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PERSPECTIVES

Demographic scenarios by age, sex and education corresponding to the SSP narratives

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Abstract In this paper, we translate the five narratives as defined by the Shared Socioeconomic Pathways (SSPs) research community into five alternative demographic scenarios using projections by age, sex and level of education for 171 countries up to 2100. The scenarios represent a significant step beyond past population scenarios used in the Intergovernmental Panel for Climate Change context, which considered only population size. The definitions of the medium assumptions about future fertility, mortality, migration and education trends are taken from a major new projections effort by the Wittgenstein Centre for Demography and Global Human Capital, while the assumptions for all the other scenarios were defined in interactions with other groups in the SSP community. Since a full data base with all country-specific results is available online, this paper can only highlight selected results.

Keywords Population projections · Education · Age structure · Scenarios · Country level · SSP

Introduction

In the context of assessing the relationships between socioeconomic development and climate change, the global modeling communities on Integrated Assessment Modeling (IAM) and Impacts, Adaptation, and Vulnerability (IAV) have launched a new effort of scenario development. Key actors of these research communities have

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recently agreed to refer to a common set of Shared Socioeconomic Pathways (SSPs) that describe alternative future worlds with respect to social and economic mitigation and adaptation challenges. Unlike the previous generation of scenarios that only considered total population size in addition to GDP, this new set of scenarios provides alternative population projections by age, sex and six levels of education for all countries in the world (KC and Lutz 2014). By doing so, it more comprehensively covers the human core of the SSPs. In this paper, we summarize and justify the different scenario assumptions and present selected findings.

The World Population Program of the International Institute for Applied Systems Analysis (IIASA) has been engaged in the analysis of population and environment interactions since the 1980s and produced several landmark studies in this field (Lutz et al. 2002; Lutz 1994a; O'Neill et al. 2001). It began producing global level population scenarios (Lutz 1994b) at the level of 13 world regions in 1994. One of the purposes was to produce population projections as part of the Special Report on Emissions Scenarios (SRES) (Nakicenovic et al. 2000) that underlie the global emission scenarios used by the Intergovernmental Panel for Climate Change (IPCC). This was followed by four rounds of probabilistic projections at the level of 13 world regions (Lutz et al. 1997, 2001, 2008; Scherbov et al. 2011). More recently, this was complemented by sets of country-specific global projections by age, sex and level of educational attainment using the methods of multi-dimensional population dynamics (KC et al. 2010).

In this tradition, the Wittgenstein Centre for Demography and Global Human Capital (a collaborative effort among IIASA's World Population Program, the Vienna Institute of Demography of the Austrian Academy of Sciences, and the Vienna University of Economics and Business) recently carried out a major expert inquiry for defining new assumptions for a comprehensive new set of population projections by age, sex and level of education for all countries in the world. In this demographic expert inquiry, more than 550 population experts from around the world (all members of international professional population associations were invited) participated. It consisted of an online questionnaire that assessed in peer review manner the validity of alternative arguments that would impact on the future trends of fertility, mortality and migration. In a series of five meta-expert meetings held on five continents, the survey findings were evaluated and ultimately translated into numerical assumptions for the actual projections for all countries. This elaborate process was concluded in late 2012—just in time to inform the final population scenarios for the SSPs that are being presented in this paper.

The medium scenario of these new Wittgenstein Centre projections for 195 countries was chosen to be identical with SSP2 (discussed below), which is seen as the middle of the road scenario. More detailed discussion of specific parameters and assumptions that underlie the projections than can be presented here are documented in the forthcoming book, *World Population and Human Capital in the 21st Century* (Lutz et al. 2014). Earlier versions of some of the chapters have been published as online Working Papers (Barakat and Durham 2013; Basten et al. 2013; Caselli et al. 2013; Fuchs and Goujon 2013; Garbero and Pamuk 2013; KC et al. 2013; Lutz and Skirbekk 2013; Sander et al. 2013) and can serve as a reference before the book's publication. An extensive online data base can be used to retrieve all the country-specific assumptions and results in five-year steps from 2010 to 2100.[1]

In this paper, we will first summarize recent work that argues that educational attainment is the third most important source of observable population heterogeneity in addition to age and sex, and that it should be routinely included into any kind of population analysis, including population projections. We then describe how the different SSP narratives have been converted into specific sets of fertility, mortality, migration and education assumptions for different groups of countries. We end with a few selected results, mostly for the global and regional level.

Adding education to age and sex in population projections and population-environment analysis

For many users of population projections, the most important piece of information is the future total size of the population. For this reason, population size was the only demographic/social variable considered in the SRES scenarios, complemented only by GDP per capita as an economic variable. Hence, for many practical purposes, population size served primarily the function of a scaling factor in the calculation of per capita indicators.

Human populations are not homogeneous, however, and this heterogeneity matters. Future population growth is a direct function of the age- and sex-structure of the population, and for this reason, all modern population projections explicitly incorporate these two sources of population heterogeneity and define their assumptions in the form of age-specific fertility, mortality and migrations rates. Moreover, the age- and sex-composition of a population is also of interest in its own right. Population aging is considered a highly important socioeconomic issue, for example, which can only be quantitatively addressed if the age structure of populations is explicitly incorporated in the projection model. This is also relevant for the analysis of population–environment interactions where the impact on the environment as well as the vulnerability to environmental change can differ by age and sex.

The same is true for other highly relevant individual characteristics such as level of education and rural/urban place of residence. Both are of dual significance: They are important sources of population heterogeneity, influencing its dynamics, and their changing composition in the population is directly relevant for anticipating socioeconomic challenges for both mitigation of and adaptation to climate change. In this paper, we address the changing educational structure of populations and the way in which fertility, mortality and migration differ among educational attainment categories. We use the techniques of multi-dimensional population dynamics, developed at IIASA during the 1970s.

[1] www.wittgensteincentre.org/dataexplorer.

Education, in particular female education, is a key determinant of future population growth. Because of the strong association between female education and fertility, future changes in the composition of the female population by educational attainment make a big difference. Lutz and KC (2011) have shown that alternative education scenarios alone (assuming identical sets of education-specific fertility and mortality trajectories) lead to a difference in more than one billion people in the world population sizes projected for 2050.

In addition to its effects on population dynamics, the changing educational composition of the population is of great importance for a broad range of social and economic development concerns. Based on a newly reconstructed set of educational attainment distributions by age and sex for most countries back to 1970 (Lutz et al. 2007), it has been shown that the improvement of educational attainment in the working age population has been the most consistent and significant driver of economic growth around the world (Lutz et al. 2008). Beyond economic growth, there is overwhelming evidence that education is a key determinant of both infant mortality (Pamuk et al. 2011) and adult health and mortality (KC and Lentzner 2010). Beyond individual benefits, improving education by age and sex has also been shown to matter for countries in transition to modern democracies and the rule of law (Abbasi-Shavazi et al. 2008; Lutz et al. 2010; Lutz 2009). For the question of food security, it has long been shown that the basic education of the agricultural labor force is a key factor in agricultural production (Hayami and Ruttan 1971). As the set of Population–Education–Development–Agriculture (PEDA) models commissioned by the UN Economic Commission for Africa for a number of African countries shows, when including education in an agricultural production function, it turns out to be one of the key determinants in reducing malnutrition and food insecurity (Lutz et al. 2004). Finally, in the context of adaptation to climate change, a series of empirical studies on differential vulnerability to various kinds of natural disasters in different parts of the world have confirmed the dominant role of education as an empowering factor that tends to reduce vulnerability and enhance the adaptive capacity to the negative consequences of climate change (Frankenberg et al. 2013; Helgeson et al. 2013; KC 2013; Sharma et al. 2013; Striessnig et al. 2013; Wamsler et al. 2012). Hence, it seems very appropriate to describe the set of population scenarios including education as the human core of the SSPs.

Converting the SSP narratives into population and education scenarios

The new approach to scenarios in the context of climate change analysis was formulated at an IPCC workshop in 2007 and 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* (van Vuuren et al. 2011). The development of the socioeconomic scenarios, known as 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 Fig. 2 in the previous paper by Hunter and O'Neill 2014) with respect to socioeconomic challenges to mitigation and adaptation. This range of the SSPs is broad enough 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 general SSP rationale as well as the storylines underlying the individual SSPs have been discussed and documented in the previous paper and need not be repeated here. In the following, we will focus on the specific way, these storylines are translated into alternative fertility, mortality, migration and education scenarios for different groups of countries. Three groups of countries are distinguished: "High fertility countries," with a total fertility rate of more than 2.9 in 2005–2010; "Low fertility countries," with a total fertility rate of 2.9 and below, and which are not included in the third category; "Rich OECD countries," defined by OECD membership and World Bank high income country status. In the SSPs, scenarios as presented here countries are assumed to stay in the same group through to 2100. Since there is an almost infinite number of ways and times at which countries could change group membership, it was decided that this should be left to users who want to define their own country-specific SSPs.

The following definitions of the specific demographic assumptions to be made for different SSPs resulted from a series of meetings and intensive interactions among members of the SSP community. The general rationale and narrative of each SSP are introduced in the previous paper; below we will specify the specific demographic trajectories that were assumed to best represent these rationales. Table 1 summarizes these choices in tabular form.

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. The population component of SSP1 is named "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.

Table 1 Matrix with SSP definitions

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

SSP2: Middle of the road

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. The corresponding population component of SSP2 is described as "Medium." This is the middle of the road scenario 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.

SSP 3: Fragmentation

This narrative is the opposite of sustainability and the corresponding population component is described as "Stalled Development." 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 groups. 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.

SSP 4: Inequality

This pathway envisions a highly unequal world, both within and across countries. The population component of SSP4 has the same name. In order to best reflect the inequality in education, we developed a special scenario that differs from the standard GET scenarios used in the other SSPs so as to produce a more polarized education distribution in each country: There is a small group with very high education in each country (which is bigger in the rich OECD countries) and large groups with low education. There is 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.

SSP 5: Conventional development

This storyline envisions a world that stresses conventional development oriented toward economic growth; the population component of SSP5 has the same name. 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.

What precisely high, medium and low assumptions mean for individual countries cannot be detailed here; for this, the reader is referred to Lutz et al. (2014) and the above mentioned online sources. As mentioned, SSP2 is identical to the medium scenario, regarded as the most likely pathway from today's perspective. The medium fertility scenario follows a model of continued demographic transition with future fertility trends in high fertility countries following the experience of other countries that have already further progressed in their demographic transitions. Once a low level of fertility has been reached (around a TFR of 1.6), then countries slowly converge to a TFR of 1.75 set for 2200. Basten et al. (2013) and Fuchs and Goujon (2013) explain the assumptions. The high and low fertility scenarios are essentially defined as being 20 % higher and lower than the medium by 2030 and 25 % different by 2050 and thereafter. Differentials in education-specific fertility levels start with those empirically observed in individual countries and then are assumed to converge to a global pattern over the coming decades.

Medium mortality assumptions are made on the basis of a global conditional convergence model, under which it is assumed that life expectancies in all countries progressively approach those in regional forerunner countries. These regional champions themselves would slowly approach the global forerunner (Japan), which is assumed to experience a constant increase of 2 years in life expectancy per decade. For the high and low scenarios, it is generally assumed that life expectancy would increase 1 year per decade faster or slower than in the "medium" case. For AIDS affected countries in Sub-Saharan Africa, special assumptions are made with larger uncertainty intervals in the nearer term. Again, the specific numerical assumptions for each country result from extensive expert argumentation as documented in Lutz et al. (2014) as well as Garbero and Pamuk (2013) and KC et al. (2013).

The migration assumptions are based on a new global level estimate of the full matrix of in- and out-migration flows as derived primarily from migrant stock data (Abel 2013). The medium scenario then assumes constant in- and out-migration rates for the coming half century followed by a slow convergence to zero net migration. It is worth noting that the assumption of constant rates, rather than constant absolute flows, can over time produce changes in the absolute flows as a function of changing national population size (for out-migration) or world population size (for in-migration). The high migration scenarios essentially assume 50 % higher and the low migration 50 % lower migration than in the medium scenario (Sander et al. 2013).

Finally, the different education scenarios require a word of clarification. The GET scenario is based on a Bayesian model that estimates the most likely future trajectory in education-specific progression rates to higher levels from the cumulative experience of all countries over the past 40 years (Barakat and Durham 2013). The resulting education trajectories for each country are not only considered to be the "medium," but they are also used as the standard—in terms of the resulting educational attainment distribution in the population—against which all the future education-specific fertility and mortality trajectories are derived. There are two other benchmark scenarios with respect to future education trends: The constant enrollment rates (CER) simply assumes that in each country, the most recently observed level of school enrollment are frozen at their current levels. Since in many countries, the younger age groups are much better educated than the older ones, even this scenario can lead to some improvements in adult education levels over the coming decades, but in the longer run, it implies stagnation. On the other extreme, there is the fast-track (FT) scenario which assumes that the country will shift gears and follow the most rapid education expansion experienced in recent history, namely that of South Korea. 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 storyline implies: "CER-10 %/GET" implies that the educational attainment progression ratio (EAPR) is further reduced by 10 %, as compared with CER for the transitions from no education to incomplete primary, incomplete primary to completed primary and from 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 % lower than under CER and hence produce a more polarized society.

Selected highlights of the resulting projections

These calculations resulted in an enormous amount of data points. For every country and for every scenario, the population-education pyramids are given in five-year intervals from 2010 to 2100. This whole exercise results in a total of 3,939,390 data points, available online under https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about.

The following figures and tables provide summary indicators for the different SSPs. This information will be presented in the form of aggregates for major world regions, the world as a whole, and for 12 selected bigger countries. The summary education indicator presented is the mean years of schooling (MYS) for the entire adult population above age 25. To make the figures clearer, the six underlying educational attainment categories were combined into four, which refer to no education, some primary, completed junior secondary and post-secondary education. For children below the age of 15, no attainment distribution is given because most of them are still in the process of education.

Table 2, as well as Figs. 1 and 2, shows that for the world as a whole the different SSPs cover a broad range of total population sizes, which are also associated with different age and education distributions. SSP2 shows a continued increase in world population size resulting in 9.17 billion in 2050, then peaking around 9.4 billion in the 2070 s and declining somewhat to 9 billion by 2100. This medium trajectory of world population growth reaching a peak during the second half of the century is consistent with earlier world population projections by IIASA (Lutz et al. 2008) as well as the United Nations (2009). The UN 2010 revision (United Nations 2011) does not project such peaking because it modified its assumption of the long-term convergence level of fertility from previously 1.85 to around 2.1. SSP2 as presented here assumes this long-term level to be at 1.75, as is extensively discussed and justified as a result of the expert solicitation in Basten et al. (2013). The most recent UN 2012 assessment (United Nations 2013) gives a higher world population trajectory than SSP2 mostly due to higher assumed fertility for Africa and for China.

The uncertainty range of future world population size in 2100 goes from 6.9 billion under SSP1 to 12.6 under SSP3. This reflects a very significant uncertainty about future fertility, mortality and education trends which translate not only into different world population sizes but also very different age and education structures. These scenarios cannot be directly compared with the UN high and low population variants because those are only based on alternative fertility assumptions (0.5 children higher and lower than in the medium variant), while assuming identical mortality and migration patterns and not explicitly addressing the population heterogeneity with respect to education.

As discussed earlier, these differences in total world population size result predominantly from two forces: different assumed trajectories in female educational attainment and different levels of education-specific fertility. Since almost universally more educated women have lower levels of fertility—an effect that is particularly strong for countries in the midst of demographic transition—the changing educational composition of young women alone (Table 3) is a major factor influencing population growth. When also introducing different sets of education-specific fertility trajectories—as is the case for the SSPs—the inter-scenario differences become even larger. Alternative mortality assumptions are of secondary importance when it comes to population size but are dominating the picture with respect to the future number of elderly people under different scenarios. Alternative migration assumptions also can make major differences with respect to projected national and to a lesser extent regional population sizes.

Figure 2 shows the time trend in population sizes by educational attainment under all five SSPs. In all cases, the absolute number of people with secondary or tertiary education will increase over the coming decades. This is a trend that is already pre-programmed in today's education structures where almost universally the younger age groups are better educated than the older ones. This may be called

Table 2 Results for major world regions and selected countries

Region	Year	Population (in millions)					MYS (mean years of schooling)				
		SSP1	SSP2	SSP3	SSP4	SSP5	SSP1	SSP2	SSP3	SSP4	SSP5
World	2010	6,871	6,871	6,871	6,871	6,871	8.6	8.6	8.6	8.6	8.6
	2050	8,461	9,166	9,951	9,122	8,559	12.1	11.2	9.0	8.7	12.1
	2100	6,881	9,000	12,627	9,267	7,363	14.1	13.4	8.3	8.1	14.2
Africa	2010	1,022	1,022	1,022	1,022	1,022	5.8	5.8	5.8	5.8	5.8
	2050	1,764	2,011	2,333	2,251	1,737	11.0	9.7	6.3	5.7	11.0
	2100	1,865	2,630	3,947	3,622	1,808	13.7	12.7	6.4	5.8	13.7
Asia	2010	4,141	4,141	4,141	4,141	4,141	7.9	7.9	7.9	7.9	7.9
	2050	4,734	5,140	5,656	4,965	4,721	11.8	10.9	8.8	8.5	11.8
	2100	3,293	4,417	6,712	4,076	3,300	14.0	13.3	8.4	8.2	14.1
Europe	2010	738	738	738	738	738	12.0	12.0	12.0	12.0	12.0
	2050	769	762	681	716	847	13.7	13.5	13.0	12.8	13.7
	2100	657	702	543	535	915	14.5	14.1	12.8	12.9	14.5
Latin Am. and the Caribbean	2010	590	590	590	590	590	9.0	9.0	9.0	9.0	9.0
	2050	679	746	859	710	655	12.6	11.9	10.2	9.6	12.6
	2100	487	673	1,085	567	453	14.7	14.1	10.3	9.9	14.6
Northern America	2010	344	344	344	344	344	13.8	13.8	13.8	13.8	13.8
	2050	460	450	372	424	535	14.8	14.6	14.3	14.1	14.8
	2100	521	513	290	406	801	15.3	15.1	14.4	14.2	15.2
Oceania	2010	36	36	36	36	36	12.1	12.1	12.1	12.1	12.1
	2050	56	57	51	56	64	14.2	13.7	12.8	12.7	14.2
	2100	59	65	50	61	87	15.2	14.9	12.4	12.6	15.3
Argentina	2010	40	40	40	40	40	10.3	10.3	10.3	10.3	10.3
	2050	45	49	56	46	44	13.3	12.6	10.5	10.1	13.3
	2100	34	47	74	35	32	14.9	14.4	10.4	10.3	14.9
Bangladesh	2010	149	149	149	149	149	5.6	5.6	5.6	5.6	5.6
	2050	178	196	222	177	171	10.1	8.8	7.0	6.5	10.1
	2100	125	167	261	116	116	13.0	12.1	7.1	6.9	13.0
Ethiopia	2010	83	83	83	83	83	2.5	2.5	2.5	2.5	2.5
	2050	140	159	185	184	137	8.9	7.5	4.4	3.8	8.9
	2100	137	191	293	289	133	13.0	11.8	4.7	4.1	13.0
Iraq	2010	32	32	32	32	32	7.9	7.9	7.9	7.9	7.9
	2050	58	68	86	84	57	11.9	11.2	6.9	6.2	11.9
	2100	60	88	174	167	57	13.3	12.9	6.9	6.3	13.3
Mali	2010	15	15	15	15	15	1.6	1.6	1.6	1.6	1.6
	2050	30	36	42	41	29	7.6	5.1	1.2	1.1	7.6
	2100	33	48	67	65	31	11.1	9.5	1.2	1.1	11.1
Morocco	2010	32	32	32	32	32	4.9	4.9	4.9	4.9	4.9
	2050	34	37	45	35	31	10.7	9.8	6.0	5.6	10.6
	2100	23	31	57	25	19	14.3	13.7	6.3	6.2	14.3
Nigeria	2010	158	158	158	158	158	6.4	6.4	6.4	6.4	6.4
	2050	329	372	434	431	326	12.9	12.2	8.3	7.8	12.9
	2100	431	582	854	833	424	15.0	14.6	8.6	8.5	15.0

Table 2 continued

Region	Year	Population (in millions)					MYS (mean years of schooling)				
		SSP1	SSP2	SSP3	SSP4	SSP5	SSP1	SSP2	SSP3	SSP4	SSP5
Pakistan	2010	174	174	174	174	174	4.0	4.0	4.0	4.0	4.0
	2050	252	293	347	340	246	9.6	7.8	4.5	4.2	9.6
	2100	217	326	551	531	207	12.4	11.6	4.6	4.5	12.4
Philippines	2010	93	93	93	93	93	10.0	10.0	10.0	10.0	10.0
	2050	133	149	174	172	130	12.6	12.2	10.3	9.4	12.6
	2100	116	160	255	250	112	13.5	13.2	10.4	9.6	13.5
Thailand	2010	69	69	69	69	69	8.5	8.5	8.5	8.5	8.5
	2050	70	74	76	69	73	12.7	12.1	10.2	9.8	12.7
	2100	43	55	77	39	45	15.0	14.5	10.3	10.3	15.0
United States of America	2010	310	310	310	310	310	13.7	13.7	13.7	13.7	13.7
	2050	411	402	334	379	476	14.8	14.5	14.2	14.1	14.7
	2100	467	459	262	365	713	15.3	15.1	14.3	14.2	15.2
Venezuela	2010	29	29	29	29	29	9.7	9.7	9.7	9.7	9.7
	2050	38	42	47	39	38	13.3	12.5	10.2	9.6	13.3
	2100	29	40	61	30	29	14.9	14.4	10.3	9.9	14.9

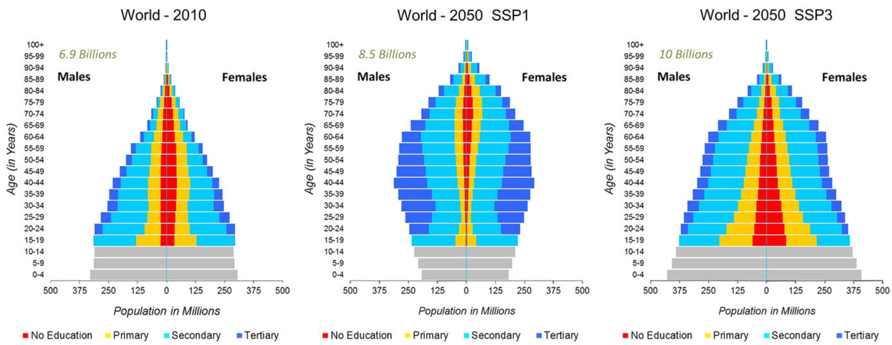

Fig. 1 World in 2010 and in 2050 under SSP1 und SSP3

the momentum of educational improvement which leads to better future education of the elderly even under the scenarios that assume no further increase in school enrollment rates (such as under SSP3). Under SSP1 and SSP5, the global proportion of people with higher education will increase dramatically and the global mean years of schooling (MYS in Table 2) of the total adult population will already by 2050 reach 12 years, which is about the current level in Europe and only somewhat below that in North America. In other words, under these scenarios the whole world in 40 years will be as well educated as Europe today and will most likely experience all the positive consequences that are associated with higher education. Even under the most likely SSP2 scenario, the global MYS will reach 11.2 years by mid-century. But SSP3 and SSP4 draw a much more pessimistic picture that is based on the assumption of a stagnation of the increase in school enrollment. In both

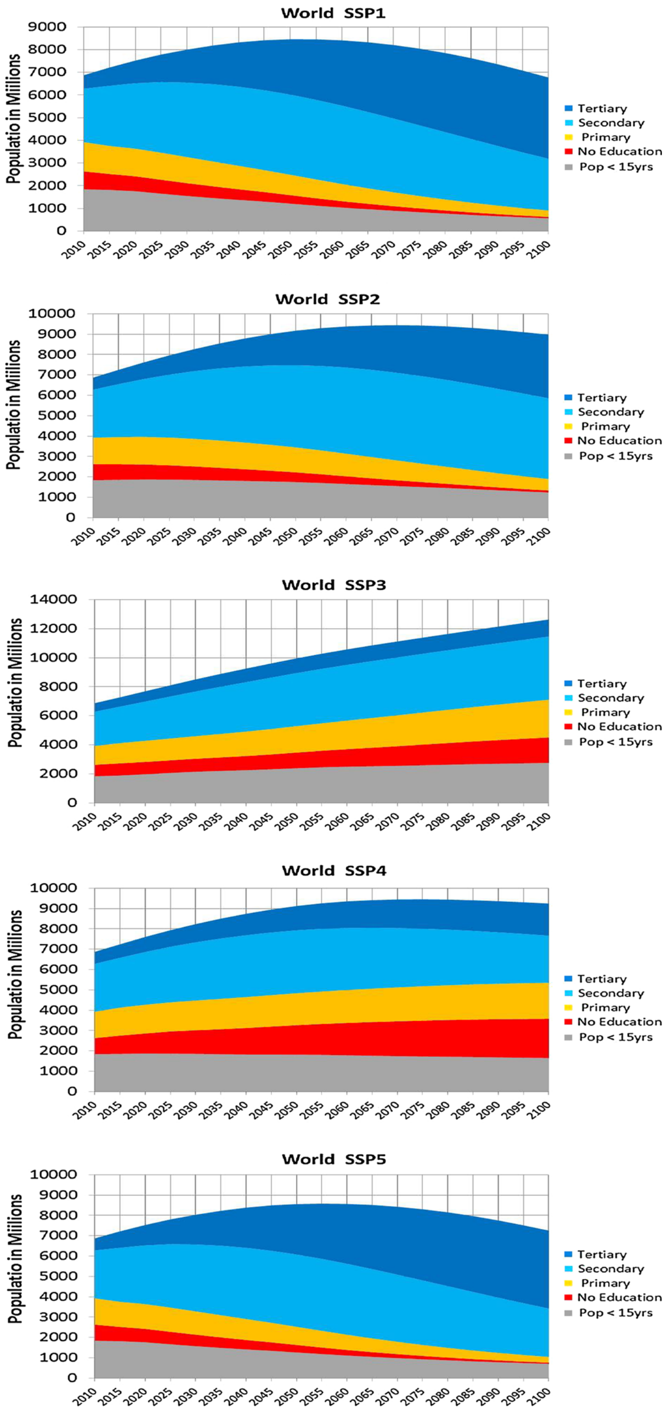

Fig. 2 World Line Charts 2010–2100, SSP1-SSP5

Table 3 Proportion of the female population aged 20–39 in the region, year and SSP stated by level of educational attainment (in percent for the four-stated categories)

Region	Year	SSP1				SSP2				SSP3				SSP4				SSP5			
		No Edu (%)	Prim (%)	Sec (%)	Tert (%)	No Edu (%)	Prim (%)	Sec (%)	Tert (%)	No Edu (%)	Prim (%)	Sec (%)	Tert (%)	No Edu (%)	Prim (%)	Sec (%)	Tert (%)	No Edu (%)	Prim (%)	Sec (%)	Tert (%)
World	2010	15	21	49	15	15	21	49	15	15	21	49	15	15	21	49	15	15	21	49	15
	2050	2	8	43	47	4	14	53	29	20	26	42	11	28	24	33	16	2	7	43	47
	2100	0	2	35	63	0	5	49	46	24	28	38	9	35	27	21	18	0	2	34	64
Africa	2010	32	31	31	6	32	31	31	6	32	31	31	6	32	31	31	6	32	31	31	6
	2050	3	14	47	36	6	25	51	17	33	35	28	5	40	32	21	8	3	14	47	36
	2100	0	4	39	57	0	9	56	35	33	35	27	5	41	33	15	11	0	4	39	57
Asia	2010	16	22	49	13	16	22	49	13	16	22	49	13	16	22	49	13	16	22	49	13
	2050	2	6	44	48	4	12	55	29	20	25	44	10	28	22	32	17	2	6	43	48
	2100	0	2	34	64	1	3	48	49	24	26	41	10	35	22	20	23	0	2	34	64
Europe	2010	0	5	67	28	0	5	67	28	0	5	67	28	0	5	67	28	0	5	67	28
	2050	0	1	38	61	0	2	52	46	0	6	67	27	4	5	64	27	0	1	38	61
	2100	0	1	30	69	0	1	39	60	0	6	69	25	3	6	60	31	0	1	30	69
Latin Am. and the Caribbean	2010	4	28	52	17	4	28	52	17	4	28	52	17	4	28	52	17	4	28	52	17
	2050	0	5	42	52	0	10	56	33	4	29	53	15	14	26	38	22	0	5	42	52
	2100	0	1	34	65	0	2	46	52	4	29	52	15	16	31	25	28	0	1	34	65
Northern America	2010	0	4	54	42	0	4	54	42	0	4	54	42	0	4	54	42	0	4	54	42
	2050	0	1	33	66	0	2	43	55	0	4	57	39	0	4	65	31	0	1	34	65
	2100	0	1	28	71	0	1	33	66	0	4	57	39	0	4	65	31	0	1	28	71
Oceania	2010	3	14	51	33	3	14	51	33	3	14	51	33	3	14	51	33	3	14	51	33
	2050	0	5	37	58	1	10	46	44	4	21	48	27	7	18	51	24	0	4	36	59
	2100	0	1	30	69	0	2	39	58	6	28	45	21	9	22	45	24	0	1	29	70

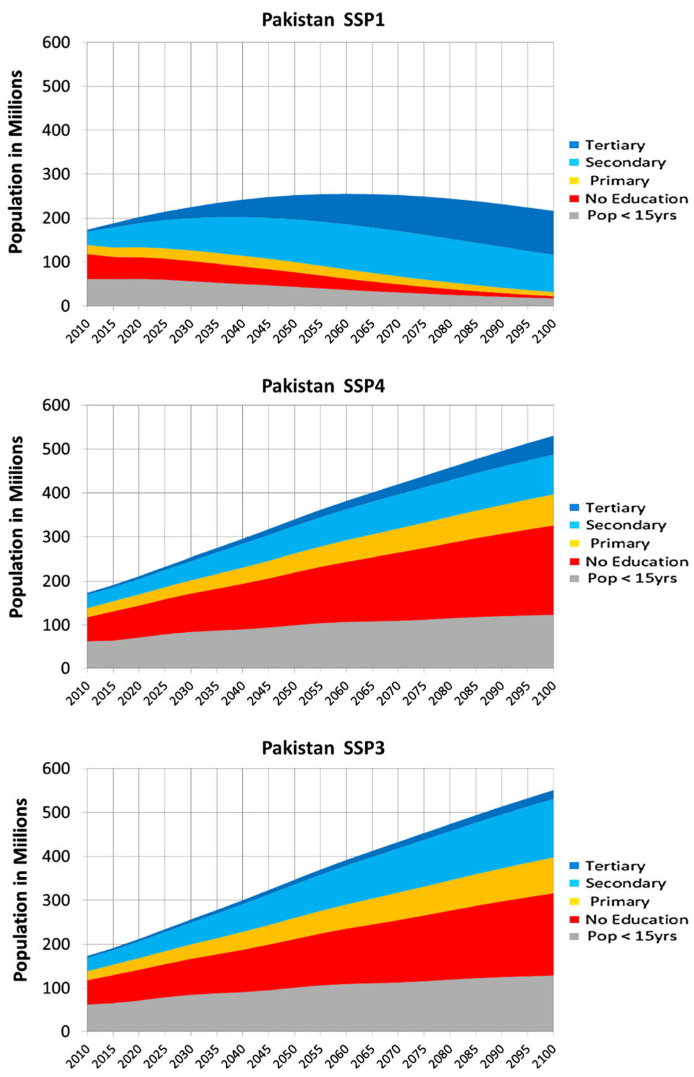

Fig. 3 Pakistan 2010–2100: SSP1, SSP3 and SSP4

scenarios, the average education of the world population will even decline slightly during the second half of the century, following a minor increase in the nearer future due to momentum. While under SSP3, there is a parallel stagnation for all education groups, SSP4 shows a polarization. While the overall MYS of these two different scenarios are quite similar, the full education distributions are very different.

A similar polarization can be illustrated with the example of Pakistan (Fig. 3). While SSP1 shows that with significant further investments in education over the coming decades, Pakistan by 2060 could already reach an education structure (at least of the younger adult population) that is similar to that in Europe today, SSP3 and SSP4 show the cases of stalled development that are associated not only with much lower education levels but also with significantly more rapid population growth. While under SSP1, Pakistan's population will only increase from currently 174–217 million by the end of the century, under SSP3, it will increase by a factor of more than three to an incredible 551 million. Again, SSP4 shows a somewhat more polarized development than SSP3 with more uneducated as well as more highly educated although the MYS are quite similar.

Conclusions

The above described new population scenarios by age, sex and level of educational attainment present a major step forward as compared with the earlier SRES scenarios 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 three key sources of population heterogeneity have been shown to be key determinants of both the mitigative and adaptive capacity of future societies. For this reason, it is justified to call the above described scenarios the "Human Core" of the SSPs.

There are many more possible uses of these scenarios in the field of population and environment analysis that go beyond the specific SSP context. These three dimensions as explicitly and quantitatively modeled and projected in the above described scenarios can be directly 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 and for men and women separately (which form two of three components of HDI) are explicitly included in the set of indicators that shape the above described scenarios. As a next step, these alternative pathways of population and human capital will be translated into alternative trajectories of future economic growth in individual countries. They will also be related to global scenarios on urbanization, which will be discussed in the following paper.

We hope that this paper could illustrate that the demographic research community can do much more in terms of contributing to and interacting with the vibrant environmental change research community. An important prerequisite, however, is to try to go beyond conventional demography—where the focus is restricted to population size, age and sex—and apply the powerful demographic toolbox to other relevant human characteristics such as level of education, place of residence, household structure, health status, labor force participation and other important demographic dimensions of sustainable development.

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Appendix

See Table 4.

Table 4 Country groupings

High fertility countries (TFR > 2.9)	Low fertility countries (TFR ≤ 2.9)	
	Rich OECD	Others
Afghanistan, Angola, Belize, Benin, Bolivia (Plurinational State of), Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, French Guiana, Gabon, Gambia, Ghana, Guatemala, Guinea, Guinea-Bissau, Haiti, Honduras, Iraq, Jordan, Kenya, Lao People's Democratic Republic, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mayotte, Micronesia (Fed. States of), Mozambique, Namibia, Nepal, Niger, Nigeria, Occupied Palestinian Territory, Pakistan, Papua New Guinea, Paraguay, Philippines, Rwanda, Samoa, Sao Tome and Principe, Saudi Arabia, Senegal, Sierra Leone, Solomon Islands, Somalia, Sudan, Swaziland, Syrian Arab Republic, Tajikistan, Timor-Leste, Togo, Tonga, Uganda, United Republic of Tanzania, Vanuatu, Yemen, Zambia, Zimbabwe	Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Slovenia, Spain, Sweden, Switzerland, United Kingdom, United States of America, Slovakia, Republic of Korea	Albania, Algeria, Argentina, Armenia, Aruba, Azerbaijan, Bahamas, Bahrain, Bangladesh, Barbados, Belarus, Bhutan, Bosnia and Herzegovina, Botswana, Brazil, Brunei Darussalam, Bulgaria, Cambodia, Cape Verde, Channel Islands, Chile, China, China, Hong Kong SAR, China, Macao SAR, Colombia, Costa Rica, Croatia, Cuba, Cyprus, Dem. People's Republic of Korea, Dominican Republic, Ecuador, Egypt, El Salvador, Fiji, French Polynesia, Georgia, Grenada, Guadeloupe, Guam, Guyana, India, Indonesia, Iran (Islamic Republic of), Jamaica, Kazakhstan, Kuwait, Kyrgyzstan, Latvia, Lebanon, Libyan Arab Jamahiriya, Lithuania, Malaysia, Maldives, Malta, Martinique, Mauritius, Mexico, Mongolia, Montenegro, Morocco, Myanmar, Netherlands Antilles, New Caledonia, Nicaragua, Oman, Panama, Peru, Puerto Rico, Qatar, Republic of Moldova, Réunion, Romania, Russian Federation, Saint Lucia, Saint Vincent and the Grenadines, Serbia, Singapore, South Africa, Sri Lanka, Suriname, TFYR Macedonia, Thailand, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Ukraine, United Arab Emirates, United States Virgin Islands, Uruguay, Uzbekistan, Venezuela (Bolivarian Republic of), Viet Nam

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