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Meeting the Sustainable Development Goals leads to lower world population growth

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Abstract

Here we show to what extent expected world population growth will be lower as a consequence of implementing the recently agreed Sustainable Development Goals (SDGs). The SDGs include specific quantitative targets on mortality, reproductive health and education for all girls by 2030, which will directly and indirectly affect future demographic trends. Based on a multi-dimensional model of population dynamics that stratifies national populations by age, sex and level of education with educational fertility and mortality differentials, we translate these goals into SDG population scenarios resulting in population sizes between 8 and 9 billion in 2100. Since these results lie outside the 95 percent uncertainty range given by the 2015 UN probabilistic population projections we complement the study through sensitivity analyses of these projections that suggest that those uncertainty intervals are too narrow because of uncertainty in baseline data, conservative assumptions on correlations, and the possibility of new policies influencing these trends. This analysis quantitatively illustrates the view that demography is not destiny and policies, particularly in female education and reproductive health, can greatly contribute to reducing world population growth.

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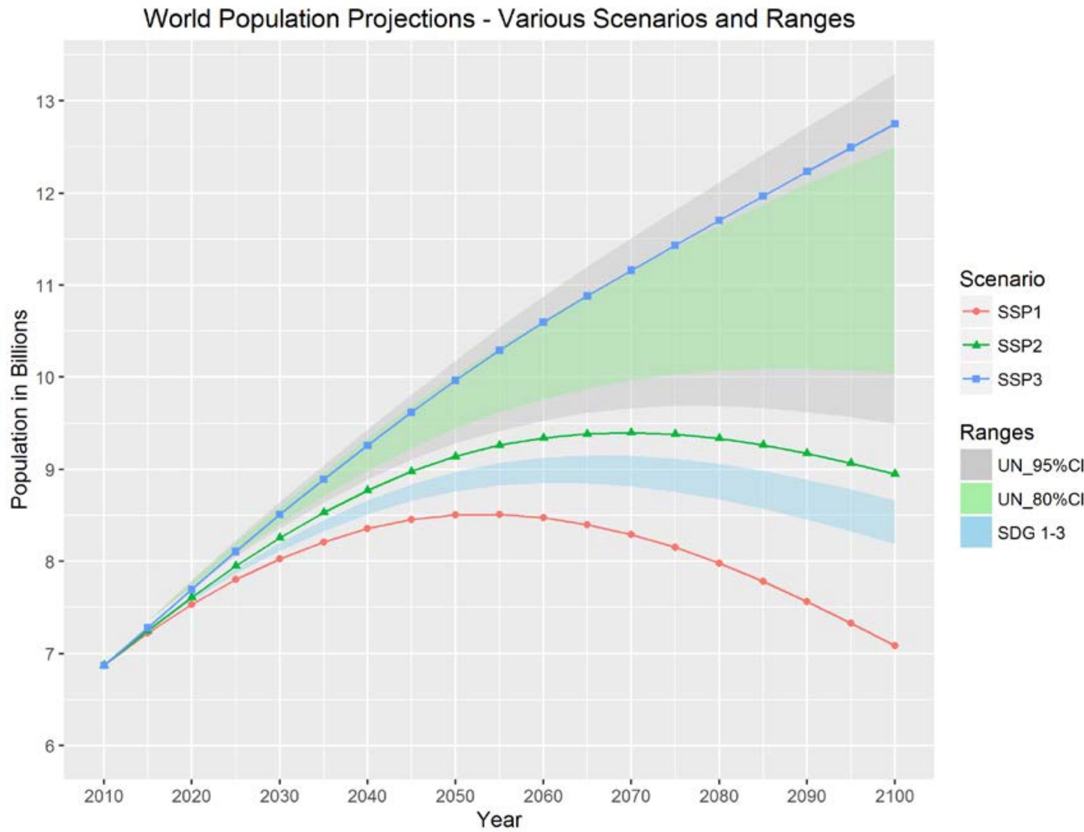
1 Introduction

Today, the future of world population growth looks more uncertain than a decade ago, due to a controversial recent stall of fertility decline in a number of African countries and a controversy over how low fertility will fall below replacement level, particularly in China (Basten et al. 2014). Probabilistic population projections try to quantify these uncertainties based on statistical extrapolation, expert judgement or a blend of both (Lutz et al. 1999; United Nations 2015). While such projections published in 2008 (Lutz, Sanderson, et al. 2008) gave a 95 percent interval for the global population ranging from 5.2 to 12.7 billion in the year 2100, probabilistic projections published by the UN Population Division in 2015 based on a different approach give a much narrower 95 percent interval ranging from 9.5 to 13 billion in 2100 (United Nations 2015). Another recent set of world population projections defined alternative global population scenarios in the context of the work of the IPCC (Intergovernmental Panel on Climate Change) and related Integrated Assessment models. These so-called SSPs (Shared Socioeconomic Pathways) show in the medium scenario a peaking of world population around 2070 at 9.4 billion, followed by a decline to 9 billion by the end of the century with high and low scenarios reaching 12.8 and 7.1 billion respectively (Lutz et al. 2014; O'Neill et al. 2015). As will be discussed below, these differences in world population projections result from different approaches taken in terms of disaggregating national populations and defining assumptions for the future.

In September 2015 the leaders of the world under the umbrella of the United Nations in New York subscribed to an ambitious set of global development goals, the Sustainable Development Goals (SDGs) which unlike earlier goals give specific targets which apply to all countries of the world. If actually pursued, several of these targets, particularly in the fields of health and female education will have strong direct and indirect effects on future population trends mostly working in the direction of lower population growth. In this paper, we endeavor to translate the most relevant of these goals into SDG population scenarios and thus quantify the likely effect of meeting these development goals on national population trajectories. The results show that this would result in world population peaking around 2060 and reaching 8-9 billion by 2100, depending on the specific variant of the SDG scenario (see Figure 1). This analysis quantitatively illustrates the view that demography is not destiny and policies, particularly in the field of female education and reproductive health, can greatly contribute to reducing world population growth.

Figure 1. Future world population growth as projected according to the three SSP scenarios, the range of SDG scenarios presented here and the probabilistic ranges given by the UN population projections



The various variants of the SDG scenario specified here, while consistent with the SPP scenarios, all lie substantially below the lower bound of the 95 percent band given by the most recent probabilistic UN projections (see Figure 1). This fact evidently poses serious questions to the reader. For this reason, after describing the definition and calibration of the demographic SDG scenarios the paper will have a second section in which we perform sensitivity analyses of the UN population projections, using their own software, which suggest that the uncertainty range given by them underestimates the full uncertainty of possible future world population growth. We study the sensitivity with respect to possible base-line errors and correlation and show how explicit incorporation of heterogeneity by level of education changes the picture. Our main point, however, is that the UN model rests on the strong assumption of structural continuity of past trends extrapolated over the full 21st century which is incompatible with the aspiration of the SDGs as an historically unprecedented effort that will change the course of global development.

2 Translating the Sustainable Development Goals (SDGs) into corresponding population scenarios

The SDGs as approved by the United Nations General Assembly in the presence of most heads of state in September 2015 contain 17 goals and 169 more specific targets. Unlike the previous Millennium Development Goals (MDGs) which were set in 2000 with the target year 2015, the SDGs refer not only to developing countries but to all countries in the world and they also include the environmental dimensions in addition to social and economic dimensions. Many of them are motivated by their longer term future impacts – such as the energy and climate change goals – but the goals themselves have a target year of 2030 in order to allow a better monitoring of the actual achievements of these goals. Some of the goals and associated targets are in precise numerical form and refer to existing indicators, others are more qualitative in nature and refer mostly to the direction of change.

Population trends are not explicitly mentioned in the SDGs but several of the SDGs are directly or indirectly related to future demographic trends. The SDG goals related to child mortality, maternal mortality, causes of death and reproductive health can be more or less directly translated into future mortality and fertility pathways. To quantitatively assess the indirect effects of improvements in education on fertility and mortality we utilize recent advances in multi-dimensional population modelling, namely the three-dimensional analysis by age, sex and level of education (Lutz & KC 2011). This work is based on the insight that level of education is the most important source of observable population heterogeneity after age and sex. Consistently, more educated women experience lower fertility and lower child mortality – in particular during the process of demographic transition – and more educated men and women exhibit higher life expectancies. This relationship has recently been corroborated (Lutz & KC 2011) and the case for functional causality from improvements in female education to declining fertility has been made (Lutz & Skirbekk 2014). It has been shown that even under identical sets of education-specific fertility trajectories, different education scenarios alone can induce variation in total world population size of more than one billion by mid-century (Lutz & KC 2011).

We define special scenarios translating the SDGs into population trajectories against the background of a recent set of scenarios developed for and by the international climate change research community, the so-called Shard Socioeconomic Pathways (SSPs) (O’Neill et al. 2015). The “human core” of the SSPs also consists of population scenarios by age, gender and level of education for all countries to 2100 (Lutz et al. 2014). In the following we will refer to three of the five SSPs, namely SSP1 (rapid development), SSP2 (middle-of-the-road) and SSP3 (stalled development). While the methodology and the empirical data set of the SSPs will be used here, we will redefine some of the specific assumptions of future fertility, mortality and education with reference to the SDGs and their specific targets. As will be specified in detail in the following paragraphs the main underlying idea is that the SDGs will help to speed up the process of demographic transition that otherwise would occur more slowly. In the following translation of the SDGs into population trends the goals are interpreted as a one time booster to development between 2015 and 2030 to be followed beyond 2030 by a more regular speed of development. For this reason the SDG population scenarios will be lower than the middle-of-the-road SSP2 scenario but not as low as the fast development SSP1 scenario which assumes accelerated social development throughout the century. Due to path dependencies of the education expansion and the demographic transition, this 15-year booster will results in education, fertility and mortality levels lower than those of SSP2 for the rest of the century. For readers who think that the development booster caused by the SDGs will continue beyond 2030 for the rest of the century, the SSP1 scenarios is a reasonable approximation although the SSPs have been defined before the SDGs and hence differ in some minor aspects.

3 Operationalizing the education targets

SDG4 which aims to “ensure inclusive and equitable quality education and promote life-long learning opportunities for all” consists of ten more specific targets. The most specific of these targets (4.1) states that “by 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes”. This is also the target that can be directly translated into demographic outcomes in the context of the multi-dimensional population projections methodology mentioned above. Other targets referring to early childhood development, equal access to vocational and tertiary education (without giving quantitative targets), skills for employment, education facilities, scholarships and teacher training highlight other important aspects of education that are more difficult to translate into quantitative models. But there are two further targets with rather specific aspects that can also be partially quantified, namely 4.5 (”By 2030, eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples and children in vulnerable situations”) and 4.6 (“By 2030, ensure that all youth and a substantial proportion of adults, both men and women, achieve literacy and numeracy”). But assuming, that 4.5 is just one specific aspect of the more general Target 4.1 which already includes universal high quality education of **all** boys and girls and that indeed by this all young men and women become literate and numerate, no additional assumptions need to be made.

While universal primary education has already been part of the earlier MDGs, the addition of universal secondary education in the SDGs is new and much more ambitious. This is partly based on recent insights that for poor countries to come out of poverty universal primary education is not enough but it must be complemented by secondary education of broad segments of the population (Lutz, et al. 2008). But assuming universal secondary education by 2030 for countries that currently have still very low primary school enrolment this target may seem overly ambitious. For this reason there have been some discussions within UNESCO and elsewhere whether this target should be interpreted in terms of the somewhat more realistic achievement of universal lower secondary education or whether it actually implies universal completing of upper secondary school which is not even achieved in all industrialized. We account for this difference in interpretation by specifying an alternative SDG education scenario in which only universal lower secondary education is reached in 2030 (SDG2) while the two other ones are based on the literal meaning of the goal that universal upper secondary education is reached by 2030, scenarios SDG1 and SDG3, which differ in terms of their fertility assumptions.

The scenarios of educational expansion underlying the population projections presented here result from a further refinement of the education model presented in Lutz et al. (2014). In summary, we project the share of the population ever reaching or exceeding a given attainment level. This is done separately by country, and gender, but with 'shrinkage' within a Bayesian framework (with weakly informative priors). The mean expansion trajectories are modelled as random walks with drift (and potential mean reversion) and independent noise at a probit-transformed scale. More details about this new education model are given in the Appendix.

4 Translating the health targets into future mortality trajectories

Like many of the other goals, SDG3 ("Ensure healthy lives and promote well-being for all at all ages") consists of some very specific and some rather general targets. There are specific numerical targets on maternal mortality and infant mortality. Less specific but still highly relevant for future fertility trends is Target 3.7 referring to reproductive health and family planning which will be discussed in the fertility section below.

Many other of the 13 specific health targets relate to individual causes of death such as HIV/AIDS, tuberculosis, malaria, water-borne diseases, accidents, substance abuse, chemical pollution and preventable non-communicable diseases in general. It goes beyond the scope of this paper to model in detail how these specific targets on certain causes of death would translate into aggregate mortality rates for all countries of the world. Instead we will refer to a major recent exercise involving over 100 international mortality experts identifying the different forces that will influence future mortality trends and translating them into alternative future mortality trajectories (Caselli et al. 2014; Garbero & Pamuk 2014). Of the three mortality trajectories (high, medium and low) that were defined for all countries the low path corresponds quite well both qualitatively and quantitatively to the health and mortality targets as discussed above. Since this trajectory was also specified in terms of education-specific mortality trends – with more educated women having universally lower child mortality rates and better educated adults living on average longer – the education scenarios discussed above will also indirectly influence the future course of national mortality trends. Furthermore, the effects on education-specific mortality rates of other goals, in particular those referring to eradication of poverty and hunger as well as to improvement of governance are assumed to be already captured by the very optimistic mortality assumptions used for this low mortality trajectory.

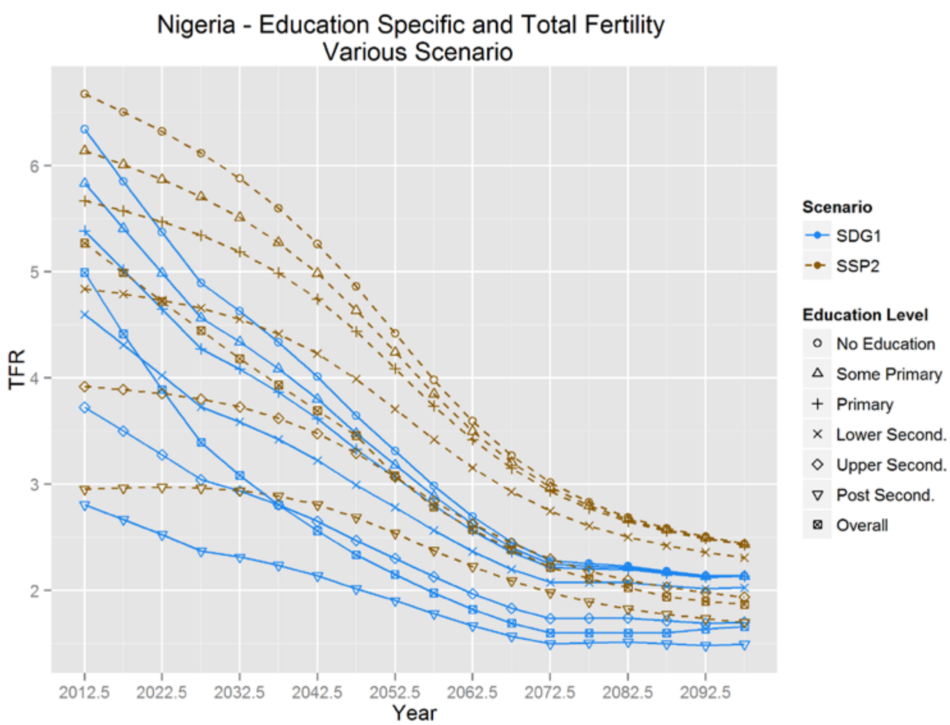
5 Defining education-specific fertility trajectories

In addition to the indirect effect of education on aggregate fertility levels the health SDG includes one target that is likely to affect education-specific fertility rates directly. Target 3.7 states "By 2030, ensure universal access to sexual and reproductive health-care services, including for family planning, information and education, and the integration of reproductive health into national strategies and programmes". While the second part of the target is of more organisational nature, the first directly refers to the concept of meeting the unmet need for contraception and has the potential to directly affect fertility levels through rapidly increasing contraceptive use. The unmet need is usually defined as the proportion of currently married women who are not currently using contraception and say that they do not want another child in the near future. When it comes to estimating the number of births that would be avoided in the hypothetical case that all unmet need would be met it is important to further distinguish between unmet need for birth spacing and for limiting family size. Only the latter can be assumed to have a lasting effect on lowering fertility rates.

Several authors have attempted to come up with quantitative estimates of what would be the effect of meeting the unmet need on national fertility levels. The most comprehensive such analysis is by Bradley at al. (2012) using all available Demographic and Health Surveys (DHS) and applying a more precise definition than before of measuring the unmet need for limiting family. For the global average of all 59 DHS for developing countries they find that in the case of eliminating unmet need the TFR would be 20 percent lower (i.e. 3.3 instead of 4.1 children per woman). They find regional differences with the hypothetical decline being the highest in absolute terms in East and Southern Africa (3.7 as compared to 5.0) and in relative terms in Latin America and Caribbean (2.0 versus 3.0). In West and Central Africa the decline would be the smallest (4.9 versus 5.4) because desired family size is still very high in this part of Africa. Hence, loosely speaking these calculations only refer to the difference between desired and actual family sizes, while education of women also tends to result in lowering the desired family size.

In operationalizing the SDG fertility scenario it is thus a rather straightforward assumption to assume that achieving "universal access to sexual and reproductive health-care services, including for family planning, information and education" will result in 20 percent lower education-specific fertility rates by 2030. Since these services cannot be expected to be established overnight this is implemented by gradually lowering fertility rates from their current levels to a level that is 20 percent lower than in the middle of the road scenario (SSP2) by 2030 (see Figure 2). For the period 2015-2030 this procedure (SDG1 and SDG2) is also equivalent to the assumptions made for education-specific fertility under the Rapid Social Development Scenario (SSP1). After 2030, however, the SSP1 and the SDG1 and SDG2 scenarios start to differ in their fertility assumptions because under SSP1 the low fertility trajectory is assumed to continue while under the SDG scenario narratives there is a gradual return to the middle of the road trajectory. The return will not be abrupt and will only be complete once the overall TFR has reached a level of 1.6 (see the Appendix for more details).

Figure. 2. Assumed education-specific fertility rates for Nigeria under the SSP2 scenario and the 20 percent lower SDG1 scenario assumptions



To further test the sensitivity of the projections to different translations of the SDGs into education-specific fertility rates we also made the more conservative assumption that those rates only decline by 10 percent by 2030 in relation to the middle of the road SSP2 scenario (as opposed to 20 percent in SDG1 and SDG2). The SDG3 scenario thus combines a 10 percent decline in education-specific fertility rates with the assumption of universal senior secondary education by 2030.

6 Migration and other factors

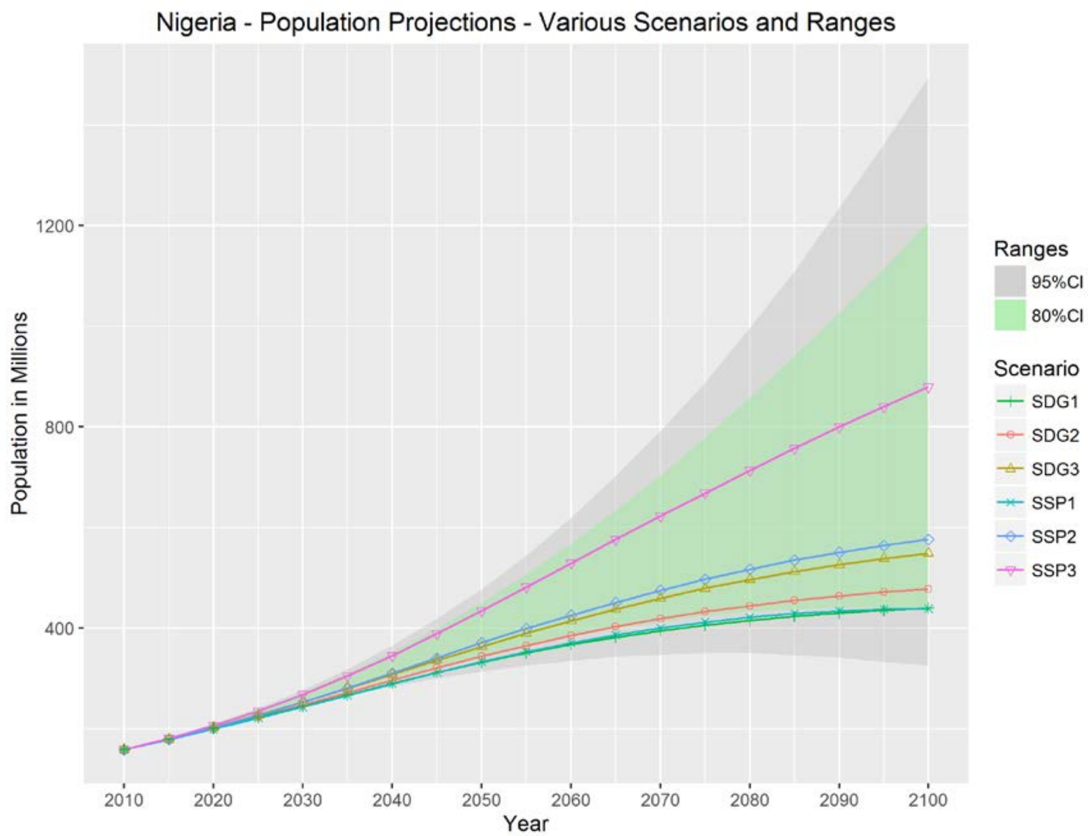
Migration is the third factor (in addition to fertility and mortality) that directly effects future national population sizes. While this factor can have significant effects especially for small populations with high in- or out-migration it is a negligible factor for global population growth, where it only affects the projections through the assumption that migrants have the fertility and mortality rates of the country of destination. Except for stressing the need for orderly migration and the rule of law, the SGDs do not give any specific quantitative targets that would suggest either higher or lower international migration streams in the future. For this reason the migration assumptions of the SDG scenarios are the same as those used for the middle of the road SSP2 Scenario, which are constant in- and out-migration rates that are gradually diminished towards the end of the of the projection period (Lutz et al. 2014).

Several of the other SDGs that have not yet been discussed above – such as end of poverty and end of hunger as well as reduced inequalities, decent work and economic growth, affordable and clean energy, climate action and quality of institutions could have potential indirect effects on future fertility, mortality, migration and education. To study whether these factors are likely to have effects beyond the ones assumed in the SDG scenarios here remains a research topic for the future. But for our attempt to develop a first approximation of demographic scenarios that reflect the SDGs we assume that the specified sets of low fertility and mortality and high education trajectories implicitly include all the other possible indirect effects of different SDGs on those demographic trends.

7 Results

Figures 1 and 3 show the resulting population growth trajectories at the global level and for the case of Nigeria. Table 1 also shows numerical results by continents. More details, including country-specific results are given in the Appendix. As expected from the above listed assumptions SDG1 gives the lowest and SDG3 the highest population of the three SDG scenarios. Against the background of the SSP1 – SSP3 range, the SDG scenarios are towards the lower end, generally below the middle of the road SSP2 and above the rapid development SSP1. As compared to the uncertainty range given by the UN probabilistic population projections at the national level the SDGs tend to fall into the lower quartile of the uncertainty ranges as can be seen in Figure 4 for Nigeria. At the global level, however, all SDG scenarios lie far below the 95 percent range of the UN range. This difference between the national level and global level results in terms of the uncertainty ranges is mostly a consequence of the very low correlations assumed in the UN projections, as will be discussed below.

Figure 3. Nigeria: Resulting population size for SDG1-3 plus SSP1-3 scenarios and UN ranges



The SDG scenarios as defined here result in a world population that still increases to 8.8 to 9.1 billion by mid-century and then levels off and starts a moderate decline to between 8.2 and 9.0 billion by 2100. This is significantly below the medium variant of the UN projections which reaches 9.7 billion in 2050 and 11.2 billion in 2100. This lower global population trajectory is primarily caused by the accelerated fertility declines associated with the female education and reproductive health goals in Africa and Western Asia.

8 Sensitivity analysis of UN probabilistic population projections

In 2012, the UN Population Division first published probabilistic world population projections to 2100 based on a Bayesian model that estimated future national fertility trajectories drawing from the collective experience of all countries for the period 1950-2010 (United Nations 2013). These include crucial model assumptions about the ultimate level of fertility and an eventual increase of fertility in countries that reach very low levels. The 2015 revision of these projections applies a very similar model with a probabilistic mortality component added and updated base-line data (United Nations 2015). As we will show in the following, this extrapolative model is particularly sensitive to small changes in the base-line data for the most recent years. This is also the reason why the 2015 UN assessment yields a significantly higher median global population for 2100 of 11.21 billion as compared to 10.85 billion in the 2012 assessment. For individual countries such a Nigeria, the differences between the two assessments are much bigger as shown below.

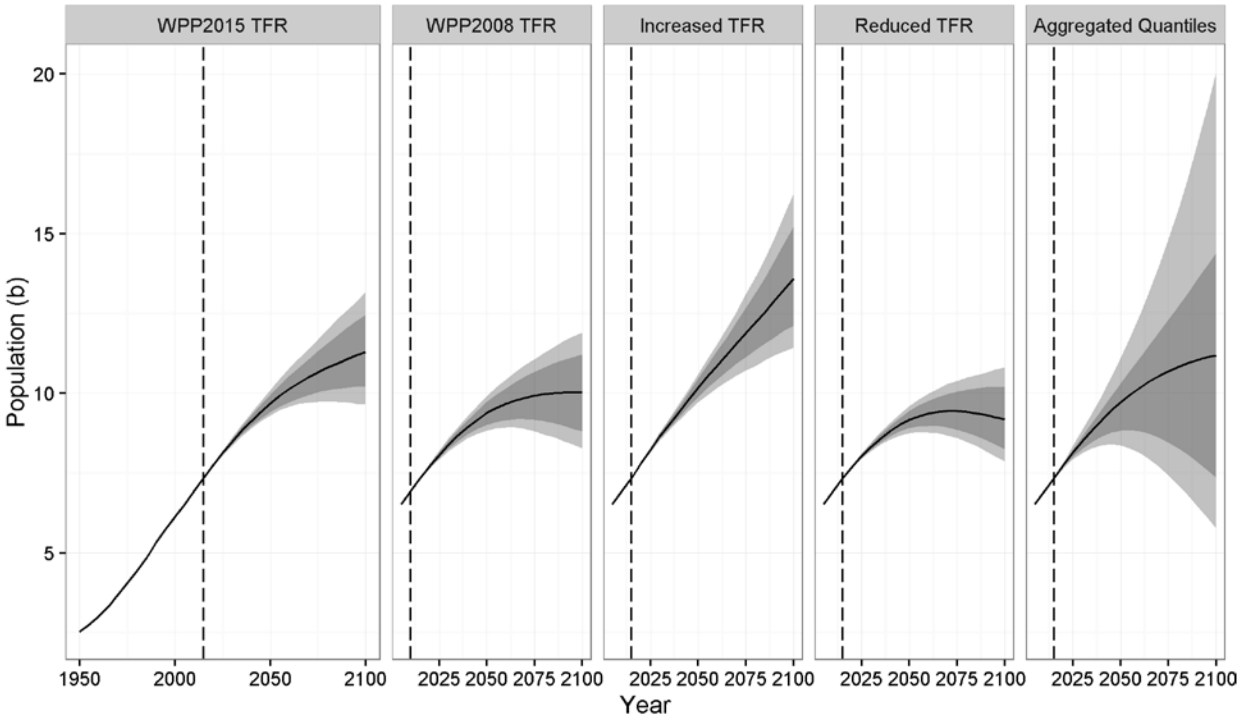
In the following we summarize sensitivity analyses of the UN 2015 projections by relaxing some of its assumptions while using the very same statistical model and software that the UN uses. We first consider the possible effect of uncertainty in the base-line data. In many countries, particularly in Sub-Saharan-Africa, the information about current population size, fertility and mortality levels is fragmentary, with estimates often based on outdated censuses or surveys that may show contradictory results. Nigeria is a case in point. With respect to fertility levels, estimated for the period 2005-10 the UN in 2008 gave a Total Fertility Rate (TFR) of 5.32 which for the 2012 assessment was corrected upwards to 6.00, which is a 13 percent correction. In the 2015 assessment the estimate for 2005-10 was again lowered somewhat to 5.91. This minimal downward correction in the baseline TFR resulted in a major change of the median population size projected for 2100 for Nigeria from 914 million (2012 assessment) to 752 million (2015 assessment). The Demographic and Health Survey (DHS) (DHS Nigeria 2014) gives a TFR of 5.5 for 2010-13 which, if implemented in the UN model would give a still much lower projection. For Kenya, the assumed/estimated TFR values for 2010-15 changed from 4.41 (2012 assessment) to 4.44 (2015 assessment) resulting in an upward correction of the projection while the 2014 DHS (DHS Kenya 2015) already gives 3.9 for the same period, a difference of about 15 percent. In China, still the world's largest national population, there is also considerable uncertainty concerning its recent TFR, with estimates ranging from 1.8 to 1.2 (Zhao & Guo 2010), an uncertainty of 20 percent up or down from 1.5.

We present three different sensitivity analyses with respect to uncertainty in the base-line data. First, we only use the UN's own fertility base-line data as they have been used in successive assessments from 2008 to 2015 and apply the identical probabilistic model as used in 2015. The first two panels on the left of Figure 5 present the results of this exercise showing that the two assessment only published seven years apart show an even qualitatively very different pattern for the 21st century. Based on the 2008 base-line the same model shows a median that levels off and starts to decline before reaching 10 billion. And this median is almost as low as the lower bound of the 2015 assessment. Although the 2015 assessment is clearly based on some more recent data which for some African data seem to imply a slowing of the fertility decline there is great uncertainty about the quality of this data which in our view does not justify a complete change of great narrative for the 21st century, from an anticipated end of world population growth to continued high growth.[1]

To further explore this important issue, we conducted more sensitivity analyses with a focus on countries where base-line uncertainty is the greatest. The third and fourth panels in Figure 5 show the results of projections in which the fertility base-line is assumed to be systematically 10 percent higher or lower than in WPP2015 in the countries of Sub-Saharan Africa, as well as in South Asia and in China, while it remains unchanged for all other countries. The results show that the projection model is so sensitive to possible systematic errors in base-line fertility that the resulting 95 percent uncertainty intervals for the world to the end of the 21st century do not even overlap. While under "reduced TFR" in 2100 the upper end of the 95 percent range is 10.8 billion under the "increased TFR" the lower end of the range is 11.4 billion.

[1] The projection based on the 2015 assessment with the latest observations (2010-15) dropped, to provide a data set of past values with the equivalent size of the 2008 assessment, follows a very similar trajectory as those shown on the left of Figure 4.

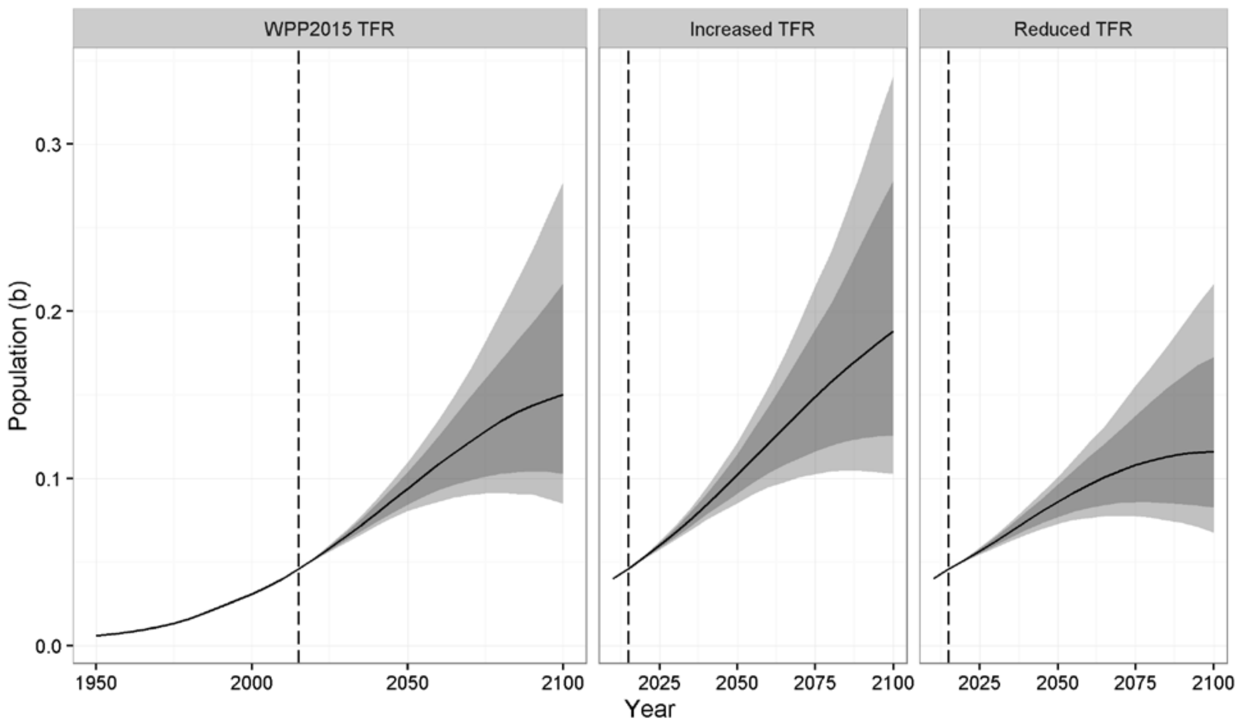
Figure 4. Sensitivity analysis, global level: From left to right the panels show the following projections: UN2015 assessment as published by UN, UN model as applied to base line data in UN2008 assessment, UN model applied to 10 percent higher base line TFR in selected countries, 10 percent lower base line TFR and UN2015 model assuming perfect correlation.



One may argue, that the possibility of a systematic upward or downward bias in base-line TFR is rather unlikely, although it cannot be ruled out due to the same kinds of measurement instruments (such as DHS or related surveys) being used for virtually all African countries. For this reason we also tested the sensitivity to base-line errors in just one country with the base-lines in all other countries of the world remaining unchanged. Figure 5 shows the results for the case of Kenya, a country already discussed above for its contradictory information regarding recent fertility levels. The results show that even without assuming any systematic error across groups of countries the median of Kenya's population size in 2100 in the case of reduced base-line TFR by 10 percent is below the lower end of the 80 percent range of the projections based on increased base-line TFR. In sum, these calculations show the very high sensitivity to possible measurement errors in the most recent data points of purely extrapolative statistical models that do not take any country-specific substantive information about socio-economic or institutional determinants of fertility into account, nor expert knowledge about foreseeable changes.

Another reason for the narrow global uncertainty interval of the UN projections that results in the fact that both the scenarios presented here as well as the UN's own high and low variants lie far outside the 95 percent range is that their probabilistic projections assume virtually no inter-country correlation for the rest of this century. In that case trajectories above expectation in one country cancel against those below expectation in another country. This also explains why for virtually all individual countries the different scenarios discussed here lie within the 95 percent ranges of the UN (see the example of Nigeria in Fig.3) while at the global level they lie far outside. The UN projections, however, do not assume zero correlation. They estimate empirically correlations among short-term fluctuations in national time series and assume that the same pattern of correlation will continue throughout the 21st century. Our replications of the UN projections, however, show that the resulting uncertainty range is only marginally broader than in case of assuming no correlation. This may have to do with the fact that short-term fluctuations in fertility tend to have a lot of noise while longer term trends in the context of the timing of demographic transition may be stronger correlated. Also, in times of increasing globalization, one might expect an increase in correlation over time.

Figure 5. Sensitivity analysis for the case of Kenya. Left panel shows UN2015 assessment results, middle panel shows results when assuming a 10 percent higher base line TFR only for Kenya and right panel shows results coming from a 10 percent lower base line TFR.



Since the given software does not allow one to specify alternative levels of correlation for the future we could only emulate the case of assumed perfect correlation (right panel in Figure 4). This is also the approach taken by the UN for defining its high and low variants where it is assumed that in all countries of the world the TFR is .5 children higher or lower than in the medium variant. The probabilistic uncertainty range resulting from perfect correlation is wider by a factor of five as compared to the "official" probabilistic projections. It also shows, that in probabilistic terms the range between the UN's high and low variants (16.6 to 7.3 billion in 2100) corresponds roughly to 85 percent of the range given by these projections with perfect correlation while they come to lie far outside the 95 percent range of the "official" projections.

9 Discussion

In the context of sustainable development, world population growth is sometimes called the elephant in the room. Many view it as one of the most important factors in causing environmental degradation as well as in making adaptation to already unavoidable environmental change more difficult (Ehrlich & Ehrlich 1990; O'Neill et al. 2001; The Royal Society 2012). At the same time it is widely perceived as a politically sensitive topic (Bongaarts 2016) and indeed the 1994 International Conference on Population and Development explicitly opposed the setting of "demographic targets". Fertility decisions are considered as a private matter with the role of the state only to assure reproductive rights and to provide reproductive health services. It is presumably for this reason that the new SDGs do not mention population growth or fertility explicitly in any of the 169 targets. Yet, many of the goals and targets deal with factors that directly or indirectly influence fertility levels and thus population growth.

In this paper we tried to quantify the likely effects of some of the most relevant SDG targets in the areas of health and education. In doing so we build on the recent literature that has quantified the effects of education, in particular female education, on fertility, child mortality and life expectancy in general. There is increasing evidence that indeed education, particularly in countries in demographic transition, has a direct causal effect on lowering desired family size and empowering women to actually realize these lower fertility goals with availability of reproductive health services also helping to enhance contraceptive prevalence. Since universal primary and secondary education of all young women around the world is a prominent goal in its own right (SDG 4) and is politically unproblematic – except for a few fundamentalist groups that oppose girl's education – this focus on education provides a strong and convincing policy paradigm which in addition to all the other beneficial consequences of education also leads to lower fertility (Lutz 2014).

Lowering child mortality and decreasing adult mortality from many preventable causes of death are also politically unproblematic policy priorities. For child mortality the SDGs give precise numerical targets which could be directly translated into demographic trajectories and could be complemented through estimates of the indirect effects of better education of survival at all ages. This exercise could also built on the recently developed set of SSPs which are now widely used among the Integrated Assessment and climate change research community and for which alternative projections of populations by age, sex and level of educational attainment provide the "human core". These scenarios also blend the effects of education with those of income and better food security which are other important SDGs. While clearly more research is needed to study the synergies between the different SDGs (Nilsson et al. 2016) and their possible additional impacts, the range of population trajectories resulting from different specifications of the SDG scenarios presented in this paper would likely not change significantly and hence present a good first approximation.

It was also noted that the population growth trajectories that would result from the successful implementation of the SDGs – while consistent with the SSP scenarios – will come to lie far outside the 95 percent uncertainty range given by the 2015 UN probabilistic population projections. For this reason we conducted sensitivity analyses of the UN projections using their own software and came to the conclusion that the uncertainty ranges as presented are likely too narrow for considering the full range of possible future trajectories including possible structural discontinuities. We presented analyses showing the great sensitivity to possible errors in base-line estimates of fertility and assumptions concerning the correlation among national trends. Both aspects suggest the consideration of markedly wider uncertainty ranges. There are further problems with the statistical extrapolation model used by the UN which go beyond the scope of this paper. In particular, the fact that all national fertility trends are given equal weight, irrespective of whether they summarize the experience of just a few thousand couples or hundreds of millions of couples. Since, in fertility, couples and not states are the relevant units of decision making and many countries are highly heterogeneous with respect to reproductive behavior, one could well argue that couples rather than countries are the independent units of observation that should be given equal weight, which would greatly change the projection results. Again, this would work in the direction of a broader range of uncertainty.

The world community under the leadership of the UN launched an unprecedented global effort to strongly accelerate global efforts in development within the framework of the SDGs. Many of these goals, if reached, will have important effects in lowering future fertility and mortality rates, particularly in the least developed countries. However ambitious they are, leaders of all countries and the entire UN system have committed themselves to do whatever it takes – which may include unconventional measures – to reach the specified targets, with progress being closely monitored. This new global effort is by definition and by its explicit aspiration a discontinuity of past trends and hence cannot be captured by statistical extrapolation of past trends.

More importantly, the analyses presented in this paper shows that, indeed, demography is not destiny and policies in the field of reproductive health and female education can have very significant longer term impacts on global population growth. More specifically, they also illustrate how progress towards reaching the SDGs can result in accelerated strictly voluntary fertility declines that could result in a global peak population already around mid-century. These strong effects of the SDGs on lowering global population growth in a politically unproblematic and widely agreed way provides an additional rationale for vigorously pursuing the implementation of the SDGs.

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11 Appendix – Materials and Methods

In this Appendix we provide additional relevant information that could not be covered in the limited space available in the main body of the paper. It will be structured into three parts: (a) a more detailed explanation of the reasoning and methodology behind the specific translation of targets stated in the Sustainable Development Goals (SDGs) into demographic scenario assumptions for the resulting SDG population scenarios; (b) a listing of results of the SDG scenarios for world regions and major high fertility countries; and (c) a short technical note on how precisely the sensitivity analysis of the UN probabilistic projections was carried out.

11.1 Translating the Sustainable Development Goals (SDGs) into corresponding population scenarios.

The SDGs contain 17 goals and 169 more specific targets. Unlike the previous Millennium Development Goals (MDGs) which were set in 2000 with the target year 2015, the SDGs refer to all countries in the world and they also include the environmental dimensions in addition to social and economic dimensions. The SDGs are not binding but they are aspirational and present the most comprehensive expression of development goals by the international community so far. In the following we refer to the Goals and Targets as listed on www.gloablgoals.org.

Many of the SDGs are directly or indirectly related to future demographic trends. In the following we will present a brief overview of how some of specific targets and goals can be assumed to influence future fertility, mortality and migration trends and, if they are successfully implemented, how would the resulting trends be different from what would be considered to be the most likely future trajectory in the absence of such additional development efforts. Of all the 169 targets some of the health and mortality related targets associated with SDG4 are most directly linked to future mortality trends, in some cases – such as for infant mortality – even specific numerical targets for the period 2015-2030 are given. Target 4.7 on universal access to reproductive health services and family panning will also be relevant for future fertility trends in countries where this is not yet the case. SDG1 and 2 on the eradication of extreme poverty and on food security also will have likely direct impacts on mortality and indirect impacts on fertility. Furthermore, due to the strong association between female education and fertility SDG4 on universal primary and secondary education for all girls and boys, this is expected to have strong indirect effects on future fertility rates particularly in countries that are still in the early stages of demographic transition. This relationship has recently been corroborated (Lutz & KC 2011) and the case for functional causality from improvements in female education to declining fertility has been made (Lutz & Skirbekk 2014). Using the tools of multi-dimensional population dynamics, recently alternative population scenarios by age, sex and six levels of educational attainment have been produced for all countries to 2100 (Lutz et al. 2014). As part of this recent effort also the Shared Socioeconomic Pathways (SSPs) which are discussed in the main text have been produced. Here we will use this methodology and the associated set of calibrated base-line data by age, sex and level of education for all countries as the basis for defining and calculating specific SDG population scenarios for all countries. Since the targets of the SDGs have only been specified up to 2030 for an illustration of the longer term impacts of meeting the targets, plausible assumptions for fertility, mortality, migration, and education trends beyond 2030 will have to be developed of the SDG scenario beyond 2030.

11.1.1 Operationalizing the SDG education targets in terms of their effects on fertility and mortality trends

We first discuss the education goal because it has effects on some of the other goals. SDG4 which aims to "ensure inclusive and equitable quality education and promote life-long learning opportunities for all" consists of ten more specific targets. The most specific of these targets (4.1) states that "by 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes". This is also the target that can be directly translated into demographic outcomes in the context of the multi-dimensional population projections methodology mentioned above. Other targets referring to early childhood development, equal access to vocational and tertiary education (without giving quantitative targets), skills for employment, education facilities, scholarships and teacher training highlight other important aspects of education that are more difficult to translate into qualitative models. But there are two further targets with rather specific aspects that can also be partially quantified, namely 4.5 ("By 2030, eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples and children in vulnerable situations") and 4.6 ("By 2030, ensure that all youth and a substantial proportion of adults, both men and women, achieve literacy and numeracy"). But assuming, that 4.5 is just one specific aspect of the more general Target 4.1 which already includes universal high quality education of **all** boys and girls and that indeed by this all young men and women become literate and numerate, no additional assumptions need to be made. With respect to the second part of Target 4.6 we do not assume that any new massive adult education programs will be launched in the near future, since for the countries concerned already universal primary and secondary education of all girls and boys is a daunting task.

While universal primary education has already been part of the earlier MDGs, a target that had been missed in a large number of African countries, the addition of universal secondary education in the SDGs is new and much more ambitious. There have been some discussions within UNESCO and elsewhere whether this should be interpreted in terms of the somewhat more realistic achievement of universal lower secondary education or whether it actually implies universal completing of upper secondary school which is not even achieved in all industrialized countries and might be exceedingly hard to reach for countries where today high proportions of children are not going to school at all. We account for this difference in interpretation by specifying two alternative SDG education scenarios, one in which universal lower secondary education is reached in 2030 (scenario SDG2) and another one in which universal upper secondary education is reached by 2030 (scenarios SDG1 and SDG3). Both assumptions have been calibrated for the following calculations.

The scenarios of educational expansion underlying the population projections presented here result from a further refinement of the education model presented in Lutz et al. (2014). In summary, we project the share of the population ever reaching or exceeding a given attainment level. This is done separately by country, and gender, but with 'shrinkage' within a Bayesian framework (with weakly informative priors). The mean expansion trajectories are modelled as random walks with drift (and potential mean reversion) and independent noise at a probit-transformed scale. The trend parameters are estimated based on reconstructed attainment histories, and extrapolated, subject to additional and some exogenously imposed convergence within regions and between females and males. SDG targets are treated as 'future observations', with a potential trend break in 2015. Limitations shared with all existing global projections of educational development include the fact that in the absence of a detailed theoretical basis, they are forced to rely heavily on statistical extrapolations. For example, there is little consensus on whether 'higher education is the new secondary education', or is fundamentally different from lower levels of schooling (e.g. in terms of institutional framework, its role in the life cycle, economic returns). In addition, global projections can necessarily not account in a satisfactory manner for idiosyncratic policy changes or shocks. In addition, the specific modelling choices outlined above imply a number of trade-offs. Using highest school attainment as the underlying measure solves many problems associated with historic enrolment data by allowing the consistent reconstruction of time series of attainment from relatively recent cross-sectional data, but comes with challenges of its own. While nevertheless preferable overall, the principal disadvantage of attainment measures deserves mention, namely the relatively long time lag with which outcomes can be observed. Late attainment is common in many developing countries, so that attainment cannot safely be assumed to be 'final' until several years above the typical graduation age.

The model operates on 5-year age groups and in 5-year time steps. While the starting (2015) and target (2030) years for the SDGs conveniently line up with this grid, typical durations and graduation ages for different attainment levels unfortunately do not. The target is interpreted such that the cohort aged 15-19 in 2030 will ultimately (not necessarily already at that age, which would be too early for the 15-year-olds with respect to upper secondary) universally attain secondary education (upper secondary for scenario SDG1, lower secondary for scenario SDG2). In order to ensure that most late attainment is captured, completed primary attainment is observed at age 15-19, completed lower secondary at age 20-24, and completed upper secondary and post-secondary by 25-29. The latter is likely to underestimate the amount of post-secondary attainment somewhat, but an even higher reference age would come at the cost of an even greater time lag and less current observational data.

The basic model specifies that the inverse probit of the share attaining a given education level or higher among the entire cohort follows a random walk with country-specific drift. In principle, the specification also allows for mean-reversion by partially backtracking an (estimated) proportion of the random shock of the previous period, but in practice no meaningful mean-reversion of this kind was picked up from the data. This is not necessarily surprising, given that mean-reversion on a year-on-year basis will largely be obscured by the 5-yearly data.

Additional complexity is layered over this basic model. Gender convergence is specified such that at each time step, the predicted values for both genders are shifted by parameter nu towards their joint average. An additional level of independent errors of small magnitude that do not persist in the random walk and do not enter the gender convergence is allowed in fitting the observed data, in order to account for exogenous errors at the level of data, rather than in the underlying educational process.

The fitted empirical model is adjusted during projection in the following ways. (Level and gender specific) country trends linearly converge over six time steps to the regional trend. The strength of gender convergence (in the form of parameter nu) is linearly increased in two steps to reach twice the past empirical value (but capped at 50 percent). The logical inequality relations between the participation shares (e.g. that the share attaining secondary or higher must be less than the share attaining primary or higher) is enforced after estimation, since they cannot be expressed within the estimation model without adversely affecting computation time. Strictly speaking, enforcing the order should occur by conditioning, i.e. omitting altogether iterations that violate the ordering. Again for computational reasons, this is approximated by capping participation at the higher attainment at the level of the prerequisite attainment. Projected attainment at the post-secondary level is rescaled to remain below 90percent, based on substantive reasoning.

In terms of prior distributions, vague priors are specified that only incorporate knowledge of the order-of-magnitude of various effects, as well as logical bounds. The mean-reversion effect theta has a Beta(1.5, 1.5) prior in the interval (0, 1). The empirical gender convergence factor nu is level and country specific, with prior Beta(1, 5), to ensure a value in the interval (0, 1), strongly skewed towards smaller values. True initial levels are given conceptually uninformative 'flat' priors, but restricted to the interval (-4, 4) to ensure a proper posterior. The idiosyncratic shocks at the probit scale, i.e. the gender, level, year, and country specific epsilons, are i.i.d. draws from a Gaussian distribution with zero mean and standard error sigma_epsilon. The additional errors stem from a Gaussian N(0, 0.05) distribution. The (gender, level, and country specific) drift parameters have Gaussian priors centred on regional means (themselves drawn from a Gaussian N(0, 1) distribution), with standard error sigma_trend. The hyper-priors on variance parameters sigma_trend and sigma_epsilon are Gaussian with mean zero and variance 0.2.

For the target scenario, the above forward projection approach is modified. While it would be possible to deterministically calculate the necessary additional drift to reach a given point target level by 2030, doing so would be a lost opportunity to gain additional insight. Instead, SDG targets are treated as 'future observations'. Specifically, they enter the likelihood by specifying that the drift resulting in the overall upward trend is allowed to increase by whatever amount necessary (with an effectively flat prior) to reach the target, starting in 2015. The start of the trend break is adjusted by attainment level, since the cohort aged 15-19 in 2010, for example, will already eventually benefit from increased post-secondary participation during the period 2015-2030. Conversely, changes starting in 2015 were largely too late to affect the primary attainment of those aged 15-19 in 2020.

The aim is a 'fuzzy' target distribution at the original scale that is practically flat over a couple of percentage points from 97percent to 99 percent, but drops off rapidly in either direction. A discontinuous cut-off below 97 percent is undesirable for computational reasons, because the implied zero gradient in the likelihood would fail to guide the algorithm towards the target region. In any case, 'meeting the target' is not a perfectly sharp concept in the policy domain either, even once it has been operationalised with a numeric threshold. In order to achieve the above pattern at the original scale, an exponentially modified Gaussian distribution (with mean corresponding to 0.97 at the untransformed scale and sigma = 0.05, lambda = 0.5) is specified around the target at the transformed scale. The reason for excluding values very close to true unity at the scale of participation shares is that these would translate to values at the transformed scale that diverge to infinity, requiring an unbounded speed-up of expansion.

Note that this specification of the target scenarios means the target of 97 percent is typically exceeded, not just barely met, in contrast to a typical 'target-achieving path' interpolated deterministically. This behaviour is desired and deliberate. Intuitively, assuming a country did meet the targets, these trajectories represent typical paths of having got there. Retrospectively, the set of countries that meet the targets will have exceeded them on average, given their lack of perfectly exact control over the outcome. An analogy will clarify this: if we invite a group of runners to attempt to run 100 m in 11 s, then the successful group will clearly have taken less than 11 s on average. Since in addition, the target scenarios have the same probabilistic nature as the trend scenario, they allow for arbitrary conditioning. Examples of such conditional perspectives include questions related to the probability of different countries meeting fixed targets by a certain time, to complement the more conventional question of the probability of exceeding certain participation levels in a fixed year. While this is fully analysed elsewhere, for present purposes we focus on the 'minimal' target path traced out by the cross-sectional 0.01 quantile of the target paths that only just reaches the SDG target. In addition to sharing their probabilistic nature, just like the trend scenario, the target scenarios incorporate the nonlinearity of educational expansion as it really occurs. In particular, this includes the likely deceleration of expansion as universal participation is approached, as well as the fact that countries that meet the targets will necessarily have 'overshot', on average. This allows us to quantify the risk of failure associated with attempting to monitor whether countries are 'on track' according to simple linear plans.

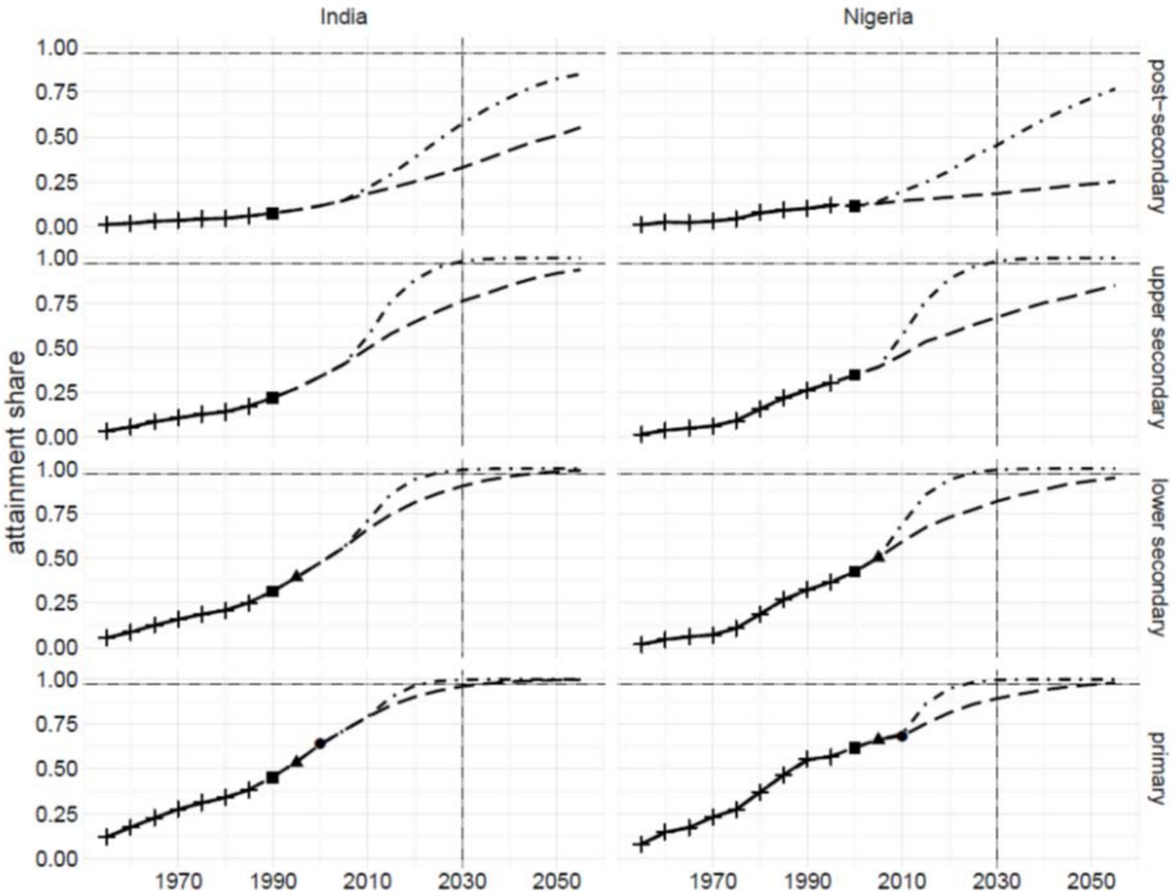
In addition, the target scenarios make explicit that accelerating expansion at one level of the education system will not leave other levels unaffected. In particular, some degree of 'spill-over' to the levels above is to be expected. This effect is modelled by exposing the attainment level above the target level, and the level above that (if any), to an increase in trend drift that is 50 percent respectively 10 percent as large as required at the target level to meet the target. This can be interpreted as an approximation to cutting the log-odds of transitioning from secondary to post-secondary in half, and maintaining those new odds into the future. If the model were specified in terms of a logit curve instead of a probit curve, this interpretation would be exact. Parenthetically, the reason why the model is in fact specified in terms of probits is because this extends more naturally to model elaborations where an underlying Gaussian latent propensity for education is assumed at the individual level.

The amount of 50 percent spill-over was chosen for substantive reasons: there is no reason to expect a targeted boost at one level would actually increase growth at the level above more than the target level itself (suggesting the spill-over should remain below 100percent), but it seems plausible to expect some upward pressure on post-secondary participation if the pool of eligible upper secondary graduates increases. The reason the spill-over is not specified proportionally to the transition rate from secondary to post-secondary is that doing so would cap a country's long-term participation in post-secondary at the level of the current transition rate, which will often be unreasonably low. If the current transition rate from secondary to post-secondary is 30 percent, for example, and this were held constant, then universal upper secondary attainment would imply merely 30 percent participation at post-secondary, and no further growth or convergence with other countries.

The above model was implemented in the 'Stan' software package and posteriors samples generated through MCMC sampling. Chains converge consistently in around 100 iterations, and a total of 500 samples was kept from four chains after discarding burn-in and checking Gelman's 'R hat' split-chain convergence criterion. The number of posterior samples is constrained not only by computation time, but also by the large number of scenario-time-country-level-gender-specific parameters. For each scenario, storage of the results requires more than 5 MB per iteration. However, even 500 samples in fact results in projection quantiles that are sufficiently smooth (as evident in Figure S1).

In addition to the main SDG1 scenario that interpret the SDG education target in terms of referring to universal completion of upper secondary education, an alternative SDG2 scenario makes the weaker (and possibly more realistic) assumption that by 2030 universal completion of lower secondary education is achieved. These two different education scenarios will then be combined with two different fertility scenarios as described below.

Figure S1. Examples of India and Nigeria for educational attainment trends of cohorts aged 15-19 in the stated year: empirical (+), trend extrapolation (---) and target scenario SDG1 (-.-.-.-)



11.1.2 Translating the health targets into future mortality trajectories

SDG3 ("Ensure healthy lives and promote well-being for all at all ages") consists of some very specific and some rather general targets. Target 3.1 for instance states precisely: "By 2030, reduce the global maternal mortality ratio to less than 70 per 100,000 live births". Global estimates show that maternal mortality rates fell by about 44 percent over 25 years from 385/100.000 in 1990 to 216 in 2015 (UNFPA et al. 2012). The target thus implies a massive acceleration in the decline over the coming 15 years, but since this is only a minuscule part of total global mortality, this specific target will hardly affect overall demographic trends.

Health Target 3.2 relates to child mortality and is much more relevant for future population growth since the prematurely dying children would also have been potential future parents. The target states precisely that all countries should reduce under-5 mortality to at least as low as 25 per 1000 live births. Given that this indicator over the past 15 years has declined from 166/1000 to currently 99/1000 in Sub-Saharan Africa (UN estimates for 1995-2000 and 2010-15), a substantial acceleration of the decline will be required. The medium UN projections (2015) only expect it to decline to 68/100 by 2020-25.

Target 3.7 referring to reproductive health and family planning will be discussed under the fertility implications below.

Several of the 13 specific health targets relate to individual causes of death such as HIV/AIDS, tuberculosis, malaria, water-borne diseases, accidents, substance abuse, chemical pollution and preventable non-communicable diseases in general. It goes beyond the scope of this paper to model in detail how these specific targets on certain causes of death would translate into aggregate mortality rates for all countries of the world. Instead we will refer to a major recent exercise involving over 100 international mortality experts identifying the different forces that will influence future mortality trends and translating them into alternative future mortality trajectories (Caselli et al. 2014; Garbero & Pamuk 2014). Of the three mortality trajectories (high, medium and low) that were defined for all countries the low path corresponds quite well both qualitatively and quantitatively to the health and mortality targets as discussed above. Since this trajectory was also specified in terms of education-specific mortality trends – with more educated women having universally lower child mortality rates and better educated adults living on average longer – the education scenarios discussed above will also indirectly influence the future course of national mortality trends. Furthermore, the effects on education-specific mortality rates of other goals, in particular those referring to eradication of poverty and hunger as well as to improvement of governance are assumed to be already captured by the very optimistic mortality assumptions used for this low mortality trajectory.

11.1.3 Defining education-specific fertility trajectories

The health SDG also includes one target that is likely to affect education-specific fertility rates directly. Target 3.7 states "By 2030, ensure universal access to sexual and reproductive health-care services, including for family planning, information and education, and the integration of reproductive health into national strategies and programmes". While the part of the target is of more organisational nature the first directly refers to the concept of meeting the unmet need for contraception and has the potential to directly affect fertility levels through rapidly increasing contraceptive use. The unmet need is usually defined as the proportion of currently married women who are not currently using contraception and say that they do not want another child in the near future. When it comes to estimating the number of births that would be avoided in the hypothetical case that all unmet need would be met it is important to further distinguish between unmet need for birth spacing and for limiting family size. Only the latter can be assumed to have a lasting effect on fertility rates.

Various studies have attempted to come up with quantitative estimates of what would be the effect of meeting the unmet need on national fertility levels. The most comprehensive such analysis is by Bradley at al. (2012) using all available Demographic and Health Surveys (DHS) and applying a more precise definition than before of measuring the unmet need for limiting family. For the global average of all 59 DHS for developing countries they find that in the case of eliminating unmet need the TFR would be 20 percent lower (i.e. 3.3 instead of 4.1 children per woman). They find regional differences with the hypothetical decline being the highest in absolute terms in East and Southern Africa (3.7 as compared to 5.0) and in relative terms in Latin America and Caribbean (2.0 versus 3.0). In West and Central Africa the decline would be the smallest (4.9

versus 5.4) because desired family size is still very high in this part of Africa. Hence, loosely speaking these calculations only refer to the difference between desired and actual family sizes, while education of women also tends to result in lowering the desired family size.

When operationalizing the SDG fertility scenario it is thus a rather straightforward assumption to assume that achieving “universal access to sexual and reproductive health-care services, including for family planning, information and education” will result in 20 percent lower education-specific fertility rates by 2030. Since these services cannot be expected to be established overnight this is implemented by gradually lowering fertility rates from their current levels to a level that is 20 percent lower than in the middle of the road scenario (SSP2) by 2030. For the period 2015-2030 this procedure is also equivalent to the assumptions made for education-specific fertility under the Rapid Social Development Scenario (SSP1). After 2030, however, the SSP1 and SDG scenarios start to differ because under SSP1 the low fertility trajectory is assumed to continue while under the SDG scenario narrative there is a gradual return to the middle of the road trajectory. The return will not be abrupt and will only be complete once the overall TFR has reached a level of 1.6.

While the SDG1 and SDG2 scenarios assume 20 percent lower education-specific fertility rates in all countries that in 2005-10 have a TFR of 2.5 or higher, this might be an overestimation of the effect due to possible interactions with education: More educated women find it easier to get access to overcome the obstacles to meeting the unmet need. For this reason we also calculated an alternative scenario with only 10 percent fertility reduction (SDG3)(Lutz 2014).

What this implies exactly in terms of assumed future trends in education-specific TFRs and population level TFRs is illustrated in Figure 2 (in the main text) for the case of Nigeria. While SDG1 and SDG2 refer to the two different education scenarios as described above combined with 20 percent declines until 2030 in education-specific fertility levels, SDG3 combine the lower secondary completion with only 10 percent declines in education-specific fertility levels.

11.1.4 Migration and other factors

Among the components of population change migration is the third factor (in addition to fertility and mortality) that directly effects future national population size. While this factor can have significant effects especially for small populations with high in- or out-migration it is a negligible factor for global population growth. Since (at last for the time being) there is no migration leaving our planet the only minor difference that can arise in global projections is due to the fact that in-migrants are assumed to be exposed to the fertility and mortality levels of their new home countries, which can be quite different from those of the countries of origin. Except for stressing the need for orderly migration and the rule of law the SGDs do not give any specific quantitative targets that would suggest either higher or lower international migration streams in the future. For this reason the migration assumptions of the SDG scenarios are the same as those used for the middle of the road SSP2 Scenario.

Important other SDGs that have not yet been discussed above – such as those on reduced inequalities, decent work and economic growth, affordable and clean energy, climate action and quality of institutions could have potential indirect effects on future fertility, mortality, migration and education. This should be a research topic for the future. But for our attempt to develop a first approximation of demographic scenarios that reflect the SDGs we assume that the specified sets of low fertility and mortality and high education trajectories implicitly include all the other possible indirect effects of different SDGs on those demographic trends.

11.2 Results

Figure 1 (in the main text) shows the global level results for population size until 2100 of the different scenarios together with the global uncertainty range given by the UN projections. It shows that all SDG scenarios as well as SSP1 and SSP2 peak during the second half of the century. Only SSP3 which is based on the narrative of a stalled fertility decline shows continued population growth throughout the century.

Table A1 lists numerical results for the three SDG scenarios defined here, for the three SSP scenarios given in the literature (7) as well as the upper and lower bounds of the 95 percent uncertainty interval given by the UN2015 probabilistic projections.

It is worth noting that the SDG and SSP scenarios are based on somewhat different country groupings that explain some of the differences in addition to the main difference explained in the main text, namely that the SDGs are viewed here as a turbo booster of development that is only turned on for the period 2015-2030. This results in the fact that the SSP1 scenario (called Sustainability) has a clearly lower total world population than the SDG scenarios. Another reason is that non-OECD countries with TFR < 3.0 in 2005-10 were under the SSP1 narrative assigned a 'low' fertility scenario, whereas under the SDG scenarios only the fertility in countries with a TFR above 2.5 was assumed to be affected and therefore were assigned 'medium' fertility in the future. Some of the larger non-OECD countries, with TFR<2.5 affected by this difference in assumptions are Indonesia, Bangladesh, China and Russia.

11.3 Technical note of the sensitivity analysis of the 2015 probabilistic UN projections

In order to analyse the sensitivity of probabilistic model of Alkema et al. (2011) and Raftery et al. (2013) that provided the basis for the 2015 UN Assessment of World Population Prospects (WPP) four sets of projections were carried out. In each projection we used the "bayesTFR" package in R, described in Ševčíková et al. (2011), to estimate parameters in Bayesian hierarchical model and generate future Total Fertility Rate (TFR) values for all countries and the "bayesPop" package to produce probabilistic population projections. Each projected population was based on the same simulated future life expectancy distributions and fixed medium migration scenario, provided as a default within the "bayesPop" package.

In the first projection, the future fertility rates were generated using TFR data from the 2015 version of the WPP. These were then passed to the population projection, to serve as a baseline predictive distribution, to compare other projections against. This replication of UN projections based on the available software packages is marginally different from the official UN probabilistic population projections as the bayesTFR and bayesPop R packages 1) implements an alternative method for the projection of mortality age patterns in some countries and 2) excludes data and projections for some very small countries for which it is not clear how the UN projections deal with them. As a result the global median in 2100 is slightly higher (11.29 billion compared to 11.21 billion) and the uncertainty range is somewhat more narrow, for example the 80 percent prediction interval shrinks from 10.04-12.50 billion to 10.21-12.45 billion. The estimation of the fertility decline model parameters, forecasts and population projection were completed in approximately 6 hours on a standard desktop 64-bit PC with 16GB RAM, 3.60GHz processor.

Figure S2. Results of different scenarios for population growth in India

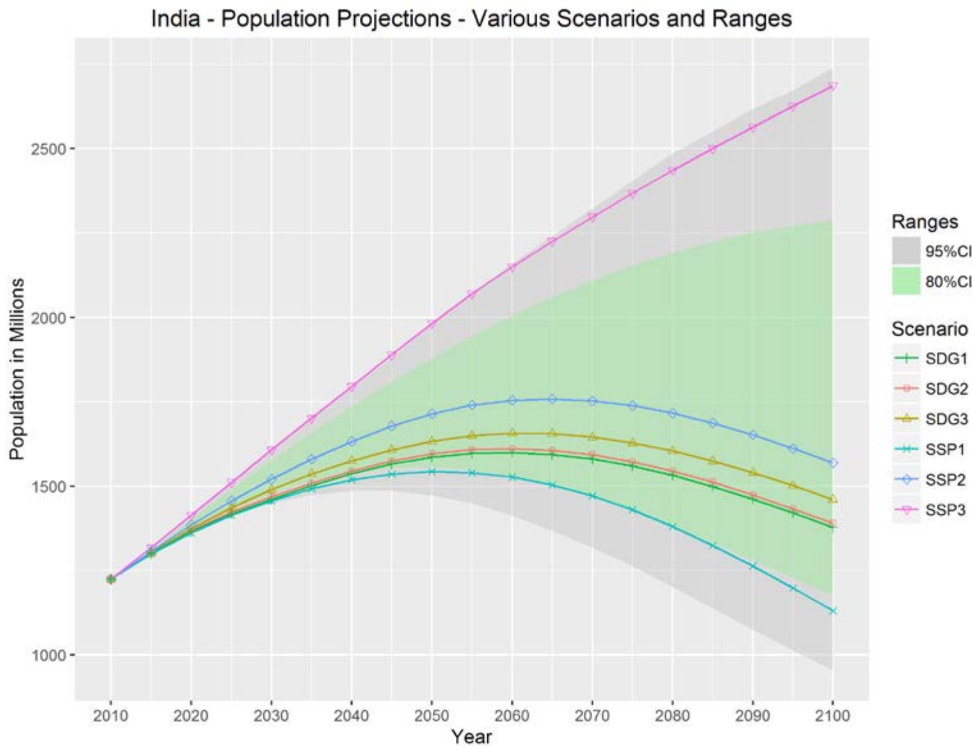


Table S1. Population projections for the world and six continents, various sources

	Year	SDG – 2016			SSPs - 2014			UN - WPP 2015	
Scenario name		SDG1	SDG2	SDG3	SSP1	SSP2	SSP3		
*Fertility Scenario^*		-20%	-20%	-10%	-20%		+20%	Lower Limit (95%)	Upper Limit (90%)
Education Scenario		Secondary Completion by 2030							
		Upper	Lower	Lower					
World	***2010***	***6,871***	***6,871***	***6,871***	***6,871***	***6,871***	***6,871***		
	2030	8,112	8,152	8,200	8,024	8,256	8,511	8,360	8,648
	2050	8,759	8,866	8,964	8,504	9,140	9,966	9,284	10,182
	2100	8,192	8,434	8,654	7,084	8,948	12,752	9,494	13,294
AFRICA	***2010***	***1,022***	***1,022***	***1,022***	***1,022***	***1,022***	***1,022***		
	2030	1,448	1,468	1,488	1,458	1,526	1,610	1,646	1,712
	2050	1,760	1,816	1,874	1,800	2,017	2,323	2,324	2,627
	2100	1,968	2,093	2,255	1,924	2,620	3,922	3,442	5,589
ASIA	***2010***	***4,141***	***4,141***	***4,141***	***4,141***	***4,141***	***4,141***		
	2030	4,752	4,769	4,797	4,680	4,828	5,019	4,805	5,044
	2050	4,946	4,987	5,031	4,727	5,107	5,682	4,928	5,634
	2100	4,135	4,220	4,294	3,320	4,355	6,858	3,843	6,317
LATIN AMERICA AND	***2010***	***590***	***590***	***590***	***590***	***590***	***590***		
	2030	695	698	698	678	702	738	702	739

	Year	SDG – 2016			SSPs - 2014			UN - WPP 2015	
Scenario name		SDG1	SDG2	SDG3	SSP1	SSP2	SSP3	Lower Limit (95%)	Upper Limit (90%)
*Fertility Scenario^*		-20%	-20%	-10%	-20%		+20%		
Education Scenario		Secondary Completion by 2030							
		Upper	Lower	Lower					
THE CARIBBEAN	***2050***	746	756	752	696	758	865	728	838
	2100	682	709	693	520	684	1,094	558	902
Burkina Faso	***2010***	***16***	***16***	***16***	***16***	***16***	***16***		
	2030	25	25	26	26	27	29	25	29
	2050	31	31	33	33	38	46	33	51
	2100	35	36	40	37	53	81	35	160
Cameroon	***2010***	***20***	***20***	***20***	***20***	***20***	***20***		
	2030	26	26	27	26	27	29	31	35
	2050	30	31	32	31	33	37	40	57
	2100	31	32	34	29	36	49	44	145
Chad	***2010***	***11***	***11***	***11***	***11***	***11***	***11***		
	2030	17	17	17	17	18	19	20	23
	2050	20	21	22	22	25	28	27	43
	2100	22	24	25	25	33	44	29	144
Egypt	***2010***	***81***	***81***	***81***	***81***	***81***	***81***		

Year	SDG – 2016			SSPs - 2014			UN - WPP 2015	
Scenario name	SDG1	SDG2	SDG3	SSP1	SSP2	SSP3		
*Fertility Scenario^*	-20%	-20%	-10%	-20%		+20%	Lower Limit (95%)	Upper Limit (90%)
Education Scenario	Secondary Completion by 2030							
	Upper	Lower	Lower					
2030	103	103	106	103	107	112	111	123
2050	116	116	122	115	126	142	130	174
2100	114	114	126	100	134	202	120	345
Ethiopia ***2010***	***83***	***83***	***83***	***83***	***83***	***83***		
2030	115	118	118	119	124	131	128	148
2050	136	141	141	143	159	183	153	228
2100	147	155	155	142	190	284	124	445
Ghana ***2010***	***24***	***24***	***24***	***24***	***24***	***24***		
2030	34	35	35	34	36	38	35	39
2050	40	42	43	41	47	55	43	58
2100	43	46	47	41	58	91	40	128
India ***2010***	***1,225***	***1,225***	***1,225***	***1,225***	***1,225***	***1,225***		
2030	1,461	1,468	1,489	1,457	1,521	1,608	1,448	1,605
2050	1,586	1,596	1,633	1,543	1,715	1,982	1,472	1,978
2100	1,378	1,390	1,460	1,131	1,569	2,687	954	2,739

Year		SDG – 2016			SSPs - 2014			UN - WPP 2015	
Scenario name		SDG1	SDG2	SDG3	SSP1	SSP2	SSP3	Lower Limit (95%)	Upper Limit (90%)
*Fertility Scenario^*		-20%	-20%	-10%	-20%		+20%		
Education Scenario		Secondary Completion by 2030							
		Upper	Lower	Lower					
Iraq	***2010***	***32***	***32***	***32***	***32***	***32***	***32***		
	2030	47	47	48	47	50	55	51	57
	2050	58	59	62	59	68	85	71	97
	2100	66	67	74	62	89	169	88	284
Kenya	***2010***	***41***	***41***	***41***	***41***	***41***	***41***		
	2030	59	60	61	59	61	66	62	69
	2050	72	75	78	73	80	95	81	111
	2100	80	86	93	75	98	157	87	268
Madagascar	***2010***	***21***	***21***	***21***	***21***	***21***	***21***		
	2030	30	31	31	31	33	35	34	38
	2050	36	37	38	38	45	52	46	65
	2100	40	41	43	38	59	89	56	187
Malawi	***2010***	***15***	***15***	***15***	***15***	***15***	***15***		
	2030	24	25	25	25	26	28	25	28
	2050	32	35	34	35	41	48	35	51

Year		SDG – 2016			SSPs - 2014			UN - WPP 2015	
Scenario name		SDG1	SDG2	SDG3	SSP1	SSP2	SSP3		
*Fertility Scenario^*		-20%	-20%	-10%	-20%		+20%	Lower Limit (95%)	Upper Limit (90%)
Education Scenario		Secondary Completion by 2030							
		Upper	Lower	Lower					
	2100	39	46	46	46	68	109	43	159
Mali	***2010***	***15***	***15***	***15***	***15***	***15***	***15***		
	2030	24	24	25	24	26	27	25	29
	2050	29	30	32	31	36	42	34	56
	2100	34	35	38	35	48	66	38	201
Mozambique	***2010***	***23***	***23***	***23***	***23***	***23***	***23***		
	2030	32	32	33	32	34	35	39	44
	2050	37	38	39	39	42	47	52	78
	2100	39	41	43	38	50	68	59	240
Nepal	***2010***	***30***	***30***	***30***	***30***	***30***	***30***		
	2030	39	40	40	40	42	45	31	35
	2050	46	46	48	45	51	62	30	42
	2100	46	47	49	40	55	102	14	49
Niger	***2010***	***16***	***16***	***16***	***16***	***16***	***16***		
	2030	26	27	27	27	30	33	33	38

Year	SDG – 2016			SSPs - 2014			UN - WPP 2015	
Scenario name	SDG1	SDG2	SDG3	SSP1	SSP2	SSP3		
*Fertility Scenario^*	-20%	-20%	-10%	-20%		+20%	Lower Limit (95%)	Upper Limit (90%)
Education Scenario	Secondary Completion by 2030							
	Upper	Lower	Lower					
2050	35	37	38	41	51	63	54	90
2100	43	48	52	57	98	161	78	524
2010	***158***	***158***	***158***	***158***	***158***	***158***		
Nigeria ***2030***	244	247	253	243	253	268	247	277
2050	332	344	363	333	371	435	313	478
2100	439	478	549	439	576	879	326	1,494
2010	***174***	***174***	***174***	***174***	***174***	***174***		
Pakistan ***2030***	224	225	229	224	237	255	232	258
2050	248	251	261	249	286	344	265	359
2100	235	241	260	212	314	551	209	629
2010	***93***	***93***	***93***	***93***	***93***	***93***		
Philippines ***2030***	117	118	120	117	122	131	117	130
2050	129	129	136	127	141	170	127	172
2100	123	124	137	107	147	251	95	295
Senegal ***2010***	***12***	***12***	***12***	***12***	***12***	***12***		

	Year	SDG – 2016			SSPs - 2014			UN - WPP 2015	
	Scenario name	SDG1	SDG2	SDG3	SSP1	SSP2	SSP3		
	*Fertility Scenario^*	-20%	-20%	-10%	-20%		+20%	Lower Limit (95%)	Upper Limit (90%)
	Education Scenario	Secondary Completion by 2030							
		Upper	Lower	Lower					
	2030	18	18	18	18	19	21	22	24
	2050	20	21	21	21	25	32	31	42
	2100	21	23	23	20	33	60	41	127
Uganda	***2010***	***33***	***33***	***33***	***33***	***33***	***33***		
	2030	55	56	56	56	60	65	57	66
	2050	73	76	79	79	93	113	79	123
	2100	90	98	108	104	154	242	89	416
United Republic of Tanzania	***2010***	***45***	***45***	***45***	***45***	***45***	***45***		
	2030	67	68	69	69	73	78	78	87
	2050	81	84	86	88	102	120	112	162
	2100	92	96	102	98	141	212	147	546

Notes: ^ Fertility Scenario: 20% lower than SSP2 for SDG1 and SDG2, and 10% lower for SDG3. SSP3 has 20% higher than SSP2 and SSP1 has 20% lower.