The human core of the shared socioeconomic pathways: Population scenarios by age, sex and level of education for all countries to 2100

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ABSTRACT

This paper applies the methods of multi-dimensional mathematical demography to project national populations based on alternative assumptions on future, fertility, mortality, migration and educational transitions that correspond to the five shared socioeconomic pathways (SSP) storylines. In doing so it goes a significant step beyond past population scenarios in the IPCC context which considered only total population size. By differentiating the human population not only by age and sex—as is conventionally done in demographic projections—but also by different levels of educational attainment the most fundamental aspects of human development and social change are being explicitly addressed through modeling the changing composition of populations by these three important individual characteristics. The scenarios have been defined in a collaborative effort of the international Integrated Assessment Modeling community with the medium scenario following that of a major new effort by the Wittgenstein Centre for Demography and Global Human Capital (IIASA, OEAW, WU) involving over 550 experts from around the world. As a result, in terms of total world population size the trajectories resulting from the five SSPs stay very close to each other until around 2030 and by the middle of the century already a visible differentiation appears with the range between the highest (SSP3) and the lowest (SSP1) trajectories spanning 1.5 billion. The range opens up much more with the SSP3 reaching 12.6 billion in 2100 and SSP1 falling to 6.9 billion which is lower than today's world population.

1. Introduction

The number of human beings on this planet has changed greatly over the past millennia and was in many aspects linked to changes in the natural environment—both in terms of being driven by changes in the environment and also of inducing such changes—as well as the evolution of technologies and human cultures. It is estimated that from the appearance of modern Homo sapiens some 200,000 years ago in Africa until around 35,000 years ago the total world population was well under one million and our species was seriously threatened by extinction (Biraben, 2002). Only after the Neolithic revolution which introduced agriculture the world population surpassed 100 million roughly 7000 years ago. But it was only in the 19th century that population growth really started to take off in the now industrialized countries as a consequence of a decline in death rates which was the result of better nutrition,

improvements in hygiene and public fresh water supply and other advances in early preventive medicine. Right after the end of World War II death rates then started to fall precipitously in almost all parts of the world which at this time was also the result of modern medicine including the invention of antibiotics. But for several decades birth rates remained very high (and in some cases even increased due to a better health status of women) since high fertility norms had been deeply imbedded in most traditional cultures and religions and such norms tend to change only slowly. As a consequence, world population size started to "explode" from 2.5 billion in 1950 to somewhat above 7 billion today. But over the past decades birth rates have also started to decline in many parts of the world—most dramatically in populous East Asia—giving rise to the expectation that over the course of the 21st century there is a high probability that world population will reach a peak and then start to decline (Lutz et al., 2001).

The scientific discipline of demography has a rather elaborate and powerful toolbox for studying population dynamics and produces detailed population projections according to different assumptions about the future trend in fertility, mortality,

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migration and other drivers of changing population composition. While population growth has been a topic of scientific enquiry and discussion for centuries and at least since Thomas Malthus entered the field of structured quantitative analysis, early population projections only applied an assumed growth rate to the population total. Only after World War II it became standard to produce projections that explicitly consider the age- and sex-structure of the population (the so-called cohort component method). Hajnal (1955) provides a good overview of these early population projections. Between 1951 and 2011, the UN published 22 sets of estimates (past and current conditions) and projections (future) for all countries and territories of the world. Before 1978 these projections were revised approximately every 5 years; since then new revisions (called assessments and published in their World Population Prospects series) have been made every 2 years. So far the UN assessments have provided projections by age and sex for a medium scenario, and alternative scenarios that are based on alternative fertility assumptions combined with identical mortality and migration assumptions.

The World Bank started to produce independent population projections in 1978. These were always meant primarily for internal use in the Bank's development planning and were published as part of the World Development Report series. After 1984, the World Bank projections were revised approximately every 2 years and in most cases only one updated variant was published but with a long time horizon to 2150. Around 1995, the World Bank stopped publishing separate projections but presumably continued to use them for internal purposes for a number of years. The Washington-based Population Reference Bureau (PRB) publishes independent world population projections (population size only and a single scenario) every year as part of its annual World Population DataSheet. The US Census Bureau (USCB) also produces single scenario projections for all countries in the world since 1985 with a varying time horizon. The World Population Program of the International Institute for Applied Systems Analysis (IIASA) based outside Vienna (Austria) began producing global population projections 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 three rounds of probabilistic projections at the level of 13 world regions (Lutz et al., 2008b, 2001, 1997).

2. Key dimensions considered in population projections

For most users of population projections clearly 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.

There are two important reasons for population projections to go beyond the consideration of population size alone, one methodological and the other substantive. Human populations are not homogeneous and this heterogeneity greatly matters for the likely future growth of the population. Populations that are selective in a way that they have only a small proportion of women or more elderly people than young adults are likely to have lower birth rates than population of comparable size but with a larger proportion of women in reproductive age. In this sense future population growth is a direct function of the age- and sex-structure of the population and for this reason all modern population projections do explicitly incorporate these two sources of population heterogeneity and define their assumptions in the form of age-specific fertility, mortality and migrations rates.

The age- and sex-composition of the population is also of interest in its own right. Population aging is considered a highly important socioeconomic issue which can only be quantitatively addressed if the age-structure of populations is explicitly incorporated in the projection model. But 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 mitigation as well as adaptation to unavoidable climate change. In this paper we will explicitly address the changing educational structure of populations while the following paper will deal with the modeling of urbanization (Jiang and O'Neill, in press).

The methods of multi-dimensional population dynamics are able to deal with populations that are stratified by further demographic dimensions in addition to age and sex. The International Institute for Applied Systems Analysis (IIASA)—where these methods were originally developed during the 1970s—has recently applied them to produce reconstructions and projections of populations by age, sex and level of educational attainment for most countries in the world (KC et al., 2010; Lutz et al., 2007). Like age and sex, education is also an important source of population heterogeneity and bears a significant weight of its own. Almost universally more educated people have lower mortality, and there is sufficient evidence that this is a real effect and not just owing to selectivity. Lutz and Skirbekk (2013) discuss the issue of causality in the effects of education and bring together many studies based on natural experiments, instrumental variable models and other approaches that clearly demonstrate that this almost universal association is not a spurious effect. They coin the notion of "functional causality" to indicate that—while it is nearly impossible to proof causality for all times and all different cultural settings—there are good reasons to assume that the effect of education on lowering mortality and fertility can indeed be assumed to hold over the projection period cover here. Finally, it needs to be stressed that the indicator of highest educational attainment that is being used here as the indicator of choice for all countries is only a proxy for skills and human capital. It does not include the quality dimension of education (because empirical data on this tend to be limited to rich countries) nor does it cover informal education which also contributes to human capital and for which even less reliable statistical information exists. In this sense the choice of educational attainment distribution was primarily driven by pragmatic considerations as the only indicator available in a rather consistent way for almost all countries of the world. While the baseline data distinguish between six educational attainment categories and the multi-dimensional projections have been carried out for these six categories, for the purpose of this paper we collapse them into four categories for the ease of presentations (for more information about the base line data and assumptions see KC et al., 2013).

The empirical data show that, in virtually all populations—and in particular those that are still in the process of demographic transition—more educated women have lower fertility. These educational differentials can be very significant. The Demographic and Health Survey for Ethiopia, for instance, shows that women without any formal education have on average six children,

whereas those with secondary education have only two (DHS Ethiopia, 2012). 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 recently shown that alternative education scenarios alone (assuming identical education-specific fertility and mortality levels) lead to a difference of 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 also 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 (Lutz et al., 2007) for most countries back to 1970, it has recently been shown that indeed 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., 2008a). In the context of the Shared Socioeconomic Pathways (SSPs) this empirically established relationship will also be used to define GDP growth scenarios that are consistent with the education-specific population scenarios described here. As will be described in the following section the different SSPs were designed to cover alternative socio-economic pathways with respect to the different levels of societal capacities to deal with climate change mitigation and adaptation challenges.

Beyond economic growth, education as a basic force of empowering people and providing access to information has been shown to matter to a large range of important aspect in the context of sustainable development. 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). But 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, 2009; Lutz et al., 2010). 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 dominating 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 for socioeconomic scenarios, which are supposed to capture the socioeconomic challenges of both mitigation and adaptation, to enrich the conventional demographic focus on population size as well as on the age- and sex-structure of the population through adding education attainment as an additional demographic dimension. Since these dimensions together comprehensively describe key characteristics of people, with respect to their mitigative and adaptive capacities, this set of scenarios may appropriately be called the human core of the SSPs.

The Wittgenstein Centre (WIC) for Demography and Global Human Capital (a collaborative effort among the International Institute for Applied Systems Analysis, IIASA, the Austrian Academy of Sciences, OeAW, and the Vienna University of Economics and Business, WU) 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 (under an ERC Advanced Granton "Forecasting Societies' Adaptive Capacities to Climate Change"). More than 550 population experts from around the world participated in this effort. It consisted of an online questionnaire that assessed in peer review manner the validity of alternative arguments that would impact the future trends of fertility, mortality and migration. In a series of five meta-expert meetings held on five different 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. All the parameter choices and justifications of assumptions that underlie the projections presented here as well as detailed country-specific results are documented in the forthcoming Oxford University Press 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).

This major new effort in establishing the scientific basis for new world population projections by age, sex and level of education directly fed into the definition of the SSP scenarios presented here. Most importantly the expert solicitation mostly focused on the medium future trajectories of all demographic components (fertility, mortality, migration and education) and this medium scenario was by definition set to be identical to SSP2 (the "middle of the road" SSP as discussed below). All the other SSPs were defined through another process of intensive consultations (at meetings in Utrecht, Boulder, The Hague and the International Institute for Applied Systems Analysis as well as countless teleconferences) among scientists from the leading Integrated Assessment Modeling groups in order to assure that the specific demographic assumptions made are consistent with the substantive narratives of the respective SSPs.

The resulting age, sex, and education components of the SSPs as they were finalized in January 2013 and are presented in this paper and in the SSP online data set have been labeled WIC-SSPs1.0. They are different from earlier education-specific projections produced for a smaller number of countries and based on older base line data by the same authors (Lutz and KC, 2011; Lutz et al., 2007). More recently (in October 2013) a slightly different updated version has been produced which is based on more recent information on migration and fertility trends in some countries (which is labeled WIC-SSPs 1.1). But since it is the WIC-SSPs1.0 that served as input to the other groups calculating GDP and other components of the SSPs we will only present this version in this paper.

3. Translation of SSP storylines into population and education scenarios

The general SSP rationale as well as the storylines underlying the individual SSPs have been extensively discussed and documented in the previous papers (Crespo Cuaresma, in press; Dellink et al., in press; Leimbach et al., in press; O'Neill et al., in press) and need not be repeated here. In the following we will only focus on the specific way these storylines are translated into alternative fertility, mortality, migration and education

Table 1
Matrix with shared socioeconomic pathways definitions for the demographic and human capital component.

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)

scenarios for different groups of countries. Three groups of countries have been distinguished: "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 of "Rich-OECD countries", the latter being defined by OECD membership and the World Bank category of high income country (see Table A.1). It is important to note that for this set of general SSPs countries are assumed to stay in the grouping that they start out. This may be unsatisfactory for countries that e.g. are in the midst of a fertility decline and are expected to soon move in the low fertility group or countries such as Singapore that a very rich but at this moment not part of the OECD. But since there is an almost infinite number of ways and times at which countries could change the groupings it was decided that this should be left to users who want to define their country-specific SSPs.

The translation of the five broader SSP narratives into specific demographic assumptions reflects the following logic. Table 1 summarizes these assumptions according to their implications for fertility, mortality and migration.

SSP1: This assumes a future that is moving toward a more sustainable path. In particular the story assumes that educational and health investments accelerate the demographic transition, leading to a relatively low world population. Also, in this storyline the emphasis should shift to strengthening human wellbeing. This definition clearly implies for all three country groups low mortality and high education assumptions. 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, and hence makes further fertility declines unlikely. For this reason for this group of countries the medium fertility assumption was chosen. For all other countries the low fertility assumptions were chosen as implied by the assumed rapid continuation of demographic transition. Migration levels were assumed to be medium for all countries under this SSP.

SSP2: This is the middle of the road scenario that corresponds exactly to the medium variant of the new IIASA-VID-Oxford projections. It combines for all countries medium fertility with medium mortality and medium migration and the Global Education Trend (GET) education scenario.

SSP3: This scenario refers to a fragmented world with an emphasis on security at the expense of international development. 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. Fertility is assumed to be low in the rich OECD countries and high in the two other country groups. Due to the emphasis on security and barriers to international exchange, migration is assumed to be low for all countries.

SSP4: This refers to a world of high inequalities, both between and within countries. There is increasing stratification between a well-educated internationally connected society on the one hand and a poorly educated society that works in labor intensive low-tech industries. In terms of education this is reflected in a special scenario that differs from the standard low-high in the sense that in every country it produces a more polarized education distribution with a certain group of very highly educated (which is bigger in the rich OECD countries) and large groups with low education. In terms of fertility at the national averages this implies continued high fertility in today's high fertility countries and continued low fertility in both groups of low fertility countries. For mortality the high fertility countries are assumed to suffer from high levels whereas the other two groups have medium mortality. Migration is assumed to be at the medium level for all countries.

SSP5: This refers to a world that stresses technological progress and where economic growth is fostered by rapid development of human capital. This is reflected in high education assumptions and low mortality assumptions across all countries. For fertility again the pattern is strongly differentiated, with relatively high fertility assumed for the rich OECD countries (as a consequence of high tech 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.

In Table 1 these choices for scenario definitions are summarized the specific choices made result from a lengthy interactive discussion process among the persons and institutes involved in this SSP effort. As discussed above, only SSP2 was taken to be identical in terms of the fertility, mortality and migration assumptions to the "medium" scenario of the new Wittgenstein Center projections (WIC-SSPs1.0 called "IIASA-WIC Population V9" in the SSP-Database https://secure.iiasa.ac.at/web-apps/ene/SspDb/). These assumptions are described in detail in KC et al. (2013). The data and assumptions used for the projections presented in this paper are labeled WIC-SSPs 1.0 reflect our work as of January 2013 and differ slightly from the more recent WIC-SSPs 1.1 that are described in the KC et al. (2013). One difference lies in the migration baseline which is due to the fact that the UN released a new update on global migration stocks that was used to re-estimate the earlier rates of migration flows. Differences are only sizeable for small islands and for developing countries with previously unreliable data. In addition to migration, assumptions for fertility trends in the near term in a few low-fertility countries were adjusted with new evidence of postponement of fertility among young women due to recent economic recession that started in 2008. Lastly, baseline education distributions for three countries (Bolivia, Guinea, and Portugal) were corrected. Bolivia and Guinea had very minor changes however, for Portugal, the proportions with no education or incomplete was too high in January version. Due to the marginal nature of these adjustments the results for longer term population aggregates differ only marginally.

With respect to fertility, the assumed country-specific trajectories result from a model that samples from the collective experience of all countries that once were in a similar standing, with respect to the fertility transition, and then adjusts these modeled values somewhat through the country-specific information, derived from the expert argument evaluation exercise and the conclusions of the meta-expert meetings. While typically the resulting trajectories are not very different from those assumed in the UN 2010 assessment, a significant difference lies in the fact that the long term convergence level for low fertility countries is assumed to be 1.75 (rather than 2.1 as in United Nations, 2011). The "high" and "low" fertility scenarios were 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 started with those empirically observed in individual countries and then were generally assumed to converge to a global pattern over the coming decades.

"Medium" mortality assumptions were made on the basis of a global conditional convergence model, under which it was 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 two years in life expectancy per decade. For the "high" and "low" scenarios it was generally assumed that life expectancy would increase one year per decade faster or slower than in the "medium" case. For AIDS effected countries in Sub-Saharan Africa special assumptions were 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 Garbero and Pamuk (2013), Caselli et al. (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.

Finally, the different education scenarios require a word of clarification. The Global Education Trend (GET) scenario is based on a Bayesian model that estimates the medium future trajectory in education-specific progression rates to higher levels from the cumulative experience of all countries over the past 40 years. The resulting education trajectories for each country are not only considered to be the "medium", but they are also used as the standard against which all the future education-specific fertility and mortality trajectories are being derived from, assumptions of overall fertility and mortality levels. 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, and hence education progression, 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 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 to CER (and hence still more pessimistic), 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 also produce a more polarized society.

4. Results

In terms of total world population size the trajectories resulting from the five SSPs stay very close to each other until around 2030 (see Fig. 1). This is due to the momentum of population growth and the fact that the differences in the assumed trajectories of the components only phase in gradually. By the middle of the century already a visible differentiation appears with the range between the highest (SSP3) and the lowest (SSP1) trajectories spanning 1.5 billion. As expected, during the second half of the 21st century the range opens up much more with the SSP3 reaching 12.6 billion in 2100 and SSP1 falling to 6.9 billion which is lower than today's world population. The medium SSP2 comes to lie at the middle with 9.2 billion in 2050 and 9.0 in 2100. SSP4 and 5 have greatly differing assumptions in different sets of countries and therefore at the global level fall in between the extremes, with SSP4 being slightly above SSP2 and SSP5 above SSP1.

But as discussed above these SSPs produce much more information than just total population size. They give for every country and for every point in time for each SSP complete distributions by age, sex and level of educational attainment. This rich data is conveniently summarized visually in the form of age pyramids by level of education as shown in Fig. 2. All the underlying numerical information is available online under https://secure.iiasa.ac.at/web-apps/ene/SspDb/.
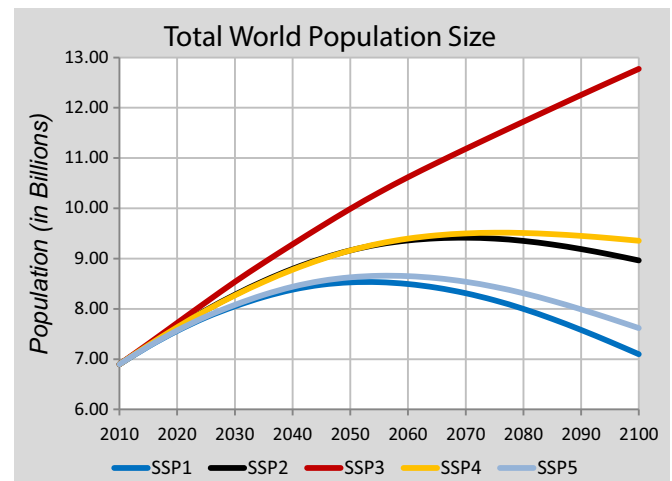
Fig. 1. Trends in total world population size to 2100 according to the five SSPs.
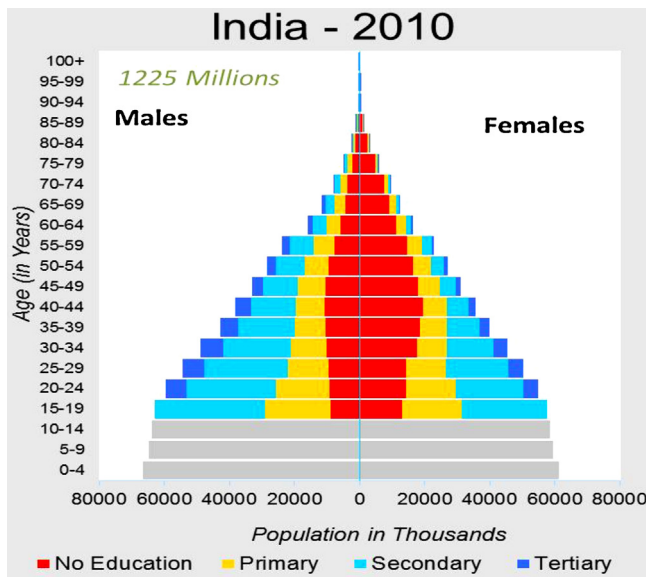
Fig. 2. Example for an age- and education-pyramid: India 2010.

Fig. 2 shows the empirically given age- and education pyramid for India for 2010. To make the picture 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. Due to the past high fertility rates and the resulting young age distribution the shape of the Indian age pyramid still looks roughly like a pyramid, although due to recent fertility declines the steps for the age groups below age 20 have become progressively more narrow. With respect to the education distribution, the figure clearly indicates that at all ages women in India are less educated than men, but for younger age-groups this gender education gap has been somewhat reduced. For all women above age 40 the majority is without any formal education. For younger cohorts the educational attainment has gradually improved. In particular for the age groups 15–24 already around half of all women have received at least junior secondary education as a result of recent government efforts to expand education particularly in rural areas. For men the educational attainment has

always been higher in any given age group and over time the average education has also significantly improved.

Fig. 3 gives the age- and education-pyramids as projected for India under the three scenarios as defined for SSP1, SSP2 and SSP3. Since most of the scenario assumptions (except for mortality) affect the younger age groups and the time horizon is only 40 years, the three pyramids are very similar for the elderly population but differ greatly for the younger ones. Most significantly, the shape of the pyramid varies greatly from SSP1 where much higher female education together with lower assumed education-specific fertility rates result in much lower birth rates which lead to a narrowing of the base of the age pyramid. SSP2 refers to the scenario that is considered as medium scenario with some moderate expansion of education together with more moderate declines in education-specific fertility rates. SSP3 in contrast, gives the picture of a stalled development both with respect to education as well as fertility declines. As a consequence the pyramid is much broader at the bottom and the total population of India is much higher. Aside from the different age and education structures of these scenarios over the coming 40 years the difference between SSP1 and SSP3 is already more than 400 million additional people. As shown in Table 2 below, by the end of the century this difference between SSP1 and SSP3 for India alone will increase to an incredible 1.5 billion people, which is much higher than India's total population today.

The following figures and tables provide summary indicators for the different SSPs and different points in time that have been derived from the fuller age–sex–education-specific projections as described above. This information will be presented in the form of aggregates for major world regions, the world as a whole as well as for 12 selected countries, two from each world region. The more detailed information for all countries is provided in the on-line data base. The presented indicator of Mean Years of Schooling (MYS) as a summary indicator for the average level of education of the adult population that is population among economists but does not reflect the distribution of educational attainment. The method of calculating Mean Years of Schooling presented in this paper is described in KC et al. (2010) and reflect our work as of January 2013 (WIC-SSPs 1.0) which differ from the more recent WIC-SSPs 1.1 that are described in KC et al. (2013).

Table 2 as well as Figs. 4 and 5 show that for the world as a whole the different SSPs cover a broad range of not only total population sizes but that they are also associated with different age and education distributions. As described above, SSP2, which also
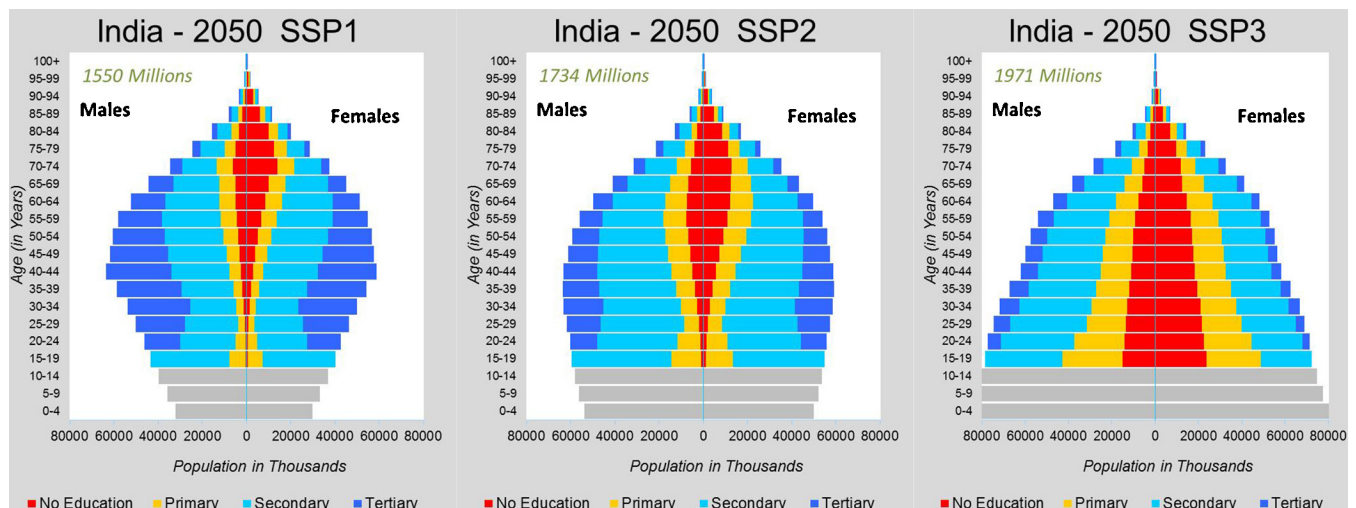

Fig. 3. Population of India by age, sex and educational attainment under SSP1, SSP2 and SSP3 scenario.

Table 2
Total population size and mean years of schooling among adult population aged 15 years and above for major world regions and selected countries.

Region	Year	Population (in millions)					MYS				
		SSP1	SSP2	SSP3	SSP4	SSP5	SSP1	SSP2	SSP3	SSP4	SSP5
World	2010	6871	6871	6871	6871	6871	8.6	8.6	8.6	8.6	8.6
	2050	8461	9166	9951	9122	8559	12.1	11.2	9.0	8.7	12.1
	2100	6881	9000	12,627	9267	7363	14.1	13.4	8.3	8.1	14.2
Africa	2010	1022	1022	1022	1022	1022	5.8	5.8	5.8	5.8	5.8
	2050	1764	2011	2333	2251	1737	11.0	9.7	6.3	5.7	11.0
	2100	1865	2630	3947	3622	1808	13.7	12.7	6.4	5.8	13.7
Asia	2010	4141	4141	4141	4141	4141	7.9	7.9	7.9	7.9	7.9
	2050	4734	5140	5656	4965	4721	11.8	10.9	8.8	8.5	11.8
	2100	3293	4417	6712	4076	3300	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. & 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	1085	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
China	2010	1341	1341	1341	1341	1341	8.8	8.8	8.8	8.8	8.8
	2050	1225	1263	1307	1183	1225	12.1	11.7	10.9	10.5	12.1
	2100	644	767	1028	555	645	13.9	13.5	11.2	11.3	13.9
Republic of Korea	2010	48	48	48	48	48	12.6	12.6	12.6	12.6	12.6
	2050	48	46	41	44	51	15.0	15.0	14.9	14.8	14.9
	2100	32	30	18	24	42	15.5	15.5	15.2	15.0	15.5
India	2010	1225	1225	1225	1225	1225	6.0	6.0	6.0	6.0	6.0
	2050	1550	1734	1971	1601	1547	11.6	10.1	7.1	6.8	11.6
	2100	1138	1603	2609	1169	1134	14.4	13.7	7.3	7.4	14.4
Indonesia	2010	240	240	240	240	240	8.5	8.5	8.5	8.5	8.5
	2050	271	288	307	261	269	12.4	11.8	10.3	9.8	12.4
	2100	184	228	292	152	180	14.8	14.3	10.6	10.7	14.8
Germany	2010	82	82	82	82	82	15.6	15.6	15.6	15.6	15.6
	2050	82	79	67	75	92	16.6	16.4	16.2	16.0	16.6
	2100	67	67	38	52	99	17.2	17.0	16.3	16.1	17.1
Russian Federation	2010	143	143	143	143	143	10.6	10.6	10.6	10.6	10.6
	2050	131	137	134	127	138	11.3	11.1	10.8	10.3	11.3
	2100	93	123	149	88	102	11.5	11.3	10.8	10.2	11.5
Kenya	2010	41	41	41	41	41	9.2	9.2	9.2	9.2	9.2
	2050	70	78	96	92	68	13.6	12.8	9.2	8.4	13.6
	2100	72	96	161	145	67	15.0	14.5	9.3	9.0	15.0
South Africa	2010	50	50	50	50	50	9.6	9.6	9.6	9.6	9.6
	2050	62	63	62	56	65	12.7	11.7	10.4	9.9	12.7
	2100	49	58	71	39	52	13.9	13.3	10.4	10.6	13.9
Egypt	2010	81	81	81	81	81	7.6	7.6	7.6	7.6	7.6
	2050	113	125	141	112	111	12.3	11.8	9.8	9.3	12.3
	2100	97	131	198	91	94	14.1	13.7	10.1	10.1	14.1
Turkey	2010	73	73	73	73	73	7.3	7.3	7.3	7.3	7.3
	2050	87	96	109	92	87	11.3	10.4	8.1	7.6	11.3
	2100	66	90	149	73	66	13.7	13.1	8.2	7.9	13.7
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
Brazil	2010	195	195	195	195	195	8.1	8.1	8.1	8.1	8.1
	2050	215	232	254	215	213	11.5	10.9	9.7	9.2	11.5
	2100	141	188	276	135	139	13.7	13.1	10.0	9.9	13.7

is considered as a medium scenario for population trajectory, shows a continued increase of world population size resulting in 9.17 billion in 2050, then peaking around 9.4 billion in the 2070s 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 the International Institute for Applied Systems Analysis (Lutz et al., 2008b) as well as the United Nations projections up to 2010 (United Nations, 2009). The UN 2010 assessment (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 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 2012 UN assessment (UN 2013) also does not result in a peaking during this century predominantly because it assumes higher fertility trajectories in Africa than it did in previous assessments. Since in several big African countries (such as Nigeria) there is even huge uncertainty about the current levels of fertility, experts tend to differ considerably about the likely future fertility levels.
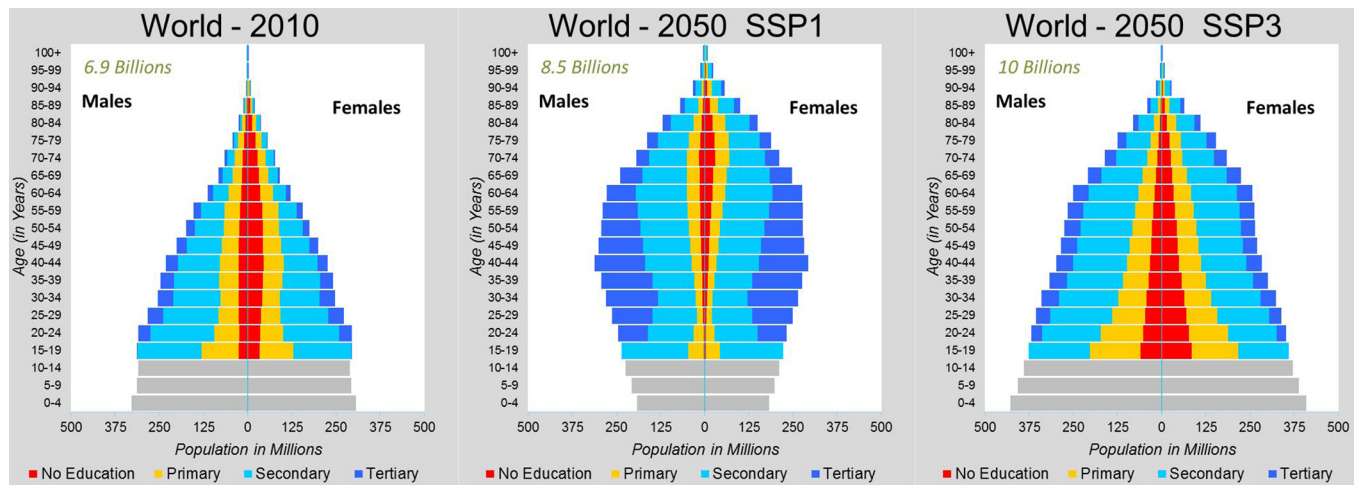
Fig. 4. Population of the World in 2010 by age, sex and educational attainment and in 2050 under SSP1 and SSP3 scenario.

In a nutshell, the uncertainty range of future world population size (from 6.9 billion under SSP1 to 12.6 under SSP3 in 2100) 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 to 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 in the section describing the scenario assumptions above, 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 is a major factor influencing population growth. Lutz and KC (2011) have recently shown that even when assuming identical education-specific fertility trends, different scenarios about future female education levels already can lead to a difference of more than 1 billion in world population by 2050. When education-specific fertility levels are also different across scenarios (as is the case for the SSPs) the inter-scenario differences are 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.

Fig. 5 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 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 (Mean Years of Schooling 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, as will be discussed in Section 2 above. Even under the medium SSP2 scenario the global Mean Years of Schooling 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 cases 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 the above described momentum. While under SSP3 there is a parallel stagnation for all education groups, SSP4 shows an interesting polarization as is suggested in the storyline for that SSP: Both the group of completely uneducated people as well as the group with tertiary education are increasing in size while the middle categories become less frequent. While the overall mean years of schooling of these two different scenarios are quite similar the full education distributions are very different. This is another point in case for representing and analyzing the full distributions and not only the Mean Years of Schooling as is done in many economic growth models.

A similar polarization is shown within countries in Fig 6. with the example of Kenya. While SSP1 shows that with significant further investments in education over the coming decades, Kenya by 2050 could already reach an education structure (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 Kenya's population will "only" increase from currently 41 million to 72 million by the end of the century, under SSP3 it will increase by a factor of four to an incredible 161 million. Again, SSP4 shows a clearly more polarized development than SSP3 although the mean years of schooling are quite similar.

Finally, several of the studies about the effects of education discussed in Section 2 show that the educational attainment distribution of younger adult women (aged 20–39) is of specific critical importance. This is evidently the case with respect to
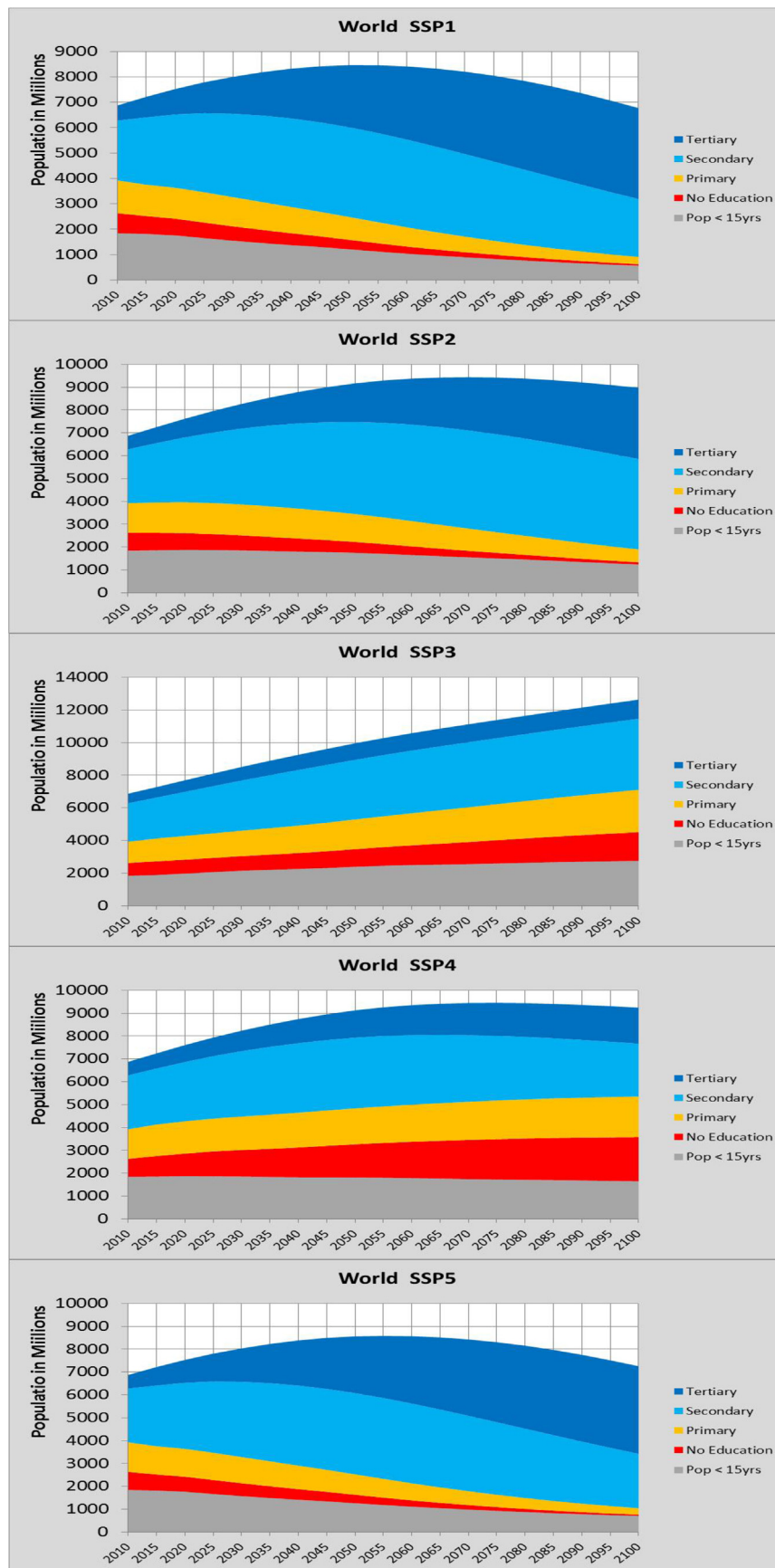
Fig. 5. Population of the World in 2010–2100 by broad age-group and educational attainment under SSP1–SSP5 scenarios.
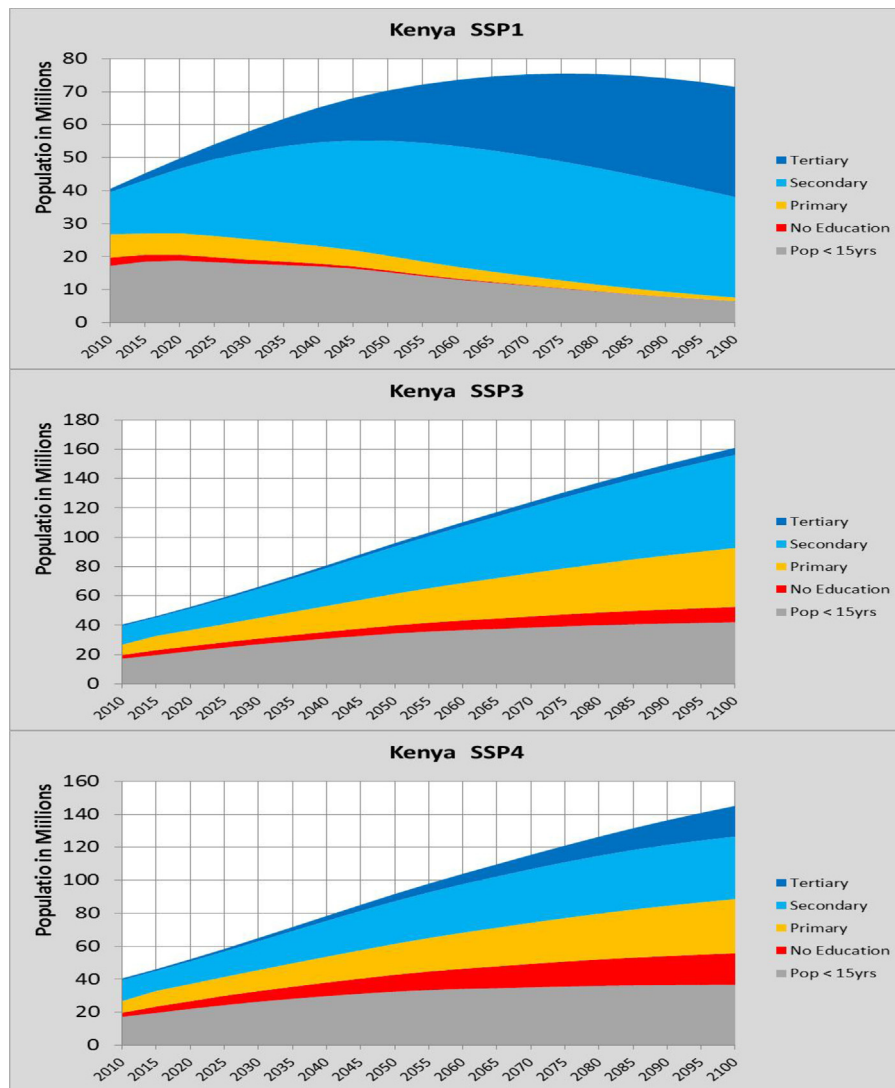
Fig. 6. Population of Kenya in 2010–2100 by broad age-group and educational attainment under SSP1, SSP3, and SSP4 scenarios.

Table 3
Proportion of female population aged 20–39 by region, year, level of educational attainment and SSP scenario (in %).

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	1	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

fertility because it covers the prime childbearing ages. It has also been shown to be the key factor for health and mortality (in particular of children but also other household members) because women tend to make decisive household decisions. Hence, female education is also closely related to household choices with respect to energy consumption and adaptation. Lutz et al. (2010) even showed that for quality of governance and democracy female education tends to be some what more relevant than male. Several of these studies show that indeed the distribution matters and not only the means. Table 3 gives these distributions at the level of major world regions. They illustrate for instance the significant differences between SSP2, 3 and 4 for 2100 in Africa where the proportion of women without any schooling is 0%, 33% and 41% respectively. As discussed above, this can have far reaching implications in particular to the future adaptive capacity of societies to unavoidable climate change.

5. Conclusions

The above described new population scenarios by age, sex and level of educational attainment present a major step forward as compared to 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 asdescribed along the three key dimensions age, gender and level of education. It also covers the "human core" of what the SSP narratives try to capture in terms of the socioeconomic challenges to both mitigation and adaptation because all three dimensions are closely linked to the capacities of human populations to deal with these challenges. In particular they also help to address the differential vulnerability of population in the sense that it not only matters where you are but also who you are in terms of your capabilities and adaptive capacity. The SSPs are thus a key component of assessing what constitutes "dangerous interference" with the climate system (as stated in the UN Framework Convention on Climate Change) in terms of anticipating the impacts that alternative paths of future climate change may have on human wellbeing under different scenarios of socioeconomic development and adaptive capacity.

These three dimensions as explicitly and quantitatively modeled and projected in the above described scenarios can also be directly related to the education goals (universal primary education and gender equity) of the Millennium Development Goals and indirectly to the health and poverty goals. They also directly relate 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 the three components of the Human Development Index) are explicitly included in the set of indicators that shape the above described human core of the SSPs. 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. This will help to project the third component of the Human Development Index (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.

Acknowledgment

Appendix A

Table A.1
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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