

Population – Environment Interactions

Popolazione: le interazioni con l'ambiente

Wolfgang Lutz

Abstract With a time horizon of up to 2050, the possible effects of environmental change on the population outlook are typically seen by experts as having only marginal impacts. This may be due to the fact that the international population experts included in the survey were almost exclusively social scientists who rarely deal with environmental issues and consider social and economic factors as the key drivers in their analyses. The slow progression of global climate change, at least on the scale of human measurement, is also a factor in the experts' judgments. Another dampening factor on the rating of environmental change is that even the more dramatic climate change scenarios do not predict significant changes over the next few decades. This paper will address the environmental change issue directly by analyzing the global population and human capital outlook for the rest of this century in a broader context of sustainable development and global environmental change.

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Key words: population, environment change.

Background

The number of people inhabiting the earth has fluctuated significantly over the course of human history, in response to both natural changes in the environment and stresses to local habitats created by the populations themselves. From the first appearance of *Homo sapiens* some 200,000 years ago in Africa until about 35,000 years ago, the world's human population was well under one million, a number that meant the threat of extinction was always looming (Biraben, 2003). Only after the Neolithic Revolution, which introduced agriculture, did the world population

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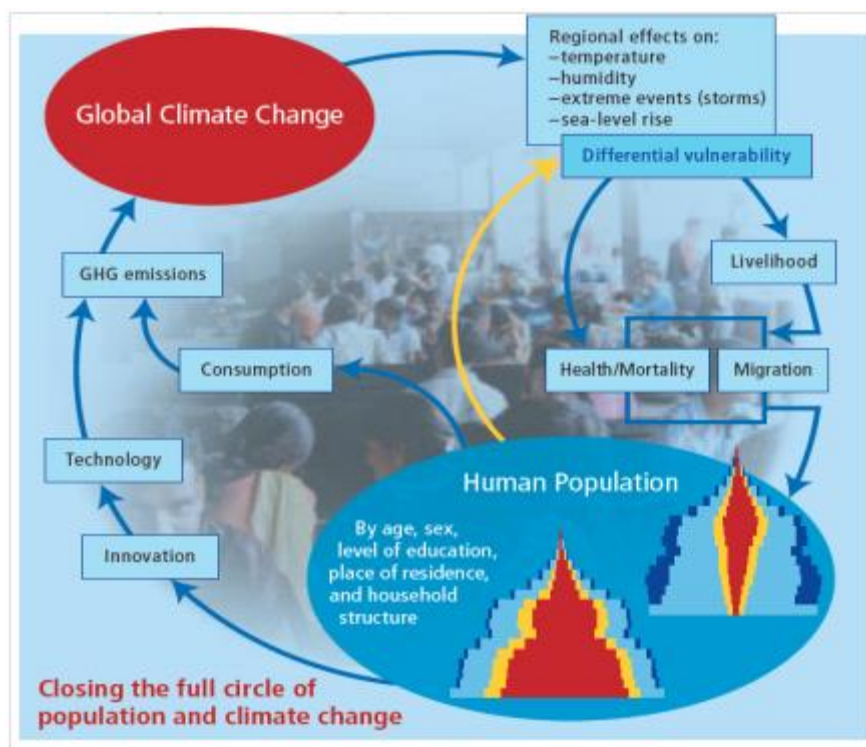
Wolfgang Lutz, Director Vienna Institute of Demography; email: wolfgang.lutz@oeaw.ac.at

increase significantly, surpassing 100 million about 7000 years ago. But it was in the 19th century that population growth began to accelerate in what are now the world's most industrialized countries. This rapid population increase was a consequence of declining death rates due to better nutrition and hygiene, more accessible fresh water supplies, and advances in preventive medicine. Immediately following World War II, death rates began a precipitous fall, due primarily to the development of antibiotics and other medical advances. For several decades following the war, birth rates remained very high (and in some cases increased due to the better health of women) because high fertility norms had been deeply imbedded in most traditional cultures and religions. Such norms tend to change only slowly, and as a consequence, the world population experienced a dramatic increase, from 2.5 billion in 1950 to more than seven billion today.

With a time horizon of up to 2050, the possible effects of environmental change on the population outlook are typically seen by experts as having only marginal impacts. This may be due to the fact that the international population experts included in the survey were almost exclusively social scientists who rarely deal with environmental issues and consider social and economic factors as the key drivers in their analyses. The slow progression of global climate change, at least on the scale of human measurement, is also a factor in the experts' judgments. Another dampening factor on the rating of environmental change is that even the more dramatic climate change scenarios do not predict significant changes over the next few decades. The significant changes in sea level rise and regional temperature and precipitation patterns could potentially have serious implications for future health and migration patterns, but not until the second half of the century and beyond. This chapter will address the environmental change issue directly by analyzing the global population and human capital outlook for the rest of this century in a broader context of sustainable development and global environmental change. In doing so, we will consider both the effects of human population on the natural environment and the vulnerability of human populations to such possible future changes.

Figure 1 depicts how the interactions between population change and climate change can be conceptualized. It shows that the changing size and structure of human populations enter into our concerns about climate change at both the beginning and the end of the causal chain. Humans have been causing the emissions that trigger climate change. In turn, climate change sets in motion forces that can threaten humans' well-being. In the past most research and policy focus has been on mitigating greenhouse gas emissions, but more recently the emphasis has been shifting to strategies for strengthening adaptive capacities for coping with unavoidable climate change. This shift opens important new areas of analysis for demographers. Although efforts to quantify the contribution of population changes to climate change have been outside the realm of demography and have proven difficult, efforts to address adaptive capacity by studying and forecasting differential vulnerability are well-suited to what the powerful demographic toolbox has to offer (Lutz, 2009).

Figure 1: Chart depicting how the human population influences climate change and is in turn affected by the consequences of climate change (Source: Lutz, 2009)



Climate change is of concern principally because it is dangerous to human well-being. The notion of “dangerous” has a specific importance with respect to climate change because the only globally binding agreement, the 1992 Framework Convention on Climate Change, postulates in its core sentence to “avoid dangerous interference with the climate system”. This convention has become the fundamental document supporting every international effort to combat or adapt to climate change. In principle, every assessment of the dangers associated with alternative emissions trajectories would have to anticipate the consequences of the resulting climate change on human well-being. This is impossible in practice because not enough is known about what changes will occur in the bio-physical conditions or how future populations will be able to cope with those changes. The European Union and the Copenhagen Climate Summit have defined a simple, clear goal in mitigating climate change: limiting the warming to not more than 2 °C in global mean temperature. This pragmatic definition of dangerous climate change, however, does not address the role of adaptation in moderating the impacts on human well-being. This path of causation is depicted on the right-hand side of the chart at the bottom of Figure 1.

On the left side of the chart, population is viewed as a driver of the emissions of green house gases (GHG), which is in line with the conventional view: The $I = PAT$ model (Ehrlich and Holdren, 1971) tried to distinguish between the supposedly separate effects of population size (P), consumption associated with affluence (A), and technological efficiency (T). Recent analyses have considered more complex effects and the possibility of interactions such as the model by O'Neill et al (2010), which includes the effects of changing household size, age structure, and urbanization on energy use. The findings show that population ageing and urbanization can have significant effects on total emissions with the magnitudes depending on the specific model definitions. In the same chart, the changing structure of the human population by age, sex, education, place of residence, and household size also appear as drivers of consumption levels.

The right hand side of Figure 1 indicates that the human population is also being affected by climate change. People will likely be exposed to increasing hazards resulting from more frequent and intensive extreme events such as storms, floods, sea-level rise, and changing regional and temporal patterns of temperature and humidity. The temperature and humidity changes are expected to affect agricultural production and the spread of certain diseases. Whether and to what extent these hazards will result in human fatalities depends on the vulnerability of the people affected. That vulnerability is dependent on their strength and resiliency.

Assessment of likely future vulnerability presents the biggest research gap for assessing the dangers associated with climate change and is difficult to conduct. Many published estimates of likely climate-induced fatalities, for instance calculations of additional malaria deaths due to climate change, assume that future climate conditions (e.g. in 2070) will affect populations that will continue into the future with similar socio-economic development and, as a result, have similar public health capabilities as they have today. But we know that societies are not stationary and will almost certainly be quite different from today. In particular, younger generations in almost all countries are on average better educated than the older ones, which will result in improvements in the average education of the future adult population. Economic growth and public health governance will also strengthen resilience. In addition to mortality and morbidity directly inflicted by such hazards, many of the expected consequences of climate change arise from climate-induced threats to traditional livelihoods. "Loss of livelihood" may constitute a push factor for migration or, in the worst case, lead to mortality – both demographic factors that change a population's structure.

But we not only know that societies change over time as a function of changing age, sex, education, and other structures, but we also have a unique tool kit (multi-state cohort component methods) to model and project those changing structures with relatively small uncertainties over several decades. Furthermore, demographers have long studied a wide variety of differentials, particularly differential vulnerability to threats such as infant mortality, adult mortality, morbidity, and disability. We can also study differentials in education and other empowerment factors that enhance the adaptive capacity of individuals, households, and communities.

The SSP Scenarios

The multi-state cohort component approach has substantial potential for studying climate change mitigation and adaptation. Accordingly, the most recent international effort to develop a shared set of socio-economic scenarios included a more detailed population component than previous efforts. For more than a dozen years the Intergovernmental Panel on Climate Change (IPCC) modeling community has used a set of emissions scenarios as defined in Nakicenovic (2000). While these SRES scenarios were very detailed on the energy, technology, and emissions side, they included only total population size and GDP per capita as indicators. Population was only used as a scaling variable.

More recently the climate change research community began development of a new framework for the creation and use of scenarios to improve interdisciplinary analysis and assessment of climate change, its impacts, and response options (O'Neill et al., 2014)

This process, as formulated at an IPCC workshop in 2007, includes a set of forcing pathways, known as the Representative Concentration Pathways (RCPs), to be combined with alternative socioeconomic development pathways (Moss et al., 2010). The development of RCPs has been completed and the pathways documented in a special issue of *Climatic Change* (Vuuren et al., 2011). The development of the socioeconomic scenarios, known as Shared Socioeconomic Pathways (SSPs) was completed in late 2012.

The SSPs were designed to include both a qualitative component in the form of a narrative on global development (see below), and a quantitative component that includes numerical pathways for certain variables (Arnell et al., 2011). Narratives were developed for basic versions of five SSPs, illustrated in Figure 2 with respect to socioeconomic challenges to mitigation and adaptation. This range of the SSPs is broad enough, in principle, to contain a large number of socioeconomic pathways that represent various combinations of challenges to mitigation and adaptation. The SSPs as presented here are single pathways that are representative of the types of socioeconomic pathways that could occupy particular domains within the overall range. The following definitions of the narratives are based on O'Neill (2014). In the following list, we present the overall storyline and then translate this general view of future global trends into specific assumptions for future fertility, mortality, migration, and education trends as they have been developed at IIASA in consultations with the global SSP community (see Table 1 below). Three groups of countries are considered: "High fertility countries" as defined by a Total Fertility Rate of more than 2.9 in 2005-2010; "Low fertility countries" including all countries with a Total Fertility Rate of 2.9 and below that are not included in the third category; "Rich-OECD countries", defined by OECD membership and the World Bank category of high income countries. It is important to note that for this set of general SSPs, countries are assumed to stay in their initial grouping throughout the process. This may be unrealistic for countries that are, for example, in the midst of a fertility decline and may move soon into the low fertility group of countries. Because there are a seemingly infinite number of ways in which countries could

change groupings, it we decided that this should be left to users who want to define their country-specific SSPs.

Although the SSP process and the effort reported in the first eleven chapters of this book were independent processes, they now have been merged in the sense that the Medium Scenario of the above described new populations projections is identical in every respect with the SSP2 as described below. Similarly, the different education scenarios and the high and low fertility, mortality, and migration assumptions used in the SSP scenarios are directly derived from the analysis presented in this book. In this way the SSP community can benefit from the scientific effort that produced this new set of projections.

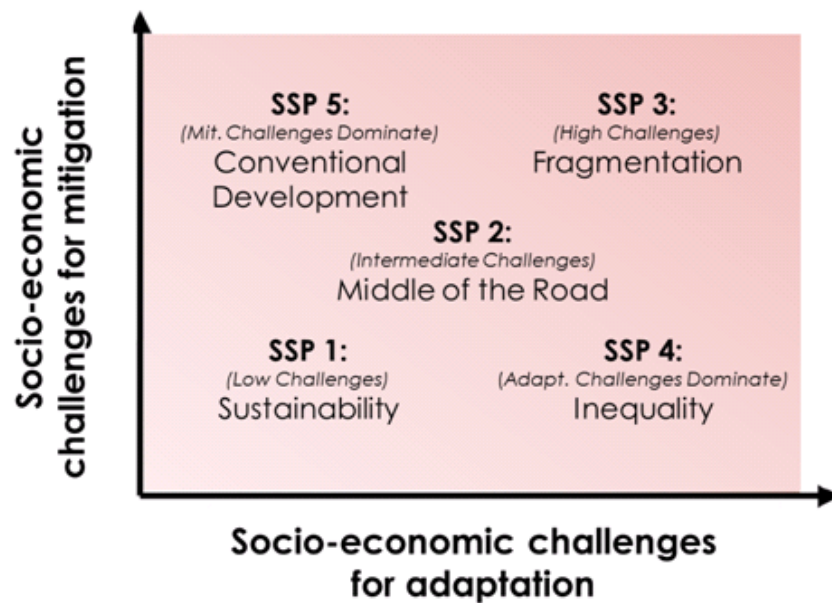


Figure 2: Location of five SSPs in space spanned by differing degrees of socio-economic challenges for adaptation and mitigation.

1.1 *SSP 1: Sustainability*

This world is making relatively good progress toward sustainability, with ongoing efforts to achieve development goals while reducing resource intensity and fossil fuel dependency. Elements that contribute to this progress are a rapid development of low-income countries, a reduction of inequality (globally and within economies), rapid technology development, and a high level of awareness regarding environmental degradation. Rapid economic growth in low-income countries reduces the number of people below the poverty line. The world is characterized by

an open, globalized economy, with rapid technological change directed toward environmentally friendly processes, including clean energy technologies and innovations that enhance agricultural output. Consumption is oriented toward low material growth and energy intensity, with a relatively low level of consumption of animal products. Significant investments in education coincide with low population growth, and both government and private institutions are working together to promote public policy solutions and economic development. The Millennium Development Goals are achieved within the next decade or two, resulting in educated populations with access to safe water, improved sanitation and medical care. Other factors that reduce vulnerability to climate and other global changes include the implementation of stringent policies to control air pollutants and rapid shifts toward universal access to clean and modern energy in the developing world.

Population Component of SSP1: Rapid Development

This storyline assumes that educational and health investments accelerate the demographic transition, leading to a relatively low world population. This implies assumptions of low mortality and high education for all three country groups. With respect to fertility assumptions the story is more complex. For rich OECD countries the emphasis on quality of life is assumed to make it easier for women to combine work and family, making further fertility declines unlikely. For this reason the medium fertility assumption was chosen for this group of countries. Low fertility assumptions were chosen for all other countries as implied by the assumed rapid continuation of demographic transition. Migration levels were assumed to be medium for all countries under this SSP.

1.2 SSP 2: *Middle of the road – continuation of trends*

In this SSP2 world, trends typical of recent decades continue, with some progress toward achieving development goals, historic reductions in resource and energy intensity, and slowly decreasing fossil fuel dependency. Development of low-income countries proceeds unevenly, with some countries making relatively good progress while others are left behind. Most economies are politically stable with partially functioning and globally connected markets. A limited number of comparatively weak global institutions exist. Per-capita income levels grow at a medium pace on the global average, with slowly converging income levels between developing and industrialized countries. Intra-regional income distributions improve slightly with increasing national income, but disparities remain high in some regions. Educational investments are not high enough to rapidly slow population growth, particularly in low-income countries. Achievement of the Millennium Development Goals at the country level is delayed by several decades, leaving populations without access to safe water, improved sanitation, or medical care. Similarly, there is only intermediate success in addressing air pollution and improving energy access for the poor.

Population Component of SSP2: Medium

This is the middle of the road scenario that that can also be seen as the most likely path for each country. It combines for all countries medium fertility with medium mortality, medium migration, and the Global Education Trend (GET) education scenario. This corresponds exactly to the medium scenario of the Wittgenstein Centre projections described in the previous chapters.

1.3 *SSP 3: Fragmentation*

This narrative is an opposite of sustainability. The world is separated into regions characterized by extreme poverty, with pockets of moderate wealth. In the majority of countries, the struggle is to maintain living standards for rapidly growing populations. Regional blocks of countries have re-emerged with little coordination between them. This is a world failing to achieve global development goals and with little progress in reducing resource intensity and fossil fuel dependency. Environmental concerns such as air pollution are not being addressed. Countries in this scenario focus on achieving energy and food security goals within their own region. The world has de-globalized, and international trade, including energy resource and agricultural markets, is severely restricted. The lack of international cooperation combined with low investments in technology development and education slow down economic growth in high-, middle-, and low-income regions. Population growth in this scenario is high as a result of the education and economic trends, and the growth in urban areas in low-income countries is often in unplanned settlements. Unmitigated emissions are relatively high, driven by the high population growth, use of local energy resources, and slow technological change in the energy sector. Governance and institutions are weak and lack cooperation, consensus, or effective leadership. Investments in human capital are low and inequality is high. A regionalized world leads to reduced trade flows, and institutional development is unfavorable, leaving large numbers of people vulnerable to climate change because of their low adaptive capacity. Policies are oriented towards security, including barriers to trade.

Population Component of SSP3: Stalled Development

In demographic terms this is a world with a stalled demographic transition. Fertility is assumed to be low in the rich OECD countries and high in the other two country groups. Population growth is assumed to be high in developing countries and low in industrialized countries. Accordingly, this scenario assumes high mortality and low education for all three country groupings. Due to the emphasis on security and barriers to international exchange, migration is assumed to be low for all countries.

1.4 *SSP 4: Inequality*

This pathway envisions a highly unequal world, both within and across countries. A relatively small, rich global elite is responsible for much of the emissions, while a larger, poorer group contributes little to emissions and is vulnerable to impacts of climate change in both industrialized and developing countries. In this world, global energy corporations use investments in Research and Development as hedging strategy against potential resource scarcity or climate policy, developing and applying low-cost alternative technologies. Mitigation challenges are therefore low due to a combination of low reference emissions and/or high latent capacity to mitigate. Governance and globalization are effective for and controlled by the elite, but are ineffective for most of the population. Access to high quality education, health services, and family planning is also limited, leading to high population growth in low-income countries. Challenges to adaptation are high due to relatively low income and low human capital among the poorer population, and ineffective institutions.

Population Component of SSP4: Inequality

In order to best reflect the inequality in education, we developed a special scenario that differs from the standard education scenarios used in the rest of the book in that it produces a more polarized education distribution in every country. There is a group with very high education levels (which is bigger in the rich OECD countries) and large groups with low education levels. In terms of fertility, the national averages imply continued high fertility in today's high fertility countries and continued low fertility in both groups of low fertility countries. The high fertility countries are assumed to suffer from high levels of mortality, whereas the other two groups have medium mortality. Migration is assumed to be at the medium level for all countries.

1.5 SSP 5: Conventional development

This storyline envisions a world that stresses conventional development oriented toward economic growth as the solution to social and economic problems through the pursuit of enlightened self-interest. The preference for rapid conventional development leads to an energy system dominated by fossil fuels, resulting in high GHG emissions and challenges to mitigation. Lower socio-environmental challenges to adaptation result from attainment of human development goals, robust economic growth, highly engineered infrastructure with redundancy to minimize disruptions from extreme events, and highly managed ecosystems.

Population Component of SSP5: Conventional Development

This world of conventional development features high education assumptions and low mortality assumptions across all countries. For fertility the pattern is strongly differentiated, with relatively high fertility assumed for the rich OECD countries (as a consequence of high technology and a very high standard of living that allows for easier combination of work and family, and possibly for immigrant domestic assistants) and low fertility assumed for all other countries. The emphasis on market

solutions and globalization also implies the assumption of high migration for all countries.

Table 1: Matrix with SSP definitions

	Country Groupings	Fertility	Mortality	Migration	Education
SSP1 Rapid Development	HiFert	Low	Low	Medium	High (FT-GET)
	LoFert	Low	Low	Medium	High (FT-GET)
	Rich-OECD	Medium	Low	Medium	High (FT-GET)
SSP2 Medium	HiFert	Medium	Medium	Medium	Medium (GET)
	LoFert	Medium	Medium	Medium	Medium (GET)
	Rich-OECD	Medium	Medium	Medium	Medium (GET)
SSP3 Stalled Development	HiFert	High	High	Low	Low (CER)
	LoFert	High	High	Low	Low (CER)
	Rich-OECD	Low	High	Low	Low (CER)
SSP4 Inequality	HiFert	High	High	Medium	CER-10%/GET
	LoFert	Low	Medium	Medium	CER-10%/GET
	Rich-OECD	Low	Medium	Medium	CER/CER-20%
SSP5 Conventional Development	HiFert	Low	Low	High	High (FT-GET)
	LoFert	Low	Low	High	High (FT-GET)
	Rich-OECD	High	Low	High	High (FT-GET)

Some of the education scenario choices presented in Table 1 for different SSPs are combinations of the above described stylized scenarios: FT-GET for SSP1 and SSP5 has been calculated for each country by taking the arithmetic mean of the education progression rates implied under the GET and FT scenarios. For SSP4 a more complex combination was chosen in order to reflect the increasing within-country inequality that this storyline implies: “CER-10%/GET” implies that the educational attainment progression ratio (EAPR) is further reduced by 10 percent, as compared to CER (and hence still more pessimistic), for the transitions from no education to incomplete primary, incomplete primary to completed primary, and completed primary to completed lower secondary. The GET transition ratios are assumed for the higher educational categories, which will produce larger groups of elites in these countries. Under “CER/CER-20%”, for the high income OECD countries, it is assumed that for these higher education groups the transition rates are 20 percent lower than under CER and hence produce a more polarized society.

SSP Scenarios Results

The calculations supporting the scenarios resulted in an enormous number of data points. For every country and for every scenario, population and education pyramids are produced for every point in time (5-year steps) from 2010 to 2100. The data result in 18 pyramids for each of the 195 countries (plus for six world regions and the world total), times five scenarios, plus a pyramid for the starting year. Each pyramid contains three age groups below age 15 and 18 age groups above age 15. The age groups are each sub-divided by sex and six different educational attainment categories. This entire exercise results in 3,939,390 data points, which obviously cannot be presented here, but are available online at: <https://secure.iiasa.ac.at/web-apps/ene/SspDb/>.

The full results are also being described in a forthcoming book with Oxford University Press entitled “World Population and Human Capital in the 21st Century” (Ed. Lutz, Butz and KC). Here we will only highlight the global level results. Figure 3 shows the full range of future trajectories of world population growth across the different SSPs. Starting from about seven billion today, the range opens to 8.5 – 10.0 billion in 2050 and 7.1 – 12.8 billion in 2100. SSP3 (Stalled Development), which combines high fertility assumptions with high mortality and low education, stands out as the top trajectory. The other SSPs come in pairs in term of global population size: The Medium Scenario SSP2 path is almost identical to that of SSP4 until the middle of the century, then declines more quickly than SSP4, which is almost flat during the second half century.

The definitions of these scenarios reveal an interesting offset. While SSP2 assumes medium assumptions for all countries, SSP4 assumes a high fertility (and mortality) trajectory for the current high fertility countries and a low fertility trajectory for the low fertility countries (including India and China). Until the middle of the century these opposing trends seem to compensate for each other. Although later in the century the successively higher weight of the more rapidly growing high fertility countries dominates and results in a somewhat higher path. At the lower end, the similarity of SSP1 (Rapid Development) and SSP5 (Conventional Development) is not surprising because of almost identical demographic assumptions for fertility and mortality trajectories. Only in the case of the rich OECD countries, SSP5 assumes high instead of low fertility, resulting in a somewhat higher trajectory of world population growth.

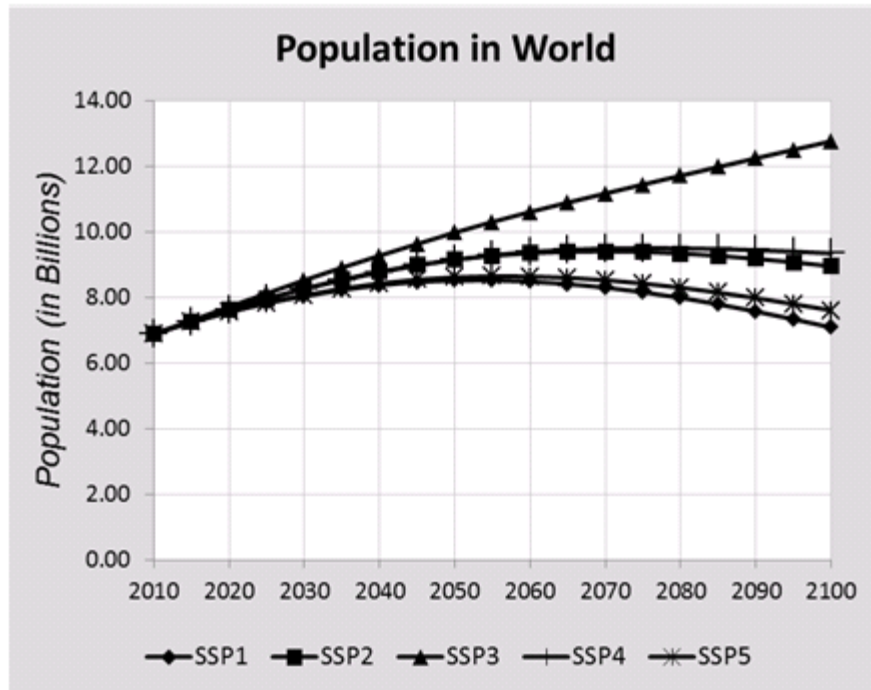


Figure 3: Trajectories of world population under the five different SSPs to 2100

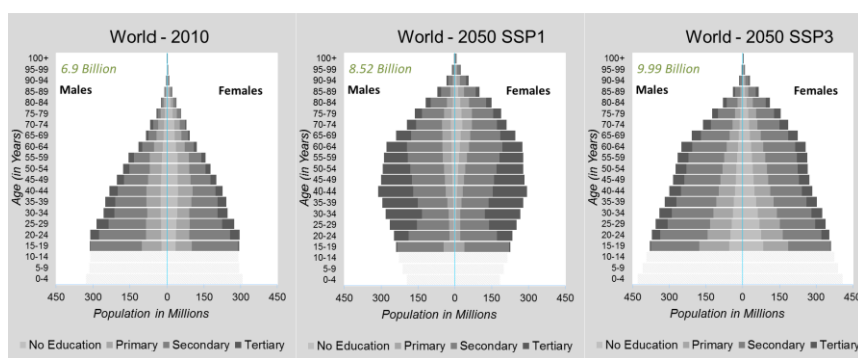
Table 2: Time series of world population size to 2100 under the different SSPs

	SSP1	SSP2	SSP3	SSP4	SSP5
2010	6,896	6,896	6,896	6,896	6,896
2020	7,560	7,636	7,719	7,633	7,568
2030	8,048	8,280	8,536	8,267	8,078
2040	8,380	8,795	9,284	8,778	8,438
2050	8,525	9,162	9,989	9,161	8,626
2060	8,492	9,361	10,619	9,398	8,649
2070	8,309	9,416	11,181	9,501	8,537
2080	7,997	9,352	11,723	9,510	8,309
2090	7,579	9,189	12,255	9,452	7,988
2100	7,096	8,963	12,774	9,355	7,616

Moving to the age and education structure of the world population, Figure 4 shows the two contrasting scenarios on the high and low side of SSP2 for the coming four decades. SSP1 shows a world that is likely to greatly benefit from the demographic

dividend. The age structure is dominated by a large group of highly educated young to middle-aged adults. SSP2, in sharp contrast, will result in a much larger population that is significantly less educated and has many more children to support. The proportion of the total world population that will be below the age of 20 will range from 20 percent under SSP1 to 31 percent under SSP3 by 2050. By 2100 this gap will widen further, with only 11 percent in SSP1 being below the age of 20, compared to 29 percent under SSP3. This gap illustrates the universal trend of population aging in which even under the highest population growth scenario, the proportion of people below the age of 20 will decline throughout this century and be always lower than the current level of 36 percent.

Figure 4: Age and Education pyramids for the world in 2010 and 2050 under SSP1 (Rapid Development) and SSP3 (Stalled Development)



Neither SSP1 nor SSP3 are likely to happen, but they span the range that the community defining these assumptions considered plausible. It is worth noting that the continental and global aggregations of the country-level SSPs being presented here show the cases in which all countries that are being aggregated follow the same SSP story line. This is comparable to the way the UN population projections aggregate the high and low variants of all individual countries. In the case that some countries follow one variant and others another, there are likely to be compensating effects with the aggregate trend coming to lie between the two extremes.

Conclusions

The new population scenarios by age, sex, and level of educational attainment represent a major step forward compared to the earlier SRES scenarios used in the environmental change research community that only considered total population size (Nakicenovic et al., 2000). From a social science perspective they provide a much richer picture of major social changes as described along the three key dimensions

of age, gender, and level of education. These dimensions as explicitly and quantitatively modeled and projected in the scenarios, can also be related to many of the Millennium Development Goals and to the main components of the Human Development Index (HDI). Level of educational attainment by gender, as well as health and mortality by age for men and women separately (which form two of the three components of HDI), are explicitly included in the set of indicators that shape the human core of the SSPs. As a next step, these alternative pathways of population and human capital are being translated by other research teams into alternative trajectories of future economic growth in individual countries. Identifying those trajectories can help project the third component of the HDI (in addition to the education and life expectancy components given here) and to derive several of the other technology- and environment-related dimensions of the SSPs. Together this new family of scenarios provides a powerful analytical handle to deal with multiple social and economic dimensions of global environmental change in the 21st century.

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