Meeting the Sustainable Development Goals leads to lower world population growth

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Here we show the extent to which the expected world population growth could be lowered by successfully implementing the recently agreed-upon Sustainable Development Goals (SDGs). The SDGs include specific quantitative targets on mortality, reproductive health, and education for all girls by 2030, measures that will directly and indirectly affect future demographic trends. Based on a multidimensional 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 8.2 and 8.7 billion in 2100. Because these results lie outside the 95% prediction range given by the 2015 United Nations probabilistic population projections, we complement the study with sensitivity analyses of these projections that suggest that those prediction intervals are too narrow because of uncertainty in baseline data, conservative assumptions on correlations, and the possibility of new policies influencing these trends. Although the analysis presented here rests on several assumptions about the implementation of the SDGs and the persistence of educational, fertility, and mortality differentials, it quantitatively illustrates the view that demography is not destiny and that policies can make a decisive difference. In particular, advances in female education and reproductive health can contribute greatly to reducing world population growth.

world population | scenarios | Sustainable Development Goals | female education | reproductive health

Today, the future of world population growth looks more uncertain than it did a decade ago because of a controversial recent stalling of fertility decline in a number of African countries and a controversy over how low below replacement level fertility will fall, particularly in China (1). Probabilistic population projections try to quantify these uncertainties based on statistical extrapolation, expert judgement, or a blend of both (2, 3). Although such projections published in 2008 (4) gave a 95% prediction interval ranging from 5.2 to 12.7 billion for the global population in the year 2100, probabilistic projections published by the United Nations (UN) Population Division in 2015 based on a different approach give a much narrower 95% interval ranging from 9.5 to 13 billion in 2100 (3). Another recent set of world population projections defined alternative global population scenarios in the context of the work of the Intergovernmental Panel on Climate Change (IPCC) and related integrated assessment models. In the medium scenario these Shared Socioeconomic Pathways (SSPs) show 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 (5, 6). As discussed below, these differences in world population projections result from different approaches taken in terms of disaggregating national populations according to age, sex, and education structures and in combining statistical extrapolation with expert knowledge in specifying 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). If actually pursued, several of these targets, particularly in the fields of reproductive health and female education, will have strong direct and indirect effects on future population trends, mostly 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 effects of meeting these development goals on national population trajectories. The results show that meeting these goals would result in the world population peaking around 2060 and reaching 8.2–8.7 billion by 2100, depending on the specific SDG scenario (Fig. 1). This analysis quantitatively demonstrates that demography is not destiny and that policies, particularly in the field of female education and reproductive health, can contribute greatly to reducing world population growth.

The different variants of the SDG scenario specified here, although consistent with the SPP scenarios, all lie substantially below the lower bound of the 95% band given by the most recent probabilistic UN projections (Fig. 1). This difference evidently poses serious questions to the reader. Therefore, after describing the definition and calibration of the demographic SDG scenarios, this paper has a second section in which we perform sensitivity analyses of the UN population projections, using the UN's software; our analyses suggest that the prediction range given by the UN underestimates the full uncertainty of possible future world population growth. We study the sensitivity with respect to possible baseline errors and correlation and show how explicit incorporation of heterogeneity in 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

Significance

The future of world population growth matters for future human well-being and interactions with the natural environment. We show the extent to which world population growth could be reduced by fully implementing the Sustainable Development Goals (SDGs) whose health and education targets have direct and indirect consequences on future mortality and fertility trends. Although this assessment is consistent with the Shared Socioeconomic Pathways scenarios used in the Intergovernmental Panel on Climate Change context, it is inconsistent with the prediction range of the United Nations projections for which we present sensitivity analyses and suggests that their range is likely too narrow. Given our assumptions, the SDGs have a sizable effect on global population growth, providing an additional rationale for vigorously pursuing their implementation.

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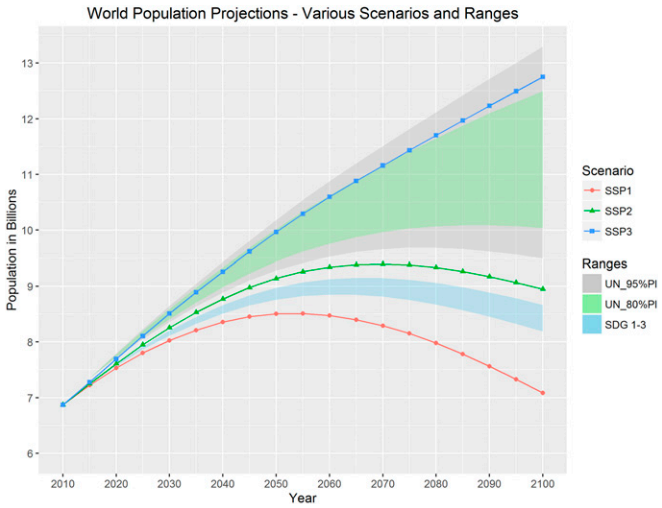

Fig. 1. Future world population growth as projected according to the three SSP scenarios, the range of SDG scenarios presented here, and the probabilistic ranges given by the UN population projections.

the full 21st century, an assumption that is incompatible with the aspiration of the UN's own SDGs to mount an historically unprecedented effort to change the course of global development.

Translating the SDGs into Corresponding Population Scenarios

The SDGs as approved by the UN General Assembly in the presence of most heads of state in September 2015 contain 17 goals and 169 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 instead to all countries in the world, and they include environmental dimensions in addition to social and economic dimensions. Many of the SDGs 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 to allow better monitoring of the actual achievements of these goals. Some of the goals and associated targets are expressed 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 translated more or less directly into future mortality and fertility pathways. To assess the indirect effects of improvements in education on fertility and mortality quantitatively, we use recent advances in multidimensional population modeling, namely the 3D analysis by age, sex, and level of education (7). This work is based on the insight that, after age and sex, the level of education is the most important source of observable population heterogeneity. Consistently, more-educated women experience lower fertility and lower child mortality, particularly during the process of demographic transition, and more-educated men and women have higher life expectancies. This relationship has been corroborated recently (7), and the case has been made that improvements in female education have functional causality on declining fertility (8). It has been shown that, even under identical sets of education-specific fertility trajectories, different education scenarios alone can induce a variation of more than 1 billion in the size of the total world population by midcentury (7).

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 SSPs (6). The human core of the SSPs also consists of population scenarios by age, sex, and level of education for all countries to the year 2100 (5). In the following discussion we refer to three of the five SSPs, namely SSP1 (the rapid-development scenario), SSP2 (the middle-of-the-road scenario), and SSP3 (the stalled-development scenario). Although the methodology and the empirical dataset of the SSPs are used here, we redefine some of the specific assumptions regarding future fertility, mortality, and education with reference to the SDGs and their specific targets. As specified in detail in the following paragraphs, the main underlying idea is that implementing the SDGs will help 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 development at a more regular speed. For this reason the SDG population scenarios are lower than the middle-of-the-road SSP2 scenario but are not as low as the fast-development SSP1 scenario, which assumes accelerated social development throughout the century. Because of the path dependencies of the education expansion and the demographic transition, this 15-y booster will result in education, fertility, and mortality levels lower than those of SSP2 for the rest of the century. For readers who think that the boost in development caused by the SDGs will continue beyond 2030, for the rest of the century, the SSP1 scenario is a reasonable approximation, although the SSPs were defined before the SDGs and hence differ in some minor aspects.

Operationalizing the Education Targets

SDG4, which aims to "ensure inclusive and equitable quality education and promote life-long learning opportunities for all" consists of 10 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 target can be directly translated into demographic outcomes in the context of the multidimensional 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. However, two further targets with rather specific aspects also can 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"). If we consider 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, if target 4.1 is realized, all young men and women will become literate and numerate, no additional assumptions need to be made.

Although universal primary education was part of the earlier MDGs, the addition of universal secondary education in the SDGs is new and much more ambitious. This addition is based partly on recent insights that, for poor countries to come out of poverty, universal primary education is not enough and must be complemented by secondary education for broad segments of the population (9). For countries that currently have very low primary school enrollment, the target of universal secondary education by 2030 may seem overly ambitious. For this reason there have been some discussions within the United Nations Educational, Scientific and Cultural Organization (UNESCO) and elsewhere about whether this target should be interpreted in

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terms of the somewhat more realistic achievement of universal lower secondary education or whether it actually implies universal completion of upper secondary school, which indeed is not achieved in all industrialized countries. We account for this difference in interpretation by specifying an alternative SDG education scenario, SDG2, in which only universal lower secondary education is reached in 2030; the two other scenarios, SDG1 and SDG3, are based on the literal meaning of the goal of universal upper secondary education by 2030 but differ in 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. (5). In summary, we project the share of the population ever reaching or exceeding a given attainment level. These projections are made separately by country and sex but with shrinkage within a Bayesian framework (with weakly informative priors). The mean expansion trajectories are modeled as random walks with drift (and potential mean reversion) and independent noise at a probit-transformed scale (see Fig. S1 for India and Nigeria). More details about this new education model are given in the *Supporting Information*.

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 general targets. There are specific numerical targets for the reduction of 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 is 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 noncommunicable diseases in general. Modeling in detail how these specific targets on certain causes of death would translate into aggregate mortality rates for all countries of the world is beyond the scope of this paper. Instead we refer to a major recent exercise involving more than 100 international mortality experts identifying the different forces that will influence future mortality trends and translating them into alternative future mortality trajectories (10, 11). Three mortality trajectories (high, medium, and low) were defined for all countries. The low path corresponds quite well, both qualitatively and quantitatively, to the health and mortality targets discussed above. Because 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 longer on average —the education scenarios discussed above also will indirectly influence the future course of national mortality trends. Furthermore, the effects on the education-specific mortality rates of other goals, in particular those referring to eradication of poverty and hunger and to improvement of governance, are assumed already to have been captured by the very optimistic mortality assumptions used for this low-mortality trajectory.

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." Although the second part of the target is more organizational in nature, the first part refers directly to the concept of meeting the unmet need for contraception and has the potential to affect fertility levels directly by rapidly increasing contraceptive use. The unmet contraceptive need is usually defined as the proportion of currently married women who are not currently using contraception and who say that they do not want another child in the near future. In estimating the number of births that would be avoided in the hypothetical case that all unmet contraceptive need were met, it is important to distinguish further between unmet needs for birth spacing and for limiting overall family size. Only the latter can be assumed to have a lasting effect in lowering fertility rates.

Several authors have attempted to estimate quantitatively the effect on national fertility levels of meeting the unmet need for contraceptives. The most comprehensive analysis is by Bradley at al (12), using all available Demographic and Health Surveys (DHS) and applying a more precise definition of measuring the unmet need for limiting family. For the global average of all 59 DHS for developing countries, they find that, if the unmet contraceptive need were eliminated, the total fertility rate (TFR) would be 20% lower (i.e., 3.3 instead of 4.1 children per woman). They find regional differences, with the hypothetical decline being highest in absolute terms in East and Southern Africa (3.7 compared with 5.0 children per woman) and in relative terms in Latin America and Caribbean (2.0 versus 3.0 children per woman). In West and Central Africa the decline would be the smallest (4.9 versus 5.4 children per woman) because the desired family size is still very high in this part of Africa. Hence, loosely speaking, these calculations refer only to the difference between desired and actual family sizes, whereas education of women also tends to result in lowering the desired family size.

In operationalizing the SDG fertility scenario, the assumption that achieving "universal access to sexual and reproductive health-care services, including for family planning, information and education" will result in 20% lower education-specific fertility rates by 2030 is relatively straightforward. Because these services cannot be established overnight, this scenario is implemented by gradually lowering fertility rates from their current levels to a level that is 20% lower than that in the middle-of-the-road scenario (SSP2) by 2030 (Fig. 2). For the period 2015–2030 the SDG1 and SDG2 scenarios are 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, whereas in the SDG scenario narratives there is a gradual return to the middle-of-the-road trajectory. The return will not be abrupt and will be complete only after the overall TFR has reached a level of 1.6 children per

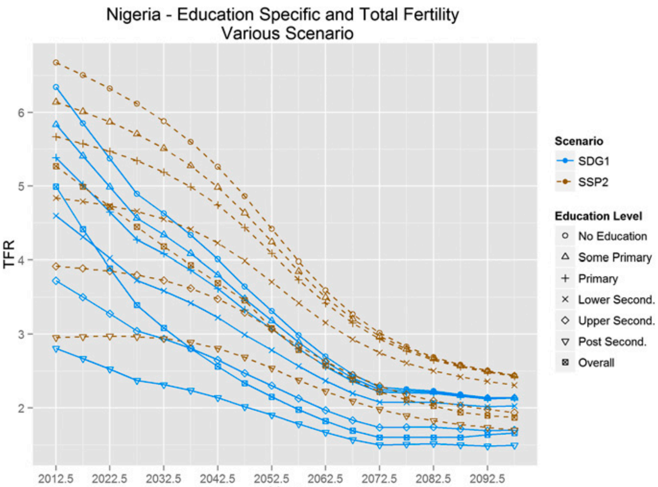

Fig. 2. Education-specific fertility rates for Nigeria under the assumptions of the SSP2 scenario and the 20% lower SDG1 scenario.

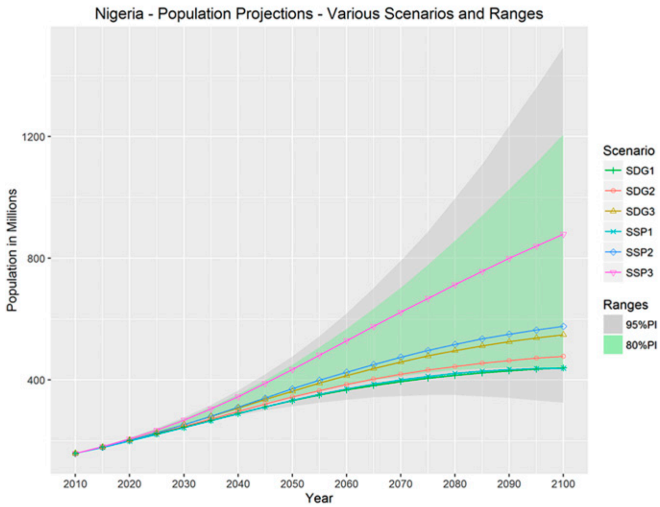

Fig. 3. Nigeria: Resulting population size for the SDG1–3 and the SSP1–3 scenarios and UN ranges.

woman (see *Supporting Information* for more details). The methods for determining the education-specific fertility trajectories for SSP1 und SSP2 are described in detail elsewhere (5).

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

Migration and Other Factors

Migration is the third factor, in addition to fertility and mortality, that directly affects national population sizes in the future. Although migration can have significant effects, especially for small populations with high in- or out-migration, it is a negligible factor for global population growth and affects the projections only through the assumption that migrants will 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 SDGs 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, i.e., that constant in- and out-migration rates gradually diminish toward the end of the of the projection period (5).

Several of the other SDGs that were not discussed above, such as end of poverty and end of hunger, reduced inequalities, decent work, 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 those assumed in the SDG scenarios here remains a research topic for the future. However, 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.

More information about methods, data, and assumptions and country-specific results are provided in the *Supporting Information*. In particular, the model producing the education scenarios is described in detail. The basic model in the education scenarios 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. The *Supporting Information* also lists in tabular form the numerical results of projections for the different SDG and SSP scenarios to 2100 for all world regions and selected larger developing countries, provides more details on the sensitivity analysis of the UN projections, and shows the results of selected country-specific sensitivity analyses. All programs and input data used can be found at www.iiasa.ac.at/SDGscenarios2016.

Scenario Results

Figs. 1 and 3 show the resulting population growth trajectories at the global level and for Nigeria (and India in Fig. S2). Table S1 also shows numerical results by continents. More details, including country-specific results, are given in the *Supporting Information*. As expected from the assumptions listed above, SDG1 gives the lowest population, and SDG3 gives the highest population of the three SDG scenarios. The SDG scenarios are toward the lower end of the SSP1–SSP3 range, generally below the middle-of-the-road scenario SSP2 and above the rapid-development scenario SSP1. The SDGs tend to fall into the lower quartile of the prediction ranges given by the UN probabilistic population projections at the national level, as can be seen for Nigeria in Fig. 4. At the global level, however, all SDG scenarios lie far below the 95% range of the UN range. This difference in the prediction ranges of the national and global results is mostly a consequence of the very low correlations assumed in the UN projections, as discussed below.

The SDG scenarios as defined here result in a world population that still increases to 8.8–9.1 billion by midcentury and then levels off and starts a moderate decline to 8.2–8.7 billion by 2100. This trajectory 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 caused primarily by the accelerated declines in fertility associated with the female education and reproductive health goals in Africa and Western Asia.

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 (13). These projections include crucial model assumptions about the ultimate level of fertility and an eventual increase of fertility in countries that reach very low fertility levels. The 2015 revision of these projections applies a similar model with the

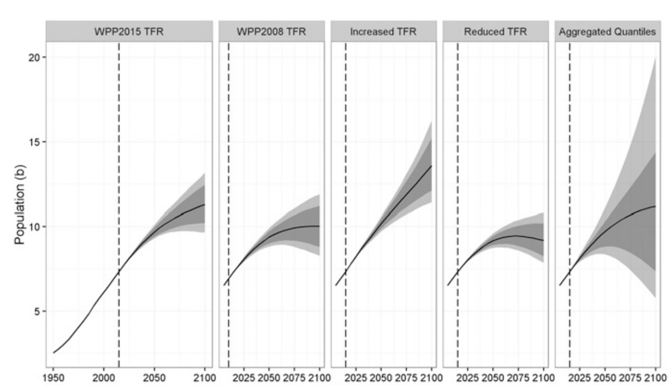

Fig. 4. Sensitivity analysis, global level. From left to right the panels show the following projections: the UN 2015 assessment as published by the UN; the UN model as applied to baseline data in the UN 2008 assessment; the UN model applied to a 10% higher baseline TFR in selected countries; the 10% lower baseline TFR; and the UN 2015 model assuming perfect correlation.

addition of a probabilistic mortality component and updated baseline data (3). As we show in the following discussion, this extrapolative model is particularly sensitive to small changes in the baseline data for the most recent years.

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. In 2008 the UN estimated a TFR of 5.32 for the period 2005–2010; for the 2012 assessment the TFR was corrected upwards by 13%, to 6.00. In the 2015 assessment the estimate for 2005–2010 again was lowered somewhat, to 5.91. This minimal downward correction in the baseline TFR resulted in a major change in the median population size projected for 2100 for Nigeria from 914 million (in the 2012 assessment) to 752 million (in the 2015 assessment). The DHS (14) gives a TFR of 5.5 for 2010–2013, which, if implemented in the UN model, would give a still much lower projection. Baseline uncertainty exists for many countries, particularly in Africa. Even in China, which still has the world's largest national population, estimates for recent the TFR range from 1.8 to 1.2 (15), an uncertainty of 20% up or down from 1.5.

We present three different sensitivity analyses with respect to uncertainty in the baseline data. In the first, we only use the UN's own fertility baseline data, because they have been used in successive assessments from 2008 to 2015 and apply the probabilistic model used in 2015. The first two panels on the left of Fig. 4 present the results of this exercise, showing that the two assessments published only 7 y apart show a qualitatively very different pattern for the 21st century. Based on the 2008 baseline the same model shows a median that levels off and starts to decline before reaching 10 billion. The third and fourth panels in Fig. 4 show the results of projections in which the fertility baseline is assumed to be systematically 10% higher or lower, respectively, than in the 2015 Revision of World Population Prospects (WPP2015) in the countries of sub-Saharan Africa and South Asia and in China but remains unchanged for all other countries. The results show that the projection model is so sensitive to possible systematic errors in baseline fertility that the resulting 95% prediction intervals for the world to the end of the 21st century do not even overlap: Under the "reduced TFR" scenario the upper end of the 95% range in 2100 is 10.8 billion, and under the "increased TFR" scenario the lower end of the range is 11.4 billion.

One may argue that the possibility of a systematic upward or downward bias in baseline TFR is rather unlikely, but it cannot be ruled out because the same kinds of measurement instruments (such as DHS or related surveys) are used for virtually all African countries. For this reason we also tested the sensitivity to baseline errors in just one country with the baselines in all other countries of the world remaining unchanged (see *Supporting Information*). The results for Kenya (in Fig. S3) show that, even without assuming any systematic error across groups of countries, the projected median population size in 2100 with the TFR reduced by 10% from baseline is below the lower end of the 80% range of the projections based on the increased baseline TFR. In sum, these calculations demonstrate that purely extrapolative statistical models that do not take into account any country-specific substantive information about socio-economic or institutional determinants of fertility or expert knowledge about foreseeable changes are highly sensitive to possible measurement errors in the most recent data points.

Another reason for the narrow global prediction interval of the UN projections results from assuming virtually no intercountry correlation for the rest of this century. As a consequence, even the UN's own high and low variants, which assume perfect correlation of fertility, lie far outside the 95% range of their probabilistic projections. In the case of no or low correlation, the trajectories above expectation in one country cancel those below expectation in another country. While for most individual countries the different SDG scenarios lie within the 95% prediction interval of the UN (see the example of Nigeria in Fig. 3 and India in Fig. S3), the assumption of virtually no intercountry correlation partially explains why at the global level they lie outside the 95% prediction interval.

Because the given software does not allow specifying alternative levels of correlation for the future, we could only emulate the case of assumed perfect correlation (right panel in Fig. 4). The resulting probabilistic prediction range is wider than the official probabilistic projections by a factor of five. It also shows that, in probabilistic terms, the range between the UN's high and low variants (16.6 and 7.3 billion in 2100, respectively) corresponds roughly to 85% of the range given by these projections with perfect correlation, although they lie far outside the 95% range of the official projections.

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 and in making adaptation to already unavoidable environmental change more difficult (16–18). At the same time it is widely perceived as a politically sensitive topic (19), and indeed the 1994 International Conference on Population and Development explicitly opposed the setting of "demographic targets." Fertility decisions are considered a private matter, with the role of the state being 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. However, many of the goals and targets deal with factors that directly or indirectly influence fertility and thus population growth.

In this paper we quantified the likely effects of some of the most relevant SDG targets in the areas of health and education based on a set of plausible assumptions. In doing so we built 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 education, particularly in countries in demographic transition, has a direct causal effect on lowering desired family size and empowering women to realize these lower fertility goals. The availability of reproductive health services also helps enhance contraceptive prevalence. Because 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 that, in addition to all the other beneficial consequences of education, also leads to lower fertility (20).

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 that could be directly translated into demographic trajectories and could be complemented through estimates of the indirect effects of better education on survival at all ages. This exercise also could build on the recently developed set of SSPs that now are 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. Although clearly more research is needed to study the synergies between the different SDGs (21) 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 is important to stress that this quantification of the likely effects of implementing of the SDGs on future population trends rests on many assumptions and therefor includes many "ifs." First, it is far from certain that the relevant SDGs will be fully implemented in all countries of the world. One can look at the MDGs set for 2000–2015 for guidance on this issue: The achievement was impressive in the global average, but at the country level the record was mixed. In particular, it may be unlikely that the ambitious education targets will be met in some of the poorest African countries. For this reason we have included some less ambitious education goals among the set of SDG scenarios. Similarly, the assumption that universal access to reproductive health services will result in 20% lower education-specific fertility rates may be questionable. Therefore we also included scenarios that assume only a 10% effect. Finally, we assume that the assessed relationships between education and fertility and between education and mortality persist over the entire projection horizon. Although there is strong theoretical and empirical support for the assumption that education has a persistent functional causal effect over the course of demographic transition (5, 7), the education effect is far from being a universal certainty, and the results based on this assumption therefore must be viewed as conditional.

It also was noted that the population growth trajectories that would result from the successful implementation of the SDGs, although consistent with the SSP scenarios, would lie far outside the 95% prediction 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 prediction 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 of the UN projections to possible errors in baseline estimates of fertility and assumptions concerning the correlation among national trends. Both aspects suggest that markedly wider prediction ranges should be considered. There are further problems with the statistical extrapolation model used by the UN that go beyond the scope of this paper. In particular, one may question the model in which all national fertility trends are given equal weight, irrespective of whether they summarize the experience of only a few thousand couples or hundreds of millions of couples. Because in fertility couples, not states, are the relevant decision-making units, 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; doing so would greatly change the projection results. Again, this change 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 accelerate global development strongly 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 as these goals are, leaders of all countries and the entire UN system have committed themselves to do whatever is required, possibly including unconventional measures, to reach the specified targets, and progress is being monitored closely. 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 show 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 toward reaching the SDGs can result in accelerated, strictly voluntary fertility declines that could result in a global peak population around midcentury. These strong effects of the SDGs on lowering global population growth in a politically unproblematic and widely accepted way provide an additional rationale for vigorously pursuing the implementation of the SDGs.

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