sari Kovats, A.J. McMichael, C.F. Corvalan, B. Menne, and A. Pruss-Ustun. 2005. "The Global Burden of Disease due to climate change: quantifying the benefits of stabilization for human health." *Avoiding Dangerous Climate Change.* Met Office, Exter, UK.

Campell, K. M., Jay Gulledge, J.R. McNeill, J. Podesta, Peter Ogden, L. Fuerth, R. J. Woosley, A.T.J. Lennon, J. Smith, R. Weitz, and D. Mix. 2007. "The Age of Consequences: The Foreign Policy and National Security Implications of Global Climate Change." Center for Strategic and International Studies, and Center for New American Security.

Cleland, J and S Bernstein. 2006. "Family Planning: The Unfinished Agenda." *The Lancet.* 368(9549): 1810-1827.

Clark, William A.V., and Marinus C. Deurloo. 2006. "Aging in place and housing over-consumption." *J Housing Built Environment* 21:257-270.

Cole, Matthew A., and Eric Neumayer. 2004. "Examing the impacts of demographic factors on air pollution." *Population and Environment* 26:5-21.

Cramer, James C. 1998. "Population Growth and Air Quality in California." *Demography* 35:45-56.

Dalton, Michael, Leiwen Jiang, Shonali Pachauri, and B.C. O'Neill. 2007. "Demographic change and future carbon emissions in China and India." *Population Association of America.* New York.

Dalton, Michael, Brian C. O'Neill, Alexia Prskawetz, Leiwen Jiang, and John Pitkin. 2008. "Population aging and future carbon emissions in the United States." *Energy Economics* 30:642-675.

Dietz, T., and E. A. Rosa. 1997. "Effects of population and affluence on CO2 emissions." *Proceedings of the National Academy of Sciences of the USA* 94:175-179.

Dietz, Thomas, Eugene A Rosa, and Richard Yok. 2007. "Driving the human ecological footprint." *Front Ecol Environ* 5:13-18.

Dorius, Shawn F. 2008. "Global demographic convergence? A reconsideration of changing intercountry inequality in fertility." *Population and Development Review* 34:519-537.

Emanuel, Kerry. 2005. "Increasing destructiveness of tropical cyclones over the past 30 years." *Nature* 435:686-688.

—. 2008. "Hurricanes and global warming: results from downscaling IPCC AR4 simulations." *Bulletin of the American Meteorological Society* 89:347-367.

Emanuel, Kerry. 2008. "Hurricanes and global warming: results from downscaling IPCC AR4 simulations." *Bulletin of the American Meteorological Society* 89:347-367.

Ehrlich, P. and J. Holdren. 1971. "Impact of population growth." *Science* 17:1212-17.

Hansen, James, Makiko Sato, Pushker Kharecha, Gary Russell, David W. Lea, and Mark Siddall. 2007. "Climate change and trace gases." *Philosophical Transactions of The Royal Society* 365:1925-1954.

Hoepf Young,, Malea, Kathleen Mogelgaard and Karen Hardee. 2009. Projecting Population, Projecting Climate Change: Population in IPCC Scenarios." *PAI Working Paper.* Forthcoming.

Houghton, J.T., B.A. Callander, and S.K. Varney (Eds.). 1992.

Climate Change 1992: The IPCC Supplementary Report. Cambridge, UK: Cambridge University Press.

Hoyos, C.D., P.A. Agudelo, P.J. Webster, and A.J. Curry. 2006. "Deconvolution of the factors contributing to the increase in global hurricane intensity." *Science* 312:94-97.

IPCC. 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

Jiang, Leiwen. 1999. *Population and Sustainable Development in China.* Amsterdam: Thela Thesis.

Jiang, Leiwen, and B.C. O'Neill. 2007. "Impacts of demographic trend on US household size and structure." *Population and Development Review* 33:429-656.

Jiang, Leiwen, and Brian C. O'Neill. 2004. "The energy transition in rural China." *International Journal of Global Energy Issues* 21:2-26.

Jones, Donald W. 1989. "Urbanization and energy use in economic development." *The Energy Journal* 10:29-44.

Keatinge, W.R., G.C. Donaldson, E. Cordioli, M. Martinelli, A.E. Kunst, J.P. Mackenbach, S. Nayha, and I. Vuori. 2000. "Heat related mortality in warm and cold regions of Europe: observational study." *British Medical Journal* 321:670-673.

Kent, Mary M., and Carl Haub. 2005. "Global Demographic Divide." *Population Bulletin.* Washington D.C.: Population Reference Bureau.

Knutson, Thomas R. 2008. "Simulated reduction in Atlantic hurricane frequency under twenty-first-century warming conditions." *Nature Geoscience* 3:359-364.

Knutson, Thomas R., and Robert Tuleya, E. 2004. "Impacts of CO2-induced warming on simulated hurrican intensity and precipitation: sensitivity to the choice of climate model and convective parameterization." *Journal of Climate* 17:3477-3495.

Kovats, Sari (Ed.). 2008. *Health Effects of Climate change in the UK 2008: an update of the Department of Health report 2001/2002.* Department of Health and Health Protection Agency.

Liu, Jianguo, G. C. Daily, P. Ehrlich, and G. W. Luck. 2003. "Effects of household dynamics on resource consumption and biodiversity." *Nature* 421:530-533.

Lutz, W., W. Sanderson and S. Scherbov. 2007. 'IIASA's 2007 Probabilistic World Population Projections', IIASA World Population Program. http://www.iiasa.ac.at/Research/POP/proj07/index.html?sb=5. Accessed 1/20/09.

Lutz, Wolfgang, Warren Sanderson, and Sergei Scherbov. 2001. "The end of world population growth." *Nature* 412:543-545.

Mackellar, F. Landis, Wolfgang Lutz, Christopher Prinz, and Anne Goujon. 1995. "Population, households and CO2 emission." *Population and Development Review* 21:849-765.

McCarthy, J., O. Canziani, N. Leary, and K. White. 2001. *Climate Change 2001: Impacts, Adaptation and Vulnerability.* Geneva: Intergovernmental Panel on Climate Change.

McGranahan, Gordon, Deborah Balk, and Bridget Anderson. 2007. "The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones." *Environment and Urbanization* 19:17-37.

McMichael, A.J., Diarmid Campbell-Lendrum, C.F. Corvalan, K.L. Ebi, A. Githeko, J.D. Scheraga, and A. Woodward. 2003. "Climate Change and Human Health - Risk and Responses." Geneva: World Health Organization.

McMichael, A.J., Diarmid Campbell-Lendrum, Sari Kovats, Sally Edwards, Paul Wilkinson, Theresa Wilson, Robert J. Nicholls, Simon Hales, Frank Tanser, David Le Sueur, Michael Schlesinge, and Natasha Andronova. 2004. "Chapter 20: Global Climate Change." Pp. 1543-1649 *Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors,* edited by M. Ezzati, A. Lopez, A. Rogers, and C. Mathers. Geneva: WHO.

Meyerson, F.A.B.. 1998. "Population, development and global warming: averting the tragedy of the climate commons." *Population and Environment* 19:443-463.

Military Advisory Board. 2007. "National Security and the Threat of Climate Change." The CNA Corperation.

Naki´cenovi´c et al, N 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.

Naki´cenovi´c, N., B. Fisher, K. Alfsen, J. Corfee Morlot, F. de la Chesnaye, J.-C. Hourcade, K. Jiang, M. Kainuma, E.L. La Rovere, A. Rana, K. Riahi, R. Richels, D.P. vanVuuren, and R. Warren. 2007. "Issues related to mitigation in the long-term context." *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* edited by B. Meta, O. Davidson, P. Bosch, R. Dave, and L. Meyer. Cambridge, UK: Cambridge University Press.

Nicholls, Robert J. 2004. "Coastal flooding and wetland loss in the 21st century: changes under the SRES climate and socio-economic scenarios." *Global Environmental Change* 14:69-86.

Nicholls, Robert J., P.P. Wong, V.R. Burkett, J.O. Codignotto, J.E. Hay, R.F. McLean, S. Ragoonaden, and C.D. Woodroffe. 2007. "Coastal systems and low lying areas." *Climate Change 2007: Impacts, Adaptation on Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* edited by M. L. Parry, J. P. Canziani, P. J. Palutikof, Anna-Lisa Linden, and C.E. Hanson. Cambridge, UK: Cambridge University Press.

O'Neill, Brian C.,2009 *Climate Change and Population Growth* in Mazur, L. (ed). Population, Justice and the Environmental Challenge, Island Press. In press.

O'Neill, Brian C., and Belinda S. Chen. 2002. "Demographic determinants of household energy use in the United States." *Population and Development Review* 28.

Pachauri, Shonali. 2004. "An analysis of cross-sectional variation in total household energy requirements in India using micro survey data." *Energy Policy* 32:1732-1735.

Pachauri, Shonali, and Leiwen Jiang. 2008. "The household energy transition in India and China." *Energy Policy* 36:4022-4035.

Palutikof, P. J., S. Subak, and M.D. Agnew (Eds.). 1997. *Economic Impacts of the Hot Summer and Unusally Warm Year of 1995.* Norwich, UK: University of East Anglia.

Parikh, Jyoti, and Vibhooti Shukla. 1995. "Urbanization, energy use and greenhouse effects in economic development - results from a cross-national study of developing countries." *Global Environmental Change* 5:87-103.

Parikh, J.K. and J.P. Painuly. 1994. "Population, consumption patterns and climate change: a socioeconomic perspective from the South." *Ambio* 23: 434-437.

Parry, M. L., C. Rosenzweig, A. Iglesias, M. Livermore, and G. Fischer. 2004. "Effects of climate change on global food production under SRES emissions and socio-economic scenarios." *Global Environmental Change* 14:53-67.

Parry, M. L., C. Rosenzweig, and M. Livermore. 2005. "Climate change, global food supply and risk of hunger." *Philosophical Transactions of The Royal Society (B)* 360:2125-2138.

Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (Eds.). 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press.

Pearce, Fred. 2005. "Warming world blamed for more strong hurricanes." *New Scientist.*

Pielke, Roger A., Joel Gratz, Christopher W. Landsea, Douglas Collins, Mark A. Saunders, and Rade Musulin. 2008. "Normalized Hurricane Damage in the United States: 1900-2005." *Natural Hazards Review* 9:29-42.

Pinstrup-Aderesen, P. 2002. Food and Agricultural Policy for a Globalizing World: Preparing for the Future. *Amer. J. Agr. Econ.*84: 1201-1214. American Agricultural Economists Association

Prskawetz, Alexia, Leiwen Jiang, and Brian C. O'Neill. 2004. "Demographic composition and projections of car use in Austria." *Vienna Yearbook of Population Research* 2004:175-201.

Reiter, P., C. Thomas, P. Atkinson, S. Hay, D. Randolph, D. Rogers, G. Shanks, R. Sonw, and Spielman. 2004. "Global Warming and malaria: a call for accuracy." *The Lancet Infectious Disease* 4:323-324.

Rogers, D., and S. Randolph. 2000. "The global spread of malaria in the future warmer world." *Science* 289:1763-1766.

Rosa, Eugene A., Richard York, and Thomas Dietz. 2004. "Tracking the anthropogenic drivers of ecological impacts." *Ambio: A Journal of the Human Environment* 32:509-512.

Ross, John. 2004. *Understanding the Demographic Dividend.* Washington, DC: Futures Group, POLICY Project.

Schar, Christoph, and Gerd Jendritzky. 2004. "Climate change: hot news from summer 2003." *Nature* 432:559-560.

Sedgh G, R Hussain, A Bankole and S Singh. 2007. "Women with an Unmet Need for Contraception in Developing Countries and Their Reasons for Not Using a Method." *Occasional Report No. 37.* New York: Guttmacher Institute.

Shi, A. 2003. "The impact of population pressure on global carbon dioxide emissions, 1975-1996: Evidence from pooled cross-country data." *Ecological Economics* 44:24-42.

Simon, Hales, Neil de Wet, John Maindonald, and A. Woodward. 2002. "Potential effect of population and climate changes on global distribution of dengue fever: an empirical model." *The Lancet* 360:830-834.

Singh S, JE Darroch, M Vlassoff, J Nadeau. 2003. *Adding It Up: The Benefits of Investing in Sexual and Reproductive Health Care.* Washington, DC: The Allan Guttmacher Institute and UNFPA.

Speidel, J and R Grossman. 2007. "Family Planning and Safe Legal Abortion are Vital to Safeguard the Environment." *Contraception* 76(2007): 415-417

Stern, Nicholas. 2006. "Stern Review executive summary." New Economics Foundation.

Stott, Peter A., D.A. Stone, and M.R. Allen. 2004. "Human contribution to the European heatwave of 2003." *Nature* 432:610-614.

UNDP. 1999. "Human Development Report." New York: United Nations Development
Program.

UNEP. 2007. *Global Outlook for Ice & Snow.* Birkeland, Norway.

UNFPA. 2008. ICPD Programme of Action. http://www.unfpa.org/icpd/docs/index.htm. Accessed 1/2/09.

UNPD. 2007. *World Population Prospects: The 2006 Revision, Highlights.* New York: United Nations, Department of Economic and Social Affairs.

USAID | Health Policy Initiatives. 2006. *Achieving the Millennium Development Goals: The contribution of fulfilling the unmet need for family planning.* Washington, DC: Futures Group: Health Policy Initatives. Written by Scott Moreland and Sandra Talbird.

US-EPA. "Climate Change-Health and Environmental Effects." edited by EPA. Washington, D.C.: EPA. Sept. 5, 2008. http://www.epa.gov/climatechange/effects/health.html.

van Diepen, A. 2000. *Household and their Spatial-Energetic Practices. Searching for Sustainable Urban forms.* Groningen, Utrecht: FRW, RUG/KNAG.

Van Diepen, A. 1994. "Demografische ontwikkelingen en milieugebruik." Pp. 357–374 in *Bevolkingsvraagstukken in Nederland Anno 1994: Demografisch Ontwikkelingen in Maatschappelijk Perspectief,* vol. 35, edited by N. v. N. a. G. Beets. Den Haag: NIDI.

Vellinga, Pier and Stephen P. Leatherman. 1989. "Sea level rise, consequences and policies." *Climatic Change* 15:175-189.

Vlassof, Michael. 2004. "Assessing Costs and Benefits of Sexual and Reproductive Health Interventions." *Occasional Report No, 11.* New York: Guttmacher Institute.

Worku, Mogues. 2007. "The Missing Links: Poverty, Population and the Environment in Ethiopia." *FOCUS on Population, Environment and Security.* Issue No. 14. October.

World Bank. 1999. "World Development Report." Washington, D.C.: World Bank.

World Resources Institute, United Nations Environment Programme, 2000. *Tomorrow's Markets, Global Trends, and Their Implications for Business.* Paris

Yamasaki, Eiji, and Norio Tominaga. 1997. "Evolution of an aging society and effects on residential energy demand." *Energy Policy* 25:903-912.

York, Richard, Eugene A. Rosa, and Thomas Dietz. 2003. "Footprints on the earth: the environmental consequences of modernity." *American Sociological Review* 68:279-300.

Zeng, Yi, Zhenglian Wang, Leiwen Jiang, and Danan Gu. 2008. "Projection of family households and elderly living arrangement in the context of rapid population aging in China - a demographic window of opportunity until 2030 and serious challenges thereafter." *Genus* LXIV (No. 1-2): 9-36.

ACKNOWLEDGMENTS

The authors greatly appreciate review from PAI staff Kathleen Mogelgaard, Malea Hoepf Young, Kimberly Rovin, and Amy Coen. The work greatly benefited from the long collaboration that Leiwen Jiang has had with Brian O'Neill, currently of the National Center for Atmospheric Research and Michael Dalton, currently of the National Oceanic and Atmospheric Administration. The work was made possible through a range of foundation funding to Population Action International.

AUTHORS

Leiwen Jiang is Senior Demographer at Population Action International.
Karen Hardee is Vice President of Research at 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