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Working Paper

Installment 3 of "Creating a Sustainable Food Future"

ACHIEVING REPLACEMENT LEVEL FERTILITY

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SUMMARY

The world's population will rise from just over 7 billion in 2012 to nearly 9.6 billion by 2050. Most of the world's regions have already achieved or are close to achieving replacement level fertility. "Replacement level fertility" is the total fertility rate—the average number of children born per woman—at which a population replaces itself from one generation to the next, without migration. This rate is roughly 2.1 children per woman for most countries, although it may modestly vary with mortality rates.

Sub-Saharan Africa is the exception to this fertility trend. Its total fertility rate was 5.4 during the 2005–10 period—double that of any other region—and is projected to decline only to 3.2 by 2050. These expected reductions in fertility rates reflect expectations of increasing urbanization, expected declines in child mortality, and increases in income, among other factors. This total fertility rate trajectory will result in a population increase of 1.2 billion people in Sub-Saharan Africa from 2012 to 2050. This increase will more than double the region's current population of 0.9 billion to 2.1 billion by 2050, and quadruple it to 3.9 billion by 2100, according to the Population Division of the United Nations Department of Economic and Social Affairs (UNDESA). The region's projected growth in population will account for half of the planet's population growth between 2012 and 2050.

This projected increase in population poses a food security challenge for the people of Sub-Saharan Africa. The region is already the world's hungriest. According to the Food and Agriculture Organization of the United Nations (FAO), 27 percent of Sub-Saharan Africa's people are undernourished, while a study by the U.S. Department

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of Agriculture estimates that it is home to 44 percent of the world's hungry people. The region currently has the world's lowest crop yields, with cereal yields of 1.5 metric tons per hectare per year—roughly half the world average. Much of the soil has lower carbon content and is depleted of nutrients.

Sub-Saharan Africa could reduce the challenge of feeding its population if it were to achieve the replacement level fertility of 2.1 by 2050. Doing so would require a reduction in the region's average total fertility rate at a faster pace than currently projected. According to analysis conducted for this working paper by the Oxford Institute of Population Ageing, such a reduction would result in a Sub-Saharan African population of 1.76 billion by 2050—roughly 390 million less than UNDESA's most recent medium fertility scenario projection for 2050.

Achieving replacement level fertility in Sub-Saharan Africa by 2050—and ensuring it is achieved as projected in other regions—could generate a number of benefits. It would reduce food demand by roughly 600 trillion kilocalories (kcal) per year by midcentury, closing about 9 percent of the 6,500 trillion kcal per year global gap between food available in 2006 and that needed in 2050. More dramatically, it would reduce the size of the projected gap in Sub-Saharan Africa's crop production for that period by approximately one quarter. The region already relies on imports for roughly 20 percent of its staple crops, so closing this food gap would significantly contribute to food security.

Reducing fertility rates could also lead to economic benefits through a "demographic dividend." During and after a rapid decline in fertility, a country simultaneously has fewer children to care for and a greater share of its population in the most economically productive age bracket. Researchers estimate that this demographic shift was responsible for up to one third of the economic growth of the East Asian "Tigers" between 1965 and 1990.

Furthermore, achieving replacement fertility would reduce agriculture's impact on the environment. Based on FAO projections for yield gains in the region, Sub-Saharan Africa will need to add more than 125 million hectares of cropland from 2006 levels to meet the region's projected crop needs in 2050. Achieving replacement level fertility would cut needed cropland expansion by one third, potentially sparing an area of forest and savannah larger than Germany from conversion. This sparing would reduce the carbon emissions that would have resulted from that conversion. A reasonable value for this reduction to the world would be US$400 billion to US$1 trillion, based on alternative mitigation costs of US$25 to US$60 per ton of carbon dioxide.

Fortunately, the most effective approaches to achieving replacement level fertility are non-coercive, save millions of lives, advance gender equity, give people more control over their lives, and contribute to economic growth. These approaches focus on increasing educational opportunities for girls; increasing access to reproductive health services, including family planning; and reducing infant and child mortality.

In most countries, national governments control, fund, and set policies for education systems and health services. Pursuing the approaches noted above for achieving replacement level fertility is, therefore, the responsibility of national governments. However, bilateral and multilateral development agencies also have a role to play by supporting programs that advance gender equity in education, reproductive health services, and nutrition and preventative health services for children under the age of five. Civil society organizations can help as well by raising awareness, generating resources, delivering services, and monitoring performance.

The most recent population data find that Sub-Saharan African fertility rates have not been declining as rapidly as anticipated by previous UNDESA projections. Yet countries such as Botswana and Rwanda have demonstrated that enormous progress is possible. Achieving replacement level fertility in Sub-Saharan Africa and elsewhere by 2050 is a multi-win solution to humanitarian, economic, and environmental challenges, and an important item on the menu for a sustainable food future.

POPULATION AND FOOD

In the first installment of the World Resources Report's *Creating a Sustainable Food Future* working paper series, "The Great Balancing Act" (Box 1), we show that the world

faces a great balancing act of three needs. It needs to close a 6,500 trillion kcal per year global gap between the food available in 2006 and that required in 2050—approximately a 69 percent increase in needed calories—to adequately feed the planet.[1] It needs agriculture to contribute to economic and social development. And it needs agriculture to reduce its impact on climate, water, and ecosystems.

Throughout the *Creating a Sustainable Food Future* series, we explore a menu of solutions that could combine to meet these three needs. One menu item is to achieve replacement level fertility in every region by 2050, which would reduce food demand by midcentury relative to the baseline scenario described in "The Great Balancing Act." "Replacement level fertility" is the total fertility rate at which a population replaces itself from one generation to the next, without migration. It generally refers to 2.1 children per woman.[2] The "total fertility rate" is the average number of children a woman would have assuming that birth rates remain constant throughout her reproductive lifetime.[3]

How much of a contribution to a sustainable food future could achieving replacement level fertility by 2050 have and how could it be realized? This working paper seeks to address these questions by discussing the nature of the population challenge globally; the effect of population growth on food demand in Sub-Saharan Africa; and the potential food security, economic, and environmental benefits of reducing fertility rates more quickly than currently projected. This working paper then explores the promising approaches for achieving replacement level fertility.

In our assessment, achieving replacement level fertility in every region by the year 2050 would meet the development and environmental criteria introduced in "The Great Balancing Act" (Table 1). Achieving replacement level fertility would help boost economic development; alleviate poverty; increase social equality; and reduce agriculture's pressure on ecosystems, climate, and water.[4]

Box 1 | The World Resources Report: *Creating a Sustainable Food Future*

How can the world adequately feed more than 9 billion people by 2050 in a manner that advances economic development and reduces pressure on the environment? This is one of the paramount questions the world faces over the next four decades.

Answering it requires a "great balancing act" of three needs—each of which must be simultaneously met. First, the world needs to close the gap between the food available today and that needed by 2050. Second, the world needs agriculture to contribute to inclusive economic and social development. Third, the world needs to reduce agriculture's impact on the environment.

The forthcoming 2013-14 World Resources Report, *Creating a Sustainable Food Future*, seeks to answer this question by proposing a menu of solutions that can achieve the great balancing act. "Achieving Replacement Level Fertility" profiles one of these solutions or "menu items," and is an installment in a series of working papers leading up to the World Resources Report.

Since the 1980s, the World Resources Report has provided decisionmakers from government, business, and civil society with analyses and insights on major issues at the nexus of development and the environment. For more information about the World Resources Report and to access previous installments and editions, visit www.worldresourcesreport.org.

Table 1 | **How "Achieving Replacement Level Fertility" Performs Against the Sustainable Food Future Criteria**

● = positive ○ = neutral/it depends ⊗ = negative

CRITERIA	DEFINITION	PERFORMANCE	COMMENT
Poverty Alleviation	Reduces poverty and advances rural development, while still being cost effective	●	■ One of the recommended approaches for achieving replacement level fertility—increasing educational opportunities for girls—can increase household income potential. ■ Under appropriate conditions, substantial declines in fertility could yield a "demographic dividend" that contributes to economic growth, in which a country simultaneously has fewer children to care for and more adults in their most economically productive ages.
Gender	Generates benefits for women	●	■ Some of the recommended approaches for achieving replacement level fertility empower women, most notably by increasing educational opportunities for girls and increasing access to reproductive health services.
Eco-systems	Avoids agricultural expansion into remaining natural terrestrial ecosystems and relieves pressure on overstrained fisheries	●	■ A lower population than projected in 2050 would reduce the need to convert more ecosystems into food production or to harvest more wild food (e.g., fish).
Climate	Helps reduce greenhouse gas emissions from agriculture to levels consistent with stabilizing the climate	●	■ A lower population than projected in 2050 would reduce the need to convert more land; apply more fertilizers; raise more livestock; and use more energy for producing, processing, transporting, and storing food.
Water	Does not deplete or pollute aquifers or surface waters	●	■ A lower population than projected in 2050 would reduce the need to withdraw more water from aquifers or add more agricultural chemicals that may pollute water bodies.

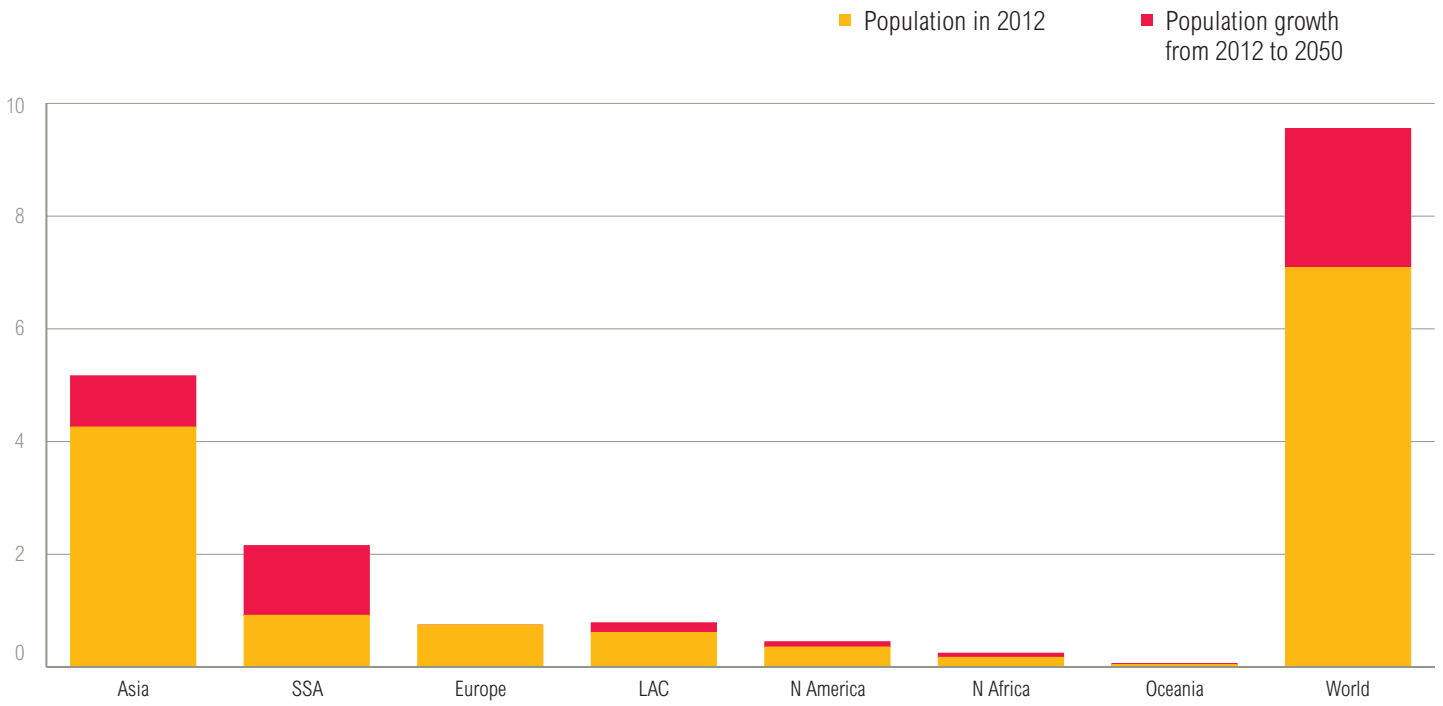
POPULATION GROWTH PROJECTIONS

According to UNDESA's updated medium fertility scenario released in June 2013, global population will rise from just over 7 billion in 2012 to nearly 9.6 billion by 2050 (Figure 1).[5] Half of this growth will occur in Sub-Saharan Africa.[6] Most of the remainder will occur in Asia (Figure 2).

Although both Africa and Asia are projected to contribute significantly to population growth, the reasons are different. Most of the world's regions are close to achieving replacement level fertility, and will achieve or even dip below it by 2050 (Figure 3). By 2010, Asia's average total fertility rate had fallen to 2.3, just slightly above the replacement level, and it will likely decline below the replacement level by 2050. Asia's population growth over coming decades will therefore occur not because of ongoing high fertility but because high fertility rates in the past have created a demographic bulge in the number of young people who are entering childbearing age. In 2010, North Africa, Latin America, and Oceania all had fertility rates just above replacement level, and all are projected to decline to slightly below replacement level by 2050. North America and Europe are already below replacement level and are projected to remain there through 2050.

Sub-Saharan Africa is the exception. From 2005–10 it had a total fertility rate of 5.4. UNDESA projects that this rate will decline gradually over the coming four decades, but will fall to only 3.2 by 2050—well above the replacement fertility level. This trajectory will result in a population increase of 1.2 billion in the region between 2012 and 2050, more than doubling the population of Sub-Saharan Africa from 0.9 billion in 2012 to 2.1 billion by midcentury. According to UNDESA, this persistence of high fertility in the region will result in a large group of young people who will enter their childbearing years over the coming decades. Thus, even with a decline in fertility rate to 3.2 in 2050, the region's population will grow to a total of 3.9 billion by 2100, more than a four-fold increase from 2012 levels.[7]

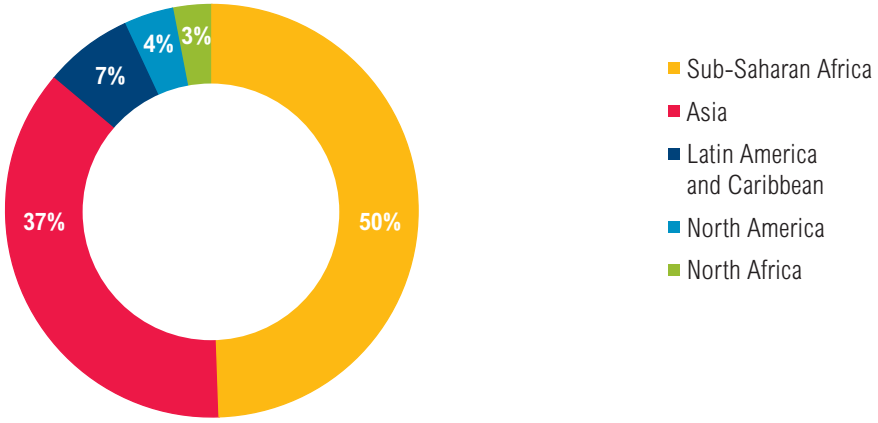
Figure 1 | **The World's Population Will Grow from About 7 Billion People in 2012 to 9.6 Billion in 2050 (Population in billions)**



Note: "SSA" = Sub-Saharan Africa. "LAC" = Latin America and Caribbean. "N America" = North America. "N Africa" = Rest of Africa.

Source: United Nations Department of Economic and Social Affairs, Population Division (UNDESA). 2013. *World Population Prospects: The 2012 Revision.* Total population by major area, region, and country. Medium fertility scenario.

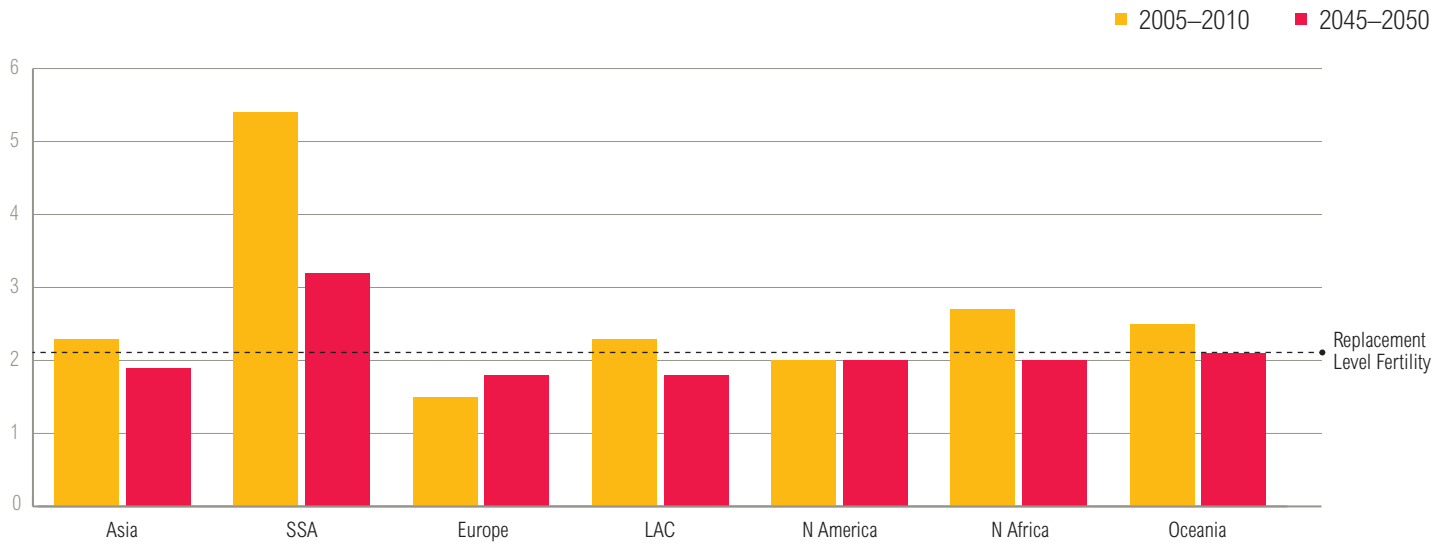
Figure 2 | **Half of Projected Population Growth from 2012–2050 Will Be in Sub-Saharan Africa (100% = 2.3 billion people)**



Note: Figures may not equal 100% due to rounding. Europe is projected to decline by 33 million people (1 percent decrease) while Australia and Oceania projected to grow by 19 million people (less than 1 percent increase) between 2012 and 2050.

Source: United Nations Department of Economic and Social Affairs, Population Division (UNDESA). 2013. *World Population Prospects: The 2012 Revision.* Medium fertility scenario.

Figure 3 | **All Regions Except Sub-Saharan Africa Are Projected to Reach Replacement Level Fertility by 2050 (Total Fertility Rate)**



Note: "SSA" = Sub-Saharan Africa. "LAC" = Latin America and Caribbean. "N America" = North America. "N Africa" = Rest of Africa.

Source: United Nations Department of Economic and Social Affairs, Population Division (UNDESA). 2013. *World Population Prospects: The 2012 Revision.*Total fertility by major area, region, and country. Medium fertility scenario.

THE CHALLENGE AND OPPORTUNITY FOR SUB-SAHARAN AFRICA

The projected increase in Sub-Saharan Africa's population poses a large, regional food security challenge. The region is already the world's hungriest; the FAO estimates that 27 percent of Sub-Saharan Africa's people are undernourished.[8] Although Sub-Saharan Africa currently consumes 9 percent of the world's food calories annually, the region will account for 39 percent of global growth in demand for food calories by 2050 and 26 percent of the total growth in crop calories.[9] Furthermore, in 2010, Africa relied on imports for one quarter of its cereals, two thirds of its vegetable oil, and 14 percent of its animal products.[10] Sub-Saharan Africa is a relatively poor region where people have limited income to purchase imported food; its reliance on imports makes the availability of and access to food unstable.

These factors make Sub-Saharan Africa the region most in need of additional food production. Yet it has the world's lowest crop yields, with cereal yields of 1.5 metric tons per hectare in 2011—roughly half the world average.[11] In addition, soil quality is poor throughout much of the region, depleted of organic matter and nutrients.[12]

Many opportunities exist to boost food production in Sub-Saharan Africa, but fully meeting needs on existing agricultural land will be difficult. This difficulty creates pressure to convert natural landscapes such as forests and savannahs into farmland and grazing land, releasing carbon, harming biodiversity, and degrading ecosystem services. Given projected growth in population and food demand, Sub-Saharan Africa would need to more than triple its cereal yields by 2050 relative to today to avoid expanding cropland even while maintaining its present heavy reliance on imports of staples.[13] This required yield growth of cereals—an additional 61 kilograms per hectare each year—is almost 50 percent higher than the global average annual cereal yield growth from 1962–2006.[14] This level of growth rivals actual yield growth in China over the past 44 years, but China's land is far wetter and more fertile.

Sub-Saharan Africa could reduce this challenge if it were to lower its present total fertility rate of 5.4 enough to reach replacement level fertility of 2.1 by 2050, instead of the projected rate of 3.2. According to the Oxford Institute of Population Ageing, reaching replacement level fertility would result in a Sub-Saharan African population of 1.76 billion by 2050.[15] This figure is roughly 390 million fewer people than UNDESA's medium fertility scenario projection for 2050.[15] If the region maintained replacement level fertility thereafter, the population would be 3.1 billion by 2100 instead of the 3.9 billion projected by UNDESA's medium fertility scenario, roughly a tripling rather than a quadrupling of current population.[16] The UNDESA's low fertility scenario projections, which do not anticipate as steep a decline between now and 2050 but do anticipate Sub-Saharan Africa fertility dropping below the replacement level after that, would result in a population increase to roughly 2.7 billion by 2100.

POTENTIAL BENEFITS OF ACHIEVING REPLACEMENT LEVEL FERTILITY

Achieving replacement level fertility by 2050 in Sub-Saharan Africa—as in every other region of the world—would generate many benefits. One is greater food security. Worldwide replacement level fertility by midcentury would reduce demand for crops in 2050 by roughly 600 trillion kcal per year compared to that needed to feed the UNDESA's estimated population. This reduction would close about 9 percent of the 6,500 trillion kcal per year global gap between crops available in 2006 and those needed in 2050.[17] More significantly, replacement level fertility in Sub-Saharan Africa would reduce by one quarter the projected growth in crop demand in the region in that period.[18] This reduction would make it easier for Africans to feed themselves without relying even more heavily on imports than they do today.

Achieving replacement level fertility would also likely lead to economic benefits through a "demographic dividend."[19] During and for several years after a rapid decline in fertility, a country simultaneously has fewer children to care for—freeing up resources—and has a greater share of its population in the most economically productive age bracket. Researchers have estimated that this demographic shift was responsible for up to one third of the economic growth of the East Asian "Tigers" between 1965 and 1990.[20] Sub-Saharan African countries should be able to reap a demographic dividend if fertility levels fall as long as weak governance and poor policies do not undercut it.[21]

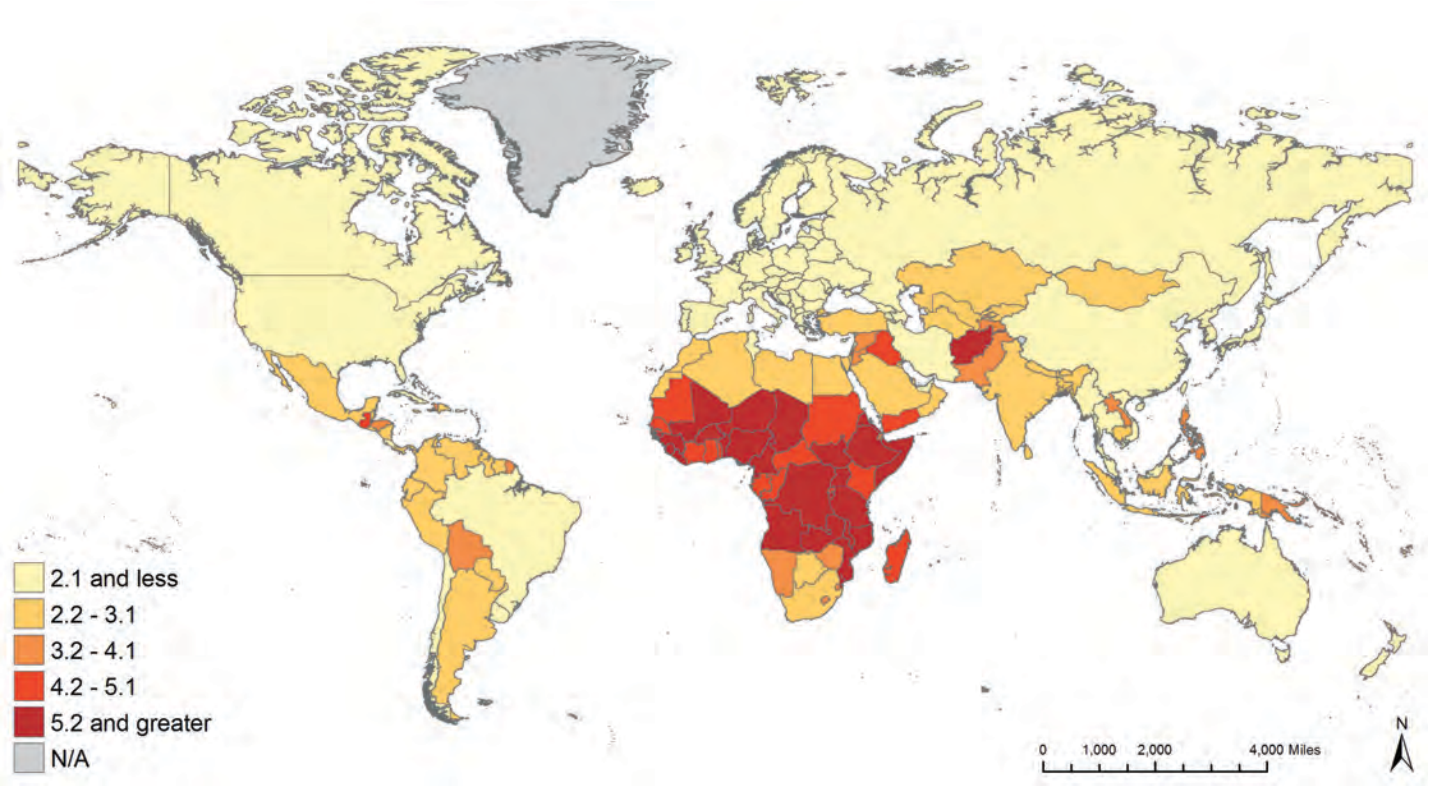
The reduced demand for food would in turn lessen agriculture's impact on the environment. It would reduce greenhouse gas emissions by reducing the need to apply more fertilizers; raise more livestock; and use more energy

for producing, processing, transporting, and storing food. Reducing food demand would reduce the need to withdraw more water from aquifers and rivers. In addition, reducing food demand would significantly reduce the need to convert more forests, woodlands, and savannahs in Africa into agricultural land. For example, cereal yields would only have to increase by roughly the world's average annual cereal yield growth from 1962–2006 to make it possible for the region's farmers to meet their food needs at the country's present level of imports without expanding cereal farmland.

A likely consequence of this reduced food demand would be substantially less land conversion in Sub-Saharan Africa. Based on the FAO's projected yield gains in the region, Sub-Saharan Africa will need to add more than 125 million hectares of cropland over 2006 levels to meet crop needs in 2050.[22] That area is comparable in size to Germany, France, and the United Kingdom combined. This growth is independent of any growth in cropland area for exports sought by many recent foreign investments in agricultural land in the region. Achieving replacement level fertility by 2050 would cut that needed cropland expansion by roughly one third, potentially sparing an area of forest and savannah larger than Germany.

According to one reasonable estimate of typical losses of 100 metric tons per hectare of pure carbon when land in Africa is converted, this land sparing would save 16 gigatons[23] of carbon dioxide emissions.[24] A wide range of estimates exist for the alternative costs of reducing carbon dioxide emissions, but at prices of US$25 to US$60 per metric ton, these savings in carbon would avoid US$400 billion to US$1 trillion in costs of reducing carbon emissions by other means.

Figure 4 | **Sub-Saharan Africa Has the Highest Total Fertility Rates (Total Fertility Rate, 2005–2010)**



Source: United Nations Department of Economic and Social Affairs, Population Division (UNDESA). 2013. *World Population Prospects: The 2012 Revision.*

Finally, achieving replacement level fertility would yield significant social benefits—especially for women and children—if the methods pursued involve empowering women and reducing infant and child mortality, as described next.

EFFECTIVE APPROACHES

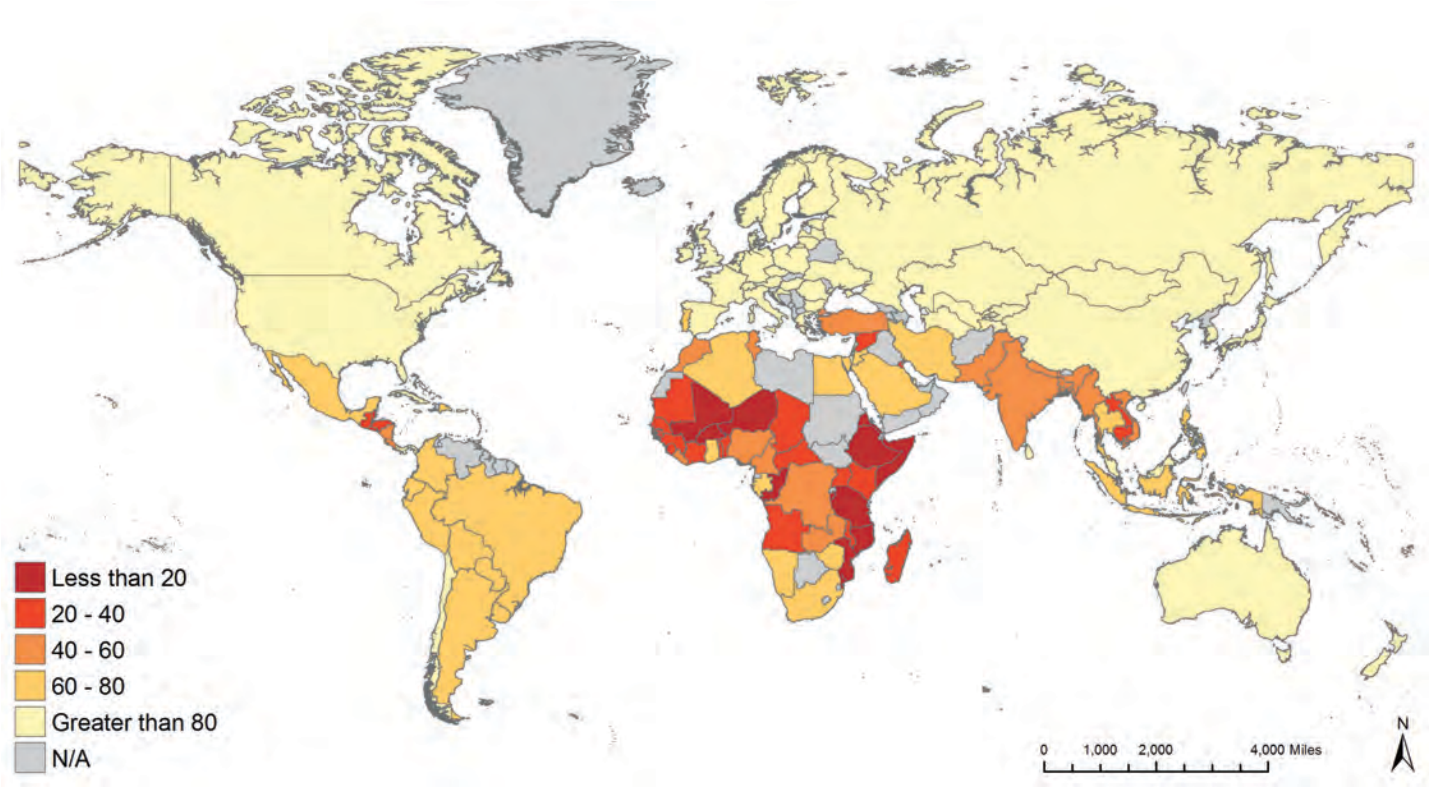
How can countries effectively achieve replacement level fertility? Experience and statistical studies point to three critical approaches with great collateral benefits:[25]

- **INCREASE EDUCATIONAL OPPORTUNITIES FOR GIRLS.** In general, the longer girls stay in school, the later they start bearing children and the fewer children they ultimately have.[26] In most countries with total fertility rates of 2.1 children per woman or lower (Figure 4), 80 to 100 percent of women of childbearing age have attained at least a lower secondary education—that is, some high school (Figure 5). As Figures 4 and 5 show, Sub-Saharan Africa illustrates this relationship in reverse: the region has a low share of women with lower secondary education and high fertility rates.

  The link between education and fertility rates occurs within countries, too. Ethiopia's 2012 Demographic and Health Survey, for instance, found that women with no formal education have on average six children, while those with a secondary education have only two.[27] Education not only increases the age at which a woman gives birth to her first child, but also helps a woman diversify and increase her income opportunities.[28]

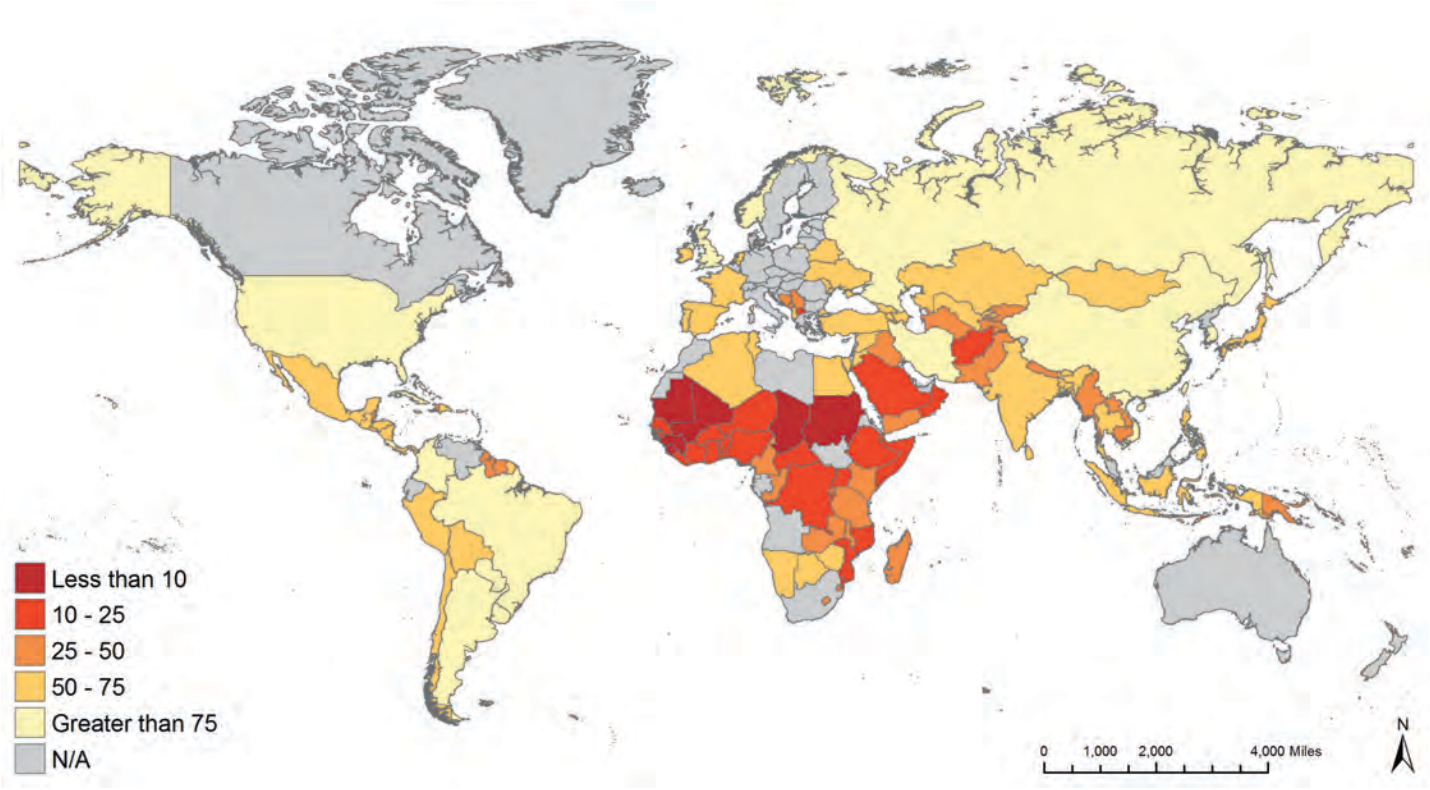
- **INCREASE ACCESS TO REPRODUCTIVE HEALTH SERVICES, INCLUDING FAMILY PLANNING.** Access to family planning counseling and technology ensures that women and men can make informed choices about reproduction. Access to reproductive health services can also lower

Figure 5 | **Sub-Saharan Africa Has the Lowest Total Share of Women with at Least Lower Secondary Education (Percent of Women Ages 20–39 with at Least Lower Secondary Education, 2005–2010)**



Source: Harper, S. 2012. "People and the planet."

Figure 6 | **Sub-Saharan Africa Has the Lowest Share of Women Using Contraception (Percent of Women Ages 15–49 Using Contraception, 2005–2010)**



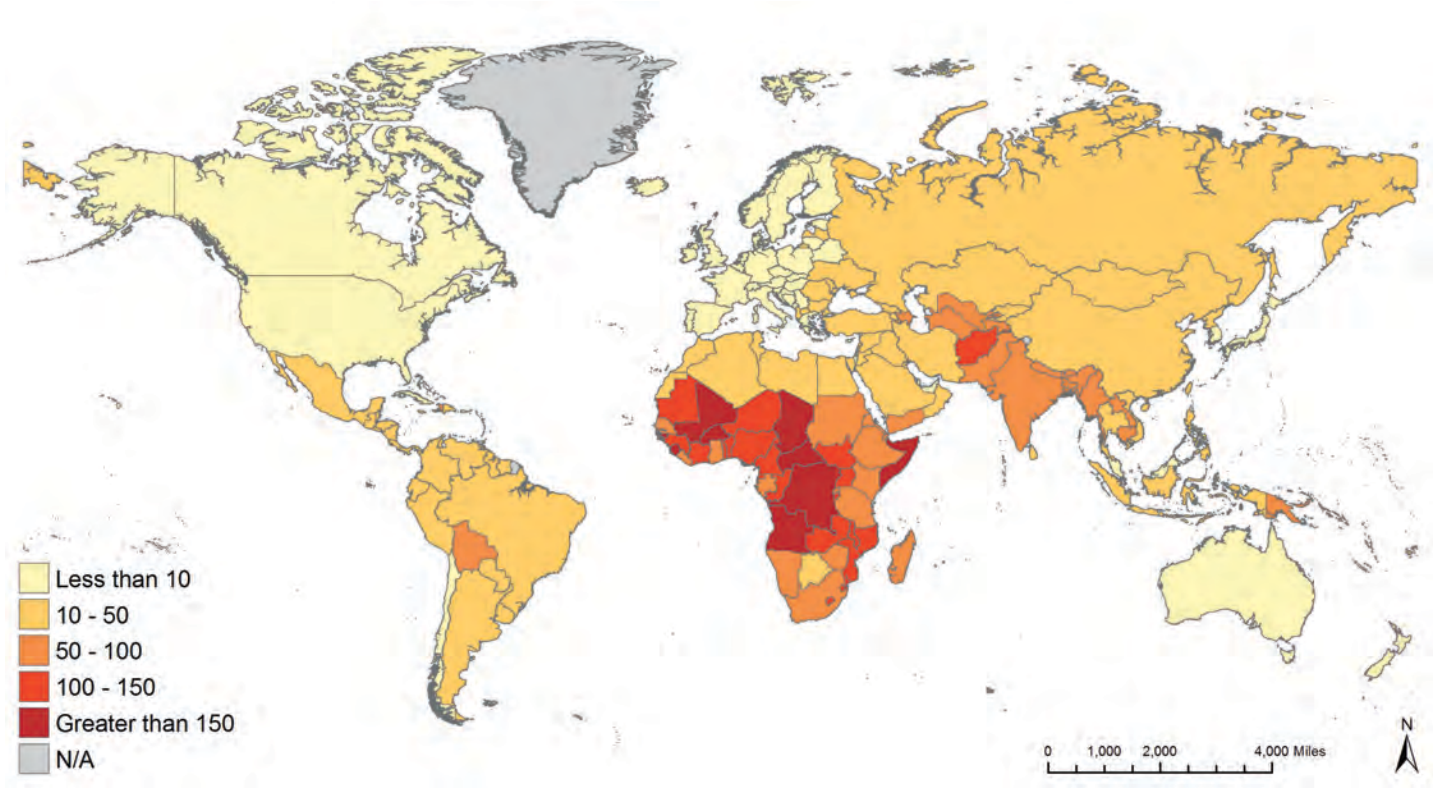
Source: World Bank. 2012d. Databank: "Contraceptive prevalence (% of women ages 15-49)." Data retrieved April 2, 2013, from World Development Indicators Online (WDI) database.

maternal mortality and rates of HIV/AIDS and other diseases.[29] Millions of women—both educated and not—want to space and limit their births but do not have adequate access to reproductive health services. The World Health Organization (WHO) found that 53 percent of women in Africa who wish to control their fertility lack access to birth control, compared with 21–22 percent in Asia and Latin America.[30] Studies also show that Sub-Saharan Africa has the lowest share of women of childbearing age who use contraception (Figure 6).[31] Increasing access to reproductive health services, combined with increasing educational opportunities for girls, can help delay a woman's first childbirth. The age at which a woman gives birth to her first child is a strong indicator of how many children she will ultimately have.[32]

- **REDUCE INFANT AND CHILD MORTALITY.** Reducing infant and child mortality assures parents that they do not need to conceive a high number of children to assure survival of a desired number.[33] On average, countries with low fertility rates have low infant and child mortality rates.[34] Once again, Sub-Saharan Africa illustrates this relationship in reverse (Figure 7).

Improving the productivity of farm labor is another strategy that could help reduce total fertility rates. Rural women in Sub-Saharan Africa do much of the farming and also face heavy demands on their time for gathering wood and water, cooking, and caring for children.[35] The demand for labor can be an incentive for farming families to have many children. Improving yields per hectare and yields per unit of work should counter the perceived need for many children.

Figure 7 | **Sub-Saharan Africa Has the Highest Child Mortality Rates (Mortality of Children Under Age 5 per 1,000 Live Births, 2005–2010)**



Source: World Bank. 2012c. Databank: "Mortality rate, under-5 (per 1,000 live births)." Data retrieved April 2, 2013, from World Development Indicators Online (WDI) database.

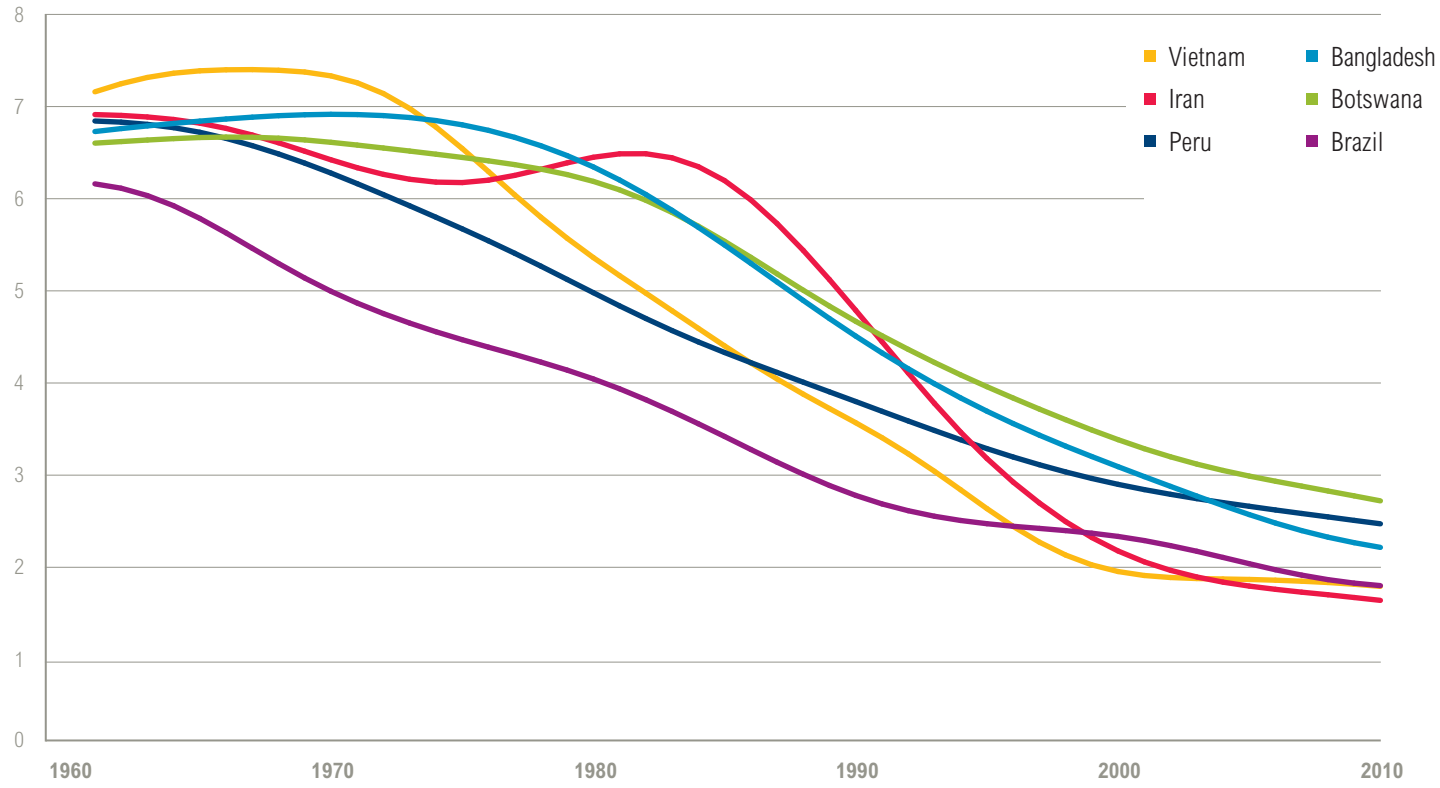
In fact, fertility rates have been declining in most Sub-Saharan African countries, albeit at varying rates, and studies have correlated these declines with improvements in women's education, decreases in infant and child mortality, and increases in access to modern contraceptives.[36] The means are clear. The challenge is that the current rates of improvements are not fast enough to avoid a doubling of the population by 2050, and a quadrupling by 2100.

POTENTIAL TO REDUCE FERTILITY RATES QUICKLY

Could Sub-Saharan Africa achieve replacement level fertility by 2050? History from other regions suggests it could. Although some researchers once believed that only developed countries could dramatically lower their birth rates,[37] a number of less developed countries have done so as well. For example, Peru, Uzbekistan, and Bangladesh all went from fertility rates of just under 7 in 1960 to around 2.5 by 2010, through voluntary family planning programs, increases in education, and improvements in child survival.[38] Yet these countries were still relatively poor in 2011, ranking 87th, 139th, and 166th out of more than 180 countries in per capita income.[39] Being "economically developed" is not a precondition for lowering total fertility rates.

Reductions in fertility rates can occur rapidly. In Vietnam, the fertility rate dropped from 7.4 to 2 in 30 years, partly in response to government penalties for larger families. Brazil went from a fertility rate of 6.2 to around 2.8 in an equivalent time period without government mandates. And Iran's fertility rate declined from 5.2 to 2.2 in the 11 years between 1989 and 2000, also without mandates (Figure 8). Rates can drop rapidly in a variety of cultures and without coercion.

Figure 8 | **Total Fertility Rates Can Decline Rapidly (Total Fertility Rate)**



Source: World Bank. 2012a. Databank: "Fertility rate, total (births per woman)." Data retrieved November 30, 2012, from World Development Indicators Online (WDI) database.

MAKING PROGRESS IN AFRICA

Nothing about Sub-Saharan Africa makes it an exception. The challenge is largely one of the wise direction and use of resources. Some Sub-Saharan countries have made progress.

Botswana's experience suggests that well-structured investments can reduce fertility rates. A countrywide, system of free health facilities that integrates maternal and child healthcare, family planning, and HIV/AIDS services has played an important role.[40] Mortality rates for children under five declined from 81 per 1,000 in 2000 to 26 per 1,000 in 2011.[41] Contraceptive use increased from 28 percent in 1984 to 53 percent in 2007.[42] For many years Botswana provided free education to all, and it still exempts the poorest from school fees, resulting in an 85 percent literacy rate and a rate of 88 percent of girls enrolled in lower secondary education. The result: Botswana's fertility rate declined from 6.1 in 1981 to 2.8 in 2010.[43]

Rwanda is at an earlier stage of making similar progress. All children are entitled to nine years of free education in state-run schools, with six years of primary education and three years of secondary education. In 2010, President Kagame announced plans to extend free education for an additional three years of secondary education, and between 2011 and 2012 the number of students in upper secondary education increased by 26 percent.[44] Girls' education in Rwanda is more widespread than ever before, with a net primary enrollment rate of 98 percent, up from 91 percent in 2008.[45] An extensive system of free health care for the poorest has helped lower Rwanda's mortality rate for children under the age of five from 120 per 1,000 in 2000 to 62 per 1,000 in 2012. Support and education for family planning has increased the rate of contraceptive use from 17 percent to 52 percent, and cut unmet needs

for family planning in half to 19 percent.[46] As a result, Rwanda's total fertility rate is on a steep decline from 8 as recently as 1985–90 to 4.8 in 2012.[47]

As these experiences illustrate, progress is mostly within the control of national governments, since they allocate funds and set policies for the public education and health-care systems in most countries. To realize the benefits of achieving replacement level fertility, national governments will need to devote additional resources to improving educational opportunities for girls, family planning, and reducing infant and child mortality. As part of this effort, governments will need to strengthen the technical skills, human capacity, and institutional coordination of agencies responsible for delivering education and health reforms.

Civil society organizations have an important role to play, too. They can raise awareness, deliver services, and monitor performance. In some countries, such as Thailand, civil society organizations have successfully generated resources to ensure effective design and delivery of maternal and reproductive health services.[48] Bilateral and multilateral development agencies can also contribute by supporting programs that advance gender equity in education, strengthen family planning programs, and improve health services for mothers and their young children.

Because many people have failed to appreciate the large reductions in fertility in most of the world, some commentators have responded too strongly and suggested that the global fertility and population problem is already solved. They may also suggest incorrectly that population growth has little significance for food security, economic development, or climate change. The progress in most of the world highlights the power of non-coercive methods for stabilizing population that are valuable in their own right. But the prospect that population in Sub-Saharan Africa will more than double by 2050 and quadruple by 2100 shows that a major challenge remains.

Fortunately, the progress in other regions and even in parts of Sub-Saharan Africa provides strong evidence that the challenge can be met. The approaches outlined in this working paper empower women and men to make their own choices about how large a family they want in part by ensuring that their children have the best chance at surviving to adulthood. Achieving replacement level fertility in all regions by 2050 is not only a multi-win solution to humanitarian, economic, and environmental problems, but also an important item on the menu for a sustainable food future.

ENDNOTES

1. These figures are modestly adjusted upward from those presented in the first installment of the World Resources Report working paper series, Searchinger et al. (2013), because UNDESA published in June 2013 (one month after the release of the first installment) increased population projections for 2050. Our adjusted figures in this working paper are based on FAO estimates of food consumption needs in 2050 in underlying data used for Alexandratos and Bruinsma (2012), adjusted by the recently released higher population estimates of UNDESA, which are higher than those used by the Alexandratos and Bruinsma (2012) study, and further adjusted to ensure a minimum food availability of 3,000 kcal per person per day in each region of the planet. The figures represent global annual crop production (measured in kcal), including all crops intended for direct human consumption, animal feed, industrial uses, seeds, and biofuels.
2. Statistics New Zealand (2013). http://www2.stats.govt.nz/domino/external/omni/omni.nsf/wwwglsry/replacement+level The level allows for the sex ratio at birth (roughly 105 males born for every 100 females) and for some mortality of females between birth and childbearing. The actual replacement level will vary slightly from country to country and over time depending on the sex ratio at birth and mortality rates.
3. UNDESA (2011). More specifically, the total fertility rate is "the average number of children a hypothetical cohort of women would have at the end of their reproductive period if they were subject during their whole lives to the fertility rates of a given period and if they were not subject to mortality."
4. In this working paper, we assess the ability of achieving replacement level fertility to serve as a menu item for a sustainable food future in isolation from other factors such as shifts in dietary patterns and agricultural production techniques.
5. UNDESA (2011). Total population by major area, region, and country (medium fertility scenario).
6. UNDESA has recently recognized in its figures the division of Sudan into Sudan and South Sudan and included only the latter in Sub-Saharan Africa. For consistency with some earlier research used to inform this paper, our figures include both countries in Sub-Saharan Africa.
7. UNDESA (2012). Total population by major area, region, and country (medium fertility scenario).
8. FAO, WFP and IFAD (2012); USDA (2012).
9. Authors' calculations. Food calories consist of the food people actually eat, both crops eaten directly and animal products. Crop calories exclude animal products but include feed. Growth of food demand in Sub-Saharan Africa is a larger percentage of the world's increase in food consumption because the FAO projects that the region will consume only modest amounts of crops as animal feed.
10. The precise figures, measured by weight, were 24.5 percent of cereals, 65.7 percent of vegetable oils, and 13.7 percent of animal products. Authors' calculations based on FAO food balance sheets.
11. Authors' calculations from FAOSTAT.
12. UNDESA (2011).
13. Authors' calculations based on average cereal yields of 1.2 metric tons per hectare in 2006 and yields of 3.8 needed in 2050 to avoid land use change while meeting cereal demand. Demand calculations are based on the assumption that the proportion of imports and exports for food and feed does not change and based on the food demand calculations in note 1. These increases are independent of any other increases in cropland area that might occur because of investments focused on agricultural exports.
14. Authors' calculations from FAOSTAT.
15. This figure is based on analysis for this paper by Sarah Harper of the Oxford Institute of Population Ageing at the University of Oxford. The estimation for an assumed closed population is based on a simple approximate mathematical relationship at the population level between the total fertility rate (TFR), total population size, and the number of births in the population on the one hand (No. of births = TFR x total population/α), and between the TFR, the total population size, and the number of deaths in the population on the other hand (No. of deaths = TFR x total population/β). The coefficients α and β are estimated from the respective series of data from the UN. The replacement level fertility scenario of this estimation to 2050 assumes the TFR declines uniformly from its 2010 level to around 2.1 by 2050. Population births and deaths are then estimated in line with the above and the population size estimated simply as follows: Estimated total population (T) = Total population (T-1) + Births (T-1,T) – Deaths (T-1,T).
16. Based on modeling analysis of the Oxford Institute of Population Ageing.
17. Calculations in Searchinger et al. (2013) have been adjusted upward due to increased population projections for 2050. See endnote 1.
18. Authors' calculations.
19. Pool (2007).
20. Bloom et al. (2003); Bloom and Williamson (1998); Bloom et al. (2000); Mason (2001). Locations where the demographic dividend contributed to economic growth include Hong Kong, Malaysia, South Korea, Singapore, Taiwan, and Thailand.
21. Sippel et al. (2011).
22. Authors' calculations from data provided by FAO underlying Alexandratos and Bruinsma (2012). The crop need starts with FAO's projected crop consumption levels per capita in 2050 from domestic (nonimported) sources. We then adjust the total crop need proportionately for the higher population in the new UNDESA projections plus assurance of 3,000 kcal per day per capita. In effect, this calculation assumes the same level of import dependence projected by FAO for 2050 for staple crops. That import dependence is roughly comparable to import dependence today. For example, cereal imports for food and feed supplied 23 percent of cereal needs in Sub-Saharan Africa in 2006 for food and feed and FAO projects imports will provide 19 percent of such needs in 2050.
23. A gigaton is one billion metric tons.
24. Gibbs et al. (2008) estimate above-ground carbon for seasonal and humid forests and savannahs in Africa to be 51 to 204 metric tons per hectare (depending on whether the lands are shrub or forest and if they are disturbed or undisturbed,) with potential soil conversion losses of 10 to 19 metric tons per hectare, assuming that conversion loses 25 percent of soil carbon (see Supporting Information Table S1.) The mix of land-use types converted is somewhat speculative, but even assuming a preference toward conversion of drier or degraded lands, one reasonable estimate would be a carbon loss of 100 metric tons per hectare, equal to 367 metric tons of carbon dioxide per hectare.
25. For studies showing strong statistical correlations between declines in fertility and increases in girls' education, increased access to family planning, and declines in infant mortality, see Shapiro and Gebreselassie (2008), Leeson and Harper (2012), and Upadhyay and Karasek (2010).

26. The correlation between female education, a decrease in fertility rates, and an increase in contraceptive use is well documented in both developed and developing countries, including across Sub-Saharan Africa. For example, see Shapiro and Gebreselassie (2008); Bbaale and Mpuga (2011) and Bloom and Canning (2004).
27. Ethiopia Central Statistical Agency (2012).
28. Chaaban and Cunningham (2011).
29. Shapiro and Gebreselassie (2008); Bongaarts (2005); Bbaale and Guloba (2011); Bbaale and Mpuga (2011).
30. WHO (2013a). Sing and Darroch (2012) cite that 58 million women in Africa—including 53 million in Sub-Saharan Africa—would like to space or limit their next birth, but do not use contraception.
31. World Bank (2013a).
32. Schmidt et al. (2012).
33. Shapiro and Gebreselassie (2008) found that among 24 Sub-Saharan African countries, progress in women's education and reductions in infant and child mortality were the key factors contributing to sustained declines in fertility rates since the early 1990s. They also found that in countries where these education and mortality indicators had stopped improving or were backsliding, fertility rates tended to stall instead of drop further. Hossain et al. (2005) found that reduced mortality rates correlated with reduced fertility in Bangladesh.
34. WHO (2013a); WHO (2013b); CIA (2013).
35. World Bank (2012a).
36. Shapiro and Gebreselassie (2008). The 14 countries with a declining trend in national total fertility rates between the 1990s and mid-2000s included Benin, Burkina Faso, Chad, Cote d'Ivoire, Eritrea, Ethiopia, Madagascar, Malawi, Namibia, Nigeria, Senegal, Togo, Zambia, and Zimbabwe. Three countries (Mali, Niger, and Uganda) were classified as "pre-fertility transition" with no significant declines in fertility rates, and seven countries were classified as "stalled fertility decline" with fertility rates that had initially declined but then stalled during the study period. Across all countries, fertility declines tended to be stronger in urban areas.
37. Coale (1973).
38. World Bank (2012a).
39. World Bank (2012b).
40. World Bank (2010).
41. World Bank (2012c).
42. UNICEF (2008).
43. World Bank (2012a).
44. Rwandan Ministry of Education (2012).
45. UNICEF (2013).
46. Muhoza et al. (2013).
47. Total fertility rate for 2005–10 from UNDESA. Figure for 2012 from the U.S. Central Intelligence Agency is at http://www.indexmundi.com/g/g.aspx?c=rw&v=31.
48. Athena Ballesteros (Senior Associate, Institutions and Governance Program, World Resources Institute). Personal communication. July 12, 2013.
49. Pearce (2011) provides an excellent summary of recent progress on fertility and appears to understate the importance of reducing fertility in Africa.
50. Some articles have correctly highlighted that income growth generates most of the increasing greenhouse gas emissions in the energy and related sectors (Pearce 2009), but these analyses typically fail to note the importance of population growth in poorer countries for greenhouse gas emissions related to agriculture and deforestation.

REFERENCES

Alexandratos, N., and J. Bruinsma. 2012. *World Agriculture towards 2030/2050: The 2012 Revision*. Rome: Food and Agriculture Organization of the United Nations.

Bbaale, E. and A. Guloba. 2011. "Maternal Education and Childbirth Care in Uganda." *Australasian Medical Journal* 4(7): 389–99.

Bbaale, E., and P. Mpuga. 2011. "Female Education, Contraceptive Use, and Fertility: Evidence from Uganda." *Consilience: The Journal of Sustainable Development* 6(1): 20–47.

Bloom, D.E. and D. Canning. 2004. "Global Demographic Change: Dimensions and Economic Significance." Paper presented at Federal Reserve Bank of Kansas City symposium on "Global Demographic Change: Economic Impacts and Policy Challenges," August 26–28, 2004, Jackson Hole, Wyoming.

Bloom, D. E. and J. G. Williamson. 1998. "Demographic Transitions and Economic Miracles in Emerging Asia." *The World Bank Economic Review* 12(3): 419–55.

Bloom, D. E., D. Canning, and P. Malaney. 2000. "Demographic Change and Economic Growth in Asia." *Population and Development Review* 26: 257–90.

Bloom, D. E., D. Canning, and J. Sevilla. 2003. *The Demographic Dividend: A New Perspective on the Economic Consequences of Population Change*. Santa Monica, California: RAND.

Bongaarts, J. 2005. "The Causes of Stalling Fertility Transitions." Working Paper, Population Council, New York.

Chaaban, J. and W. Cunningham. 2011. "Measuring the Economic Gain of Investing in Girls: The Girl Effect Dividend." Policy Research Working Paper 5753, World Bank, Washington, DC.

CIA (Central Intelligence Agency). 2013. *The World Factbook*. Accessible at: https://www.cia.gov/library/publications/the-world-factbook/.

Coale, A. J. 1973. "The Demographic Transition." Proceedings, International Population Conference, Liège, Belgium, Vol. I :53–72.

Ethiopia Central Statistical Agency. 2012. *Ethiopia Demographic and Health Survey 2011*. Addis Ababa, Ethiopia: Central Statistical Agency.

FAO, WFP, and IFAD (Food and Agriculture Organization of the United Nations, World Food Programme, and International Fund for Agricultural Development). 2012. *The State of Food Insecurity in the World 2012. Economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition*. Rome: FAO.

Gibbs, H., M. Johnston, J. A. Foley, T. Holloway, C. Monfreda, N. Ramankutty, and D. Zaks. 2008. "Carbon Payback Times for Crop-Based Biofuel Expansion in the Tropics: The Effects of Changing Yield and Technology." *Environmental Research Letters* 3, 034001.

Harper, S. 2012. "People and the planet." University of Oxford. Presentation at The Royal Society, London, April 2012.

Hossain, M. B., J. F. Phillips, and T. K. LeGrand. 2005. "The Impact of Childhood Mortality on Fertility in Six Rural Thanas of Bangladesh." Working Paper. Population Council, New York.

Leeson, G., and S. Harper. 2012. "Inequalities in Access to Education: Failing to Provide Skills-Building and Empowerment to Girls." *Journal of Population Ageing* 5.4: 211–14.

Mason, A. 2001. "Population and Economic Growth in Eastern and South-Eastern Asia." In *Population Change and Economic Development in Eastern and South-Eastern Asia: Challenges Met, Opportunities Seized*, edited by A. Mason, 1-30. Stanford: Stanford University Press.

Muhoza, D. N., P. C. Rutayisire, and A. Umubyeyi. 2013. "Measuring the Success of Family Planning Initiatives in Rwanda: A Multivariate Decomposition Analysis." Demographic and Health Survey Working Paper, ICF International for U.S. Agency for International Development. Accessible at: http://www.measuredhs.com/pubs/pdf/WP94/WP94.pdf.

Pearce, F. 2009. "Consumption Dwarfs Population as Main Environment Threat." *Environment 360*. Accessible at: http://e360.yale.edu/feature/consumption_dwarfs_population_as_main_environmental_threat/2140.

Pearce, F. 2011. *The Coming Population Crash and Our Planet's Surprising Future*. Boston: Beacon Press.

Pool, I. 2007. "Demographic Dividends – Determinants of Development or Merely Windows of Opportunity?" *Ageing Horizons* 7: 28–35.

Rwandan Ministry of Education. 2012. *2012 Education Statistics Yearbook*. Accessible at: http://www.mineduc.gov.rw/IMG/pdf/2012_Education_statistical_yearbook.pdf.

Schmidt, L., T. Sobotka, J.G. Bentzen, and A. Nyboe-Andersen. 2012. "Demographic and Medical Consequences of the Postponement of Parenthood." *Journal of Human Reproduction Update* 18(1): 29–43.

Searchinger, T., C. Hanson, J. Ranganathan, B. Lipinski, R. Waite, R. Winterbottom, A. Dinshaw and R. Heimlich. 2013. "The Great Balancing Act." Working Paper, Installment 1 of *Creating a Sustainable Food Future*. World Resources Institute, Washington, DC. Accessible at: http://www.worldresourcesreport.org.

Shapiro, D. and T. Gebreselassie. 2008. "Fertility Transition in Sub-Saharan Africa: Falling and Stalling." *African Population Studies* 23 (1): 3–23.

Singh, S. and J.E. Darroch. 2012. *Adding It Up: Costs and Benefits of Contraceptive Services – Estimates for 2012*. New York: Guttmacher Institute and United Nations Population Fund.

Sippel, L., T. Kiziak, F. Woellert, and R. Klingholz. 2011. *Africa's Demographic Challenges: How a Young Population Can Make Development Possible*. Berlin: DSW (Deutsche Stiftung Weltbevoelkerung).

Statistics New Zealand. 2013. "Glossary Term – Replacement Fertility." Accessible at: http://www2.stats.govt.nz/domino/external/omni/omni.nsf/wwwglsry/replacement+level.

UNDESA (United Nations Department of Economic and Social Affairs) Population Division. 2013. "World Population Prospects: The 2012 Revision, Highlights and Advance Tables." Working Paper ESA/P/WP.220, United Nations, New York.

UNICEF (United Nations Children's Fund). 2008. "Botswana – Contraceptive Prevalence." Accessible at: http://www.indexmundi.com/facts/botswana/contraceptive-prevalence.

UNICEF. 2013. "Statistics: Rwanda." Accessible at: http://www.unicef.org/infobycountry/rwanda_statistics.html.

Upadhyay, U. D., and D. Karasek. 2010. "Women's Empowerment and Achievement of Desired Fertility in Sub-Saharan Africa." Demographic and Health Survey Working Paper 80, IFC International for U.S. Agency for International Development. Calverton, MD: ICF Macro.

USDA (United States Department of Agriculture). 2012. *International Food Security Assessment*, 2012–2022. Washington, DC: USDA.

WHO (World Health Organization). 2013a. "Fact sheet N°351: Family Planning." Accessible at: http://www.who.int/mediacentre/factsheets/fs351/en/index.html.

WHO. 2013b. WHO Mortality Database. Accessible at: http://www.who.int/healthinfo/mortality_data/en/index.html.

WHO and the United Nations Children's Fund (UNICEF). 2013. *Accountability of Maternal, Newborn & Child Survival*. Geneva, Switzerland: WHO.

World Bank. 2010. "Fertility Decline in Botswana 1980–2006: A Case Study." Washington, DC: World Bank.

World Bank. 2012a. Databank: "Fertility rate, total (births per woman)." World Bank, Washington, DC. Accessible at: http://data.worldbank.org/indicator/SP.DYN.TFRT.IN.

World Bank. 2012b. Databank: "GDP per capita (current US$)." World Bank, Washington, DC. Accessible at: http://databank.worldbank.org/ddp/home.do?Step=12&id=4&CNO=2.

World Bank. 2012c. Databank: "Mortality rate, under-5 (per 1,000 live births)." World Bank, Washington, DC. Accessible at: http://data.worldbank.org/indicator/SH.DYN.MORT?page=2.

World Bank. 2012d. Databank: "Contraceptive prevalence (% of women ages 15-49)." World Bank, Washington, DC. Accessible at: http://data.worldbank.org/indicator/SP.DYN.CONU.ZS.

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