CHAPTER

12

Climate change and world population

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OUTLINE

1 Introduction

Anthropogenic climate change, as a cumulative impact of human activity, is intimately entwined with human demography. The more people there are, the greater are our collective impacts on the environment. Yet none of the associations are simple, and many evoke sensitivities that cause population to be given little attention in climate change discourse.

There are three relevant dimensions to this relationship. The most obvious to our theme is how climate change might affect population change, through impacts on births, deaths, and movements of people. The second is the extent to which demographic factors influence the vulnerability of communities to the effects of climate change. The third is the effect of

The Impacts of Climate Change
https://doi.org/10.1016/B978-0-12-822373-4.00008-2

population change on the climate, greenhouse gas emissions, and our prospects for abating them. To orient ourselves, we will first review the current trends in global demography.

2 The human population in the 21st century

It took over 100,000 years for the population of humans to reach 1 billion. It took only about 220 years for it to double three times over to 8 billion. The global population will likely reach between 9.5 and 14 billion unless the burden on planetary systems becomes so great as to cause an unthinkable escalation in deaths.

For the past half-century, 1 billion people have been added roughly every 12 years. During 2021, somewhere between 80 million and 90 million people will be added to planet Earth's population. It is difficult to imagine where an extra country the size of Germany could be accommodated, this year and again the next year and the year after. In reality, these people are mainly accommodated in the burgeoning slums of cities in poor countries. They draw increasingly on their local resources, particularly freshwater, soil, forests, fisheries, and wildlife but also increasingly depend on global trade in food, influencing land-use decisions throughout the world.

It is commonly reported that global population growth is already decelerating toward a population peak, and will then decline in the not-too-distant future. This is misleading. While it is true that the growth rate has fallen, from its peak of 2.1% in 1968 to around 1.05% in 2020, this is entirely because the denominator—global population—has doubled, not because the increment added each year has declined. So, it is premature to say that population growth is tapering off. There was the beginning of a downward trend in the 1990s but since around the turn of the century, the annual increment has grown again. It might now be turning the corner, but we do not yet know.

It is impossible to know exactly how much the world population changes each year because the data are incomplete. In many countries, birth and death records are far from comprehensive. Censuses are infrequent and do not reach all households. However, thanks to "demographic and health surveys" (DHS) conducted in most developing countries every few years and overseen by the United Nations (UN), we have a fairly good idea of who is living where and about their fertility, mortality, living arrangements, and family size preferences.

The past 75 years have seen dramatic changes in world demography. A post-WWII baby boom in the West coincided with the rapid dissemination of antibiotics, immunization, and sanitation programs in developing countries. These two trends together generated an enormous increase in population growth. By the 1960s, there was mounting concern that population growth in developing countries would lead to major famines. This threat was averted by the rapid deployment of new crop varieties and fertilizers in an agricultural transformation known as the "green revolution." Norman Borlaug, the plant breeder most prominent in the development of green revolution crops, won the Nobel Prize in 1970 for "eradicating hunger." Many people still claim that the green revolution proved the "Malthusians" wrong. However, in his Nobel lecture, Borlaug insisted that the new technologies had only bought us a breathing space of perhaps three decades, as "the frightening power of human reproduction must also be curbed; otherwise the success of the green revolution will be ephemeral only" (Borlaug, 1970).

Five decades later, fertility rates have fallen dramatically in most countries but they remain persistently high in some regions. Although on average women are having half as many children, with more than twice as many women, the population is increasing by even greater numbers than in 1970. This fertility decline bought us some extra breathing space, but we could be approaching its limit: the incidence of hunger and undernutrition, after falling for decades, has been rising again since 2014 (FAO, IFAD, UNICEF, WFP, and WHO, 2020).

Despite the persistent specter of food insecurity and increasingly disturbing symptoms of environmental strain (UNEP, 2019), political attention to population growth has diminished. In less developed countries, fertility fell by 1.4 children per woman in the 1970s, but it fell by only 0.16 in the decade since 2010. Is complacency justified? Will the unfinished business of population stabilization solve itself?

2.1 The role of voluntary family planning programs

The contraceptive pill was a welcome innovation in the 1960s, and its uptake rapidly reduced fertility levels in developed countries, many of which achieved "below replacement" fertility by the mid-1970s. (The "replacement" level is that at which the children's generation equals in number the parents' generation—around 2.08 children per woman where child mortality rates are low.) New contraceptive technologies also enabled family planning to emerge as a major focus of development efforts, recognizing not only the threat of famine but also the economic challenge of population growth (Coale and Hoover, 1958). The United Nations hosted international conferences on population and development to garner donor support and disseminate best practice, and the United Nations Fund for Population Activities (UNFPA) was born in 1967.

Under well-promoted voluntary family planning and reproductive health programs, fertility fell rapidly in many countries (Fig. 1). In addition to ensuring contraception access to all parts of the country, programs generally included a range of measures aimed at changing

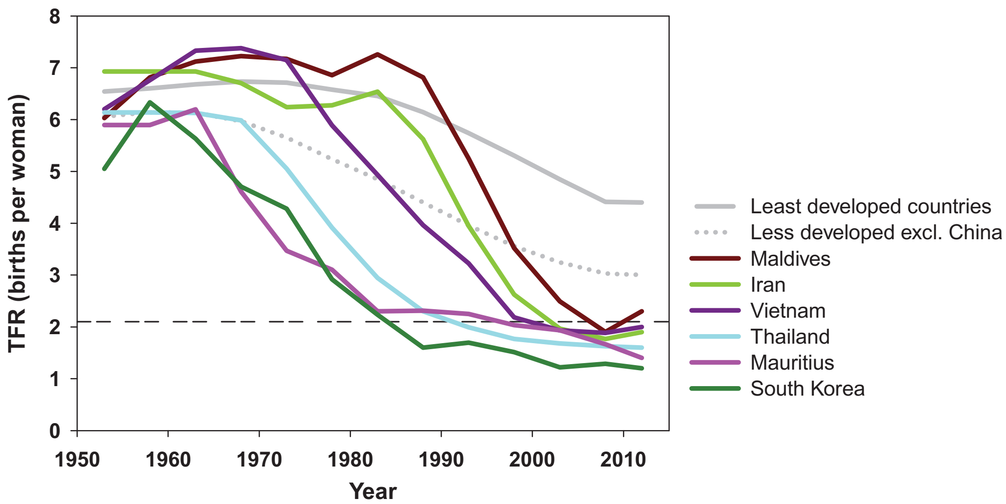

FIG. 1 Time course of total fertility rate (TFR, average births per woman) for selected countries which implemented population-focused voluntary family planning programs at differing times, showing rapid change in fertility, compared with aggregate TFR for less developed countries (excluding China), and for least developed countries.

attitudes to family size, as well as encouraging later marriage and greater autonomy for women. Different countries took different measures to address the complex barriers to family planning uptake specific to their societies; some recruited the support of religious leaders, while others provided female community health workers or mothers' clubs. Some promoted child spacing to mothers after childbirth, and some implemented school-based programs or premarital classes. However, all aimed to reduce the population growth rate, not merely to avoid unwanted births (Robinson and Ross, 2007).

Most countries in East- and South-East Asia were early and strong adopters of family planning. In the Muslim world, Tunisia led the way, particularly with measures increasing women's autonomy and reproductive rights, and good progress was made in Morocco, Egypt, Indonesia, and Bangladesh, among others. Iran came late to population concern but achieved spectacularly rapid fertility decline during the 1990s under an exemplary program focused on public education, premarital counseling, and free access to contraception, with endorsement from religious leaders (Dérer, 2019). More gradual transitions occurred in the Catholic countries of Latin America and the Philippines, several of which still have a way to go. However, in sub-Saharan Africa and parts of South and Western Asia, efforts were sparse and political will has been low. Where programs were implemented, such as in Kenya and Ghana during the 1980s and more recently in Ethiopia and Rwanda (Habumuremyi and Zenawi, 2012), fertility did fall appreciably in the communities served by the programs, but falls ended when programs ended (Ezeh et al., 2009). On a local scale, NGO projects are demonstrating considerable success, particularly those implementing integrated development interventions under the "Population, Health and Environment" (PHE) model (Oglethorpe et al., 2008; Wilson Center, 2013). However, compared with the most successful family planning countries, priority given to family planning in Africa has been low.

Since the mid-1990s, family planning has largely fallen off the international development agenda. A backlash against it was building during the 1980s through a combination of suspicion of neocolonial motives and Catholic opposition to contraception. These parties seized on the rare incidents of coercive measures within national programs, most notably China's one-child policy from 1979 and India's coerced vasectomies in the late 1970s. Coercion had never been condoned by international family planning agencies, which have always emphasized serving clients' choices safely, accessibly, and affordably, but national programs at times failed to maintain these standards. In both the above cases, coercion was the result of applying targets for local administrators to meet, with too little concern for how they were met. Such excursions into coercive measures only served to show how counterproductive they are—the outrage over the Indian program set back voluntary family planning there for decades, while in China, the rapid fertility decline achieved under its earlier voluntary program, initiated in the late 1960s, became a slower trickle-down after the one-child policy was introduced.

Despite coercive measures being anomalies which the family planning movement actively addressed, the opponents of contraception argued that any demographic motivation for family planning would naturally lead to abuses of human rights, and that family planning should be reframed as serving women's reproductive health and rights exclusively (Sinding, 2016). This reframing was consolidated at the UN's 1994 International Conference on Population and Development (ICPD) in Cairo. The Cairo statement itself (the ICPD Program of Action) (UNFPA, 1994) acknowledges the importance of minimizing population growth for poverty reduction and environmental security, but its implementers have cultivated a taboo around

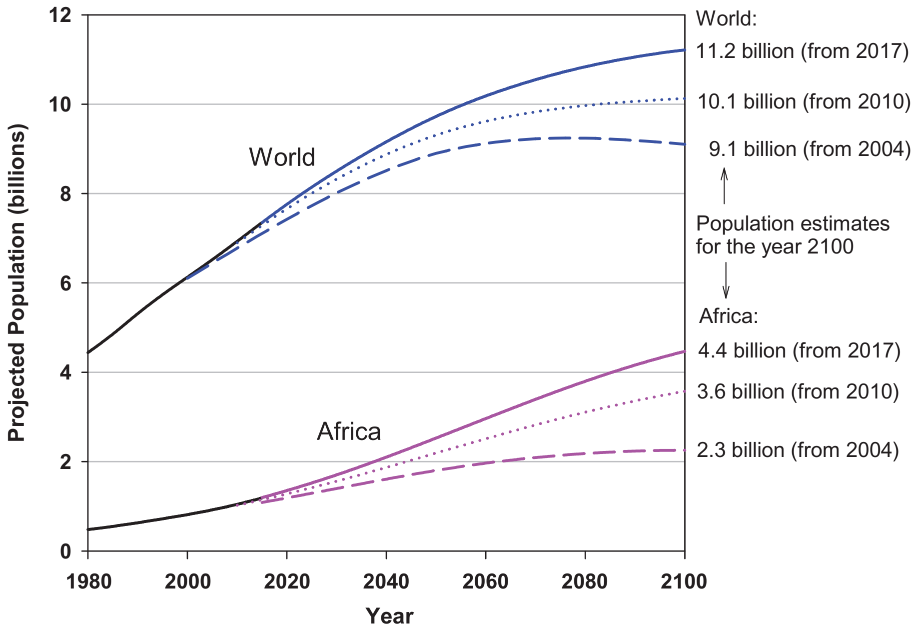

FIG. 2 Population projections from the United Nations, showing a dramatic rise in expected outcomes since 2004.

the population issue. It is implied that any reference to population growth as a problem masks a callous agenda to suppress "people of color" or to deflect blame for global issues away from rich people in developed countries onto the poor (Monbiot, 2020). The sad irony of this perspective is that the family planning movement was instigated to empower women, deflect threats to poor communities, and close the gap between developed and underdeveloped countries (Potts, 2014).

The result of this paradigm shift has been a tragedy for the poor. International aid for family planning plummeted (Sinding, 2009), national programs were wound back, and fertility declines slowed, stalled, or even reversed in several countries such as Indonesia and Egypt (Bongaarts, 2008). The UN population projections, based on earlier trends, underestimated global growth and were repeatedly revised upward, adding 2 billion people to the global population projected for the year 2100 (Fig. 2). Almost all of this additional growth is anticipated to occur in Africa, formerly expected to level not far above 2 billion but now projected to soar past 4 billion.

When we look at the annual increment of the global population, the reversal around the year 2000 is evident (Fig. 3). The UN projections persisted in assuming fertility decline would get back on track everywhere, quickly resuming the downward trend in increment seen in the 1990s. But annual estimates of the global population, published by the Population Reference Bureau (PRB), continued to show a rising increment.

This rise cannot be explained by the factors usually cited as the main drivers of fertility decline: reducing poverty, increasing girls' education, and stemming infant mortality. All three of these aims were accelerated over the same period under the Millennium Development Goals (the overarching UN agenda between 2000 and 2015, now replaced by the Sustainable Development Goals). The decline in funding and political priority for family planning efforts is the most plausible explanation. The policy shift that was intended to

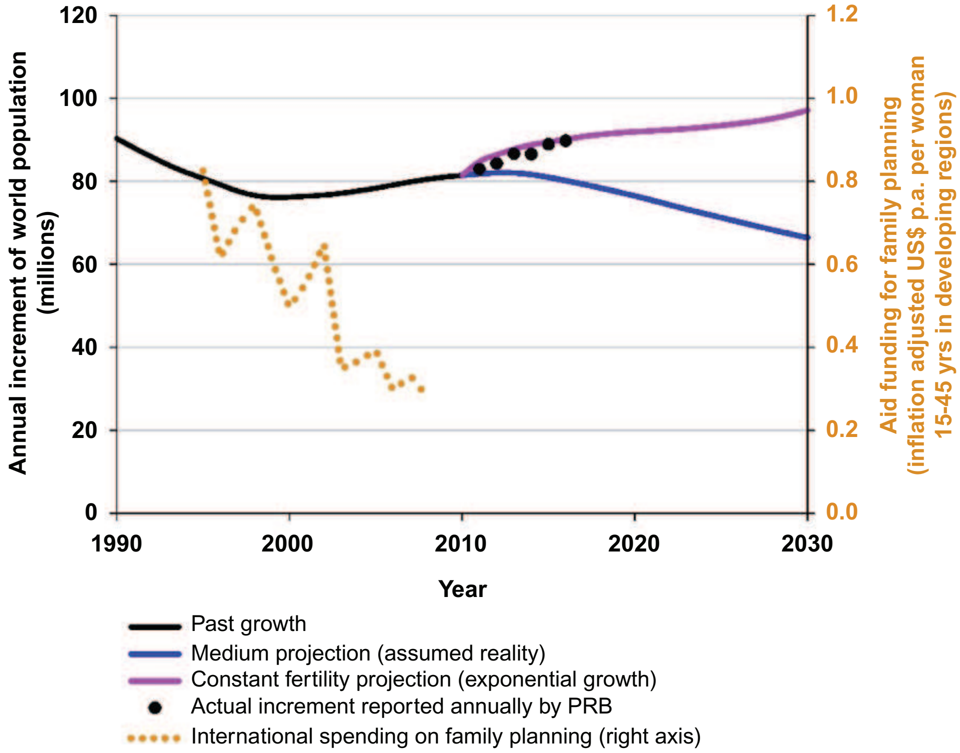

FIG. 3 The annual increment of global population 1990–2010, and that projected under the UN's 2012 medium fertility and constant fertility projections (UNDESA, 2013). *Black dots* give estimates of actual increment reported annually in the Population Reference Bureau's "World Population Datasheets" (PRB, 2011–2016). International aid spending on family planning is plotted against the right axis (UN Economic and Social Council, 2010).

promote women's health and rights has perversely undermined women's health and rights (Sinding, 2016).

2.2 Myths that maintain the population taboo

To sustain the taboo on population, two myths have found a widespread following. The first is that population growth does not impede economic development as "with every mouth, God sends a pair of hands" (Robinson, 1974). It was argued that human ingenuity had always triumphed over scarcity of resources, and hence is "the ultimate resource" (Simon, 1981). While not everyone accepted the idea of "the more people, the better," economists predominantly adhered to the revisionist view that population growth was economically benign (Kelley, 2001), much to the concern of family planning practitioners, who saw the impoverishment of high fertility firsthand (Potts, 1999; Sinding, 2009).

Around the turn of the century, the increasingly evident gap between the economic performance of developing countries that lowered their fertility and those that did not led to a new theory that it was not population growth but age structure that mattered (Bloom et al., 2001). Dubbed the "demographic dividend," the theory holds that lowering the birth rate reduces the ratio of dependent children to working-age people and hence increases economic output per capita. The theory has been actively promoted by the UNFPA, allowing fertility reduction to be encouraged without invoking the taboo population growth (Herrmann, 2017). But the theory lacks direct evidence that the age structure was responsible for any part of the economic stimulus in the Asian Tiger economies, and the correlation does not hold in Africa (Garenne, 2016). Demographic dividend theory provides no incentive to get fertility below replacement level, where it needs to be to end population growth. In addition, it has the harmful effect of implying that the eventual rise in the proportion of elderly people will become an economic millstone. This "challenge of population aging" is almost universally decried, although the evidence to date is that a declining proportion of "working-age" people merely leads to less unemployment, not less employment (O'Sullivan, 2014, 2020b). Regardless of the evidence, the fear of population aging has already led some national leaders, such as Tanzania's President Magufuli, and Turkey's Prime Minister Erdoğan, to decry family planning and advocate more births (BBC, 2018; MacFarlane et al., 2016). Iran, formerly an exemplar of successful rights-based family planning, backflipped spectacularly with its 2015 "Comprehensive Population and Exaltation of Family Bill" stripping women of reproductive rights and contraception access (Kokabisaghi, 2017; Zaynab, 2018).

Throughout this discourse, the limitations of land and natural resources continue to be ignored. Even the obvious burden of needing to generate sufficient new infrastructure and other durable items each year to equip additional people has so far eluded most economic analysts (O'Sullivan, 2012). High-fertility countries find themselves scrambling up a down-escalator, and naturally get ahead more quickly when the escalator is slowed (O'Sullivan and Martin, 2016). The French economist Alfred Sauvy described this "demographic investment" as early as 1958 (Sauvy, 1958), and the Cambridge economist Austin Robinson applied Sauvy's thesis to the budget for Bangladesh's first 5-year plan. He concluded that the cost of "standing still" at the prevailing 3% per annum population growth represented around 75% of all the budgeted investment. With the planned level of investment, incomes might be raised by 30% over 20 years, but if population growth were at the European level (0.45% p.a. at that time), an income increase of 150% would be expected (Robinson, 1974). The Harvard economist Lester Thurow invoked the same idea in a 1986 opinion piece challenging the revisionists (Thurow, 1986). In a thought-experiment, he estimated that no country was likely to be able to achieve sufficient investment to get ahead if population growth exceeded 2% per annum. However, under the long shadow of the population taboo, such ideas have not regained traction.

The second myth serving the taboo is that past fertility declines have been driven by indirect influences including reducing poverty, educating girls, and lowering infant mortality rates, and that addressing these factors is the best way to solve population growth. It is indisputable that these factors tend to correlate with lower fertility, and all are goals of development in their own right. But the focus on these drivers is calculated to discredit the role of family planning programs. Literature linking female education to fertility tends to omit any mention of the presence or strength of concurrent family planning efforts, and rarely acknowledges reverse causation (the well-established effect that lower fertility enhances girls' access to education) (Lutz et al., 2014). To meet the reproductive rights of women, *access to* contraception is emphasized, but the promotion of smaller families and direct efforts to change social norms around family size are avoided. It is not that the harms of overpopulation are denied, but we are assured that when women are educated and empowered, they choose small families. While we might consider it a moral obligation to inform people of the risks of consuming alcohol or smoking tobacco, it is implied that informing them of the consequences of large families would be coercive. Any right-thinking person, the discourse maintains, knows that population growth will solve itself if we look after women and, therefore, anyone who advocates for any focus on population growth itself is acting against individual freedoms.

A brief perusal of national-level data soundly debunks both of these myths. As was illustrated in Fig. 1, national family planning programs were instrumental in every case of rapid fertility decline. The strength of family planning programs explains most of the pace of fertility decline, whereas improvement in education had little effect (de Silva and Tenreyo, 2017; Psaki et al., 2019). Importantly, these programs included both provision of contraceptives and reproductive health services, as well as mass-media campaigns to communicate the benefits of smaller families (Elkamel, 2020). Changing social norms around family size turns out to be pivotal for accelerating fertility decline (de Silva and Tenreyo, 2020). The withdrawal of advocacy components of national family planning programs after 1994 has contributed to the slowdown in the fertility transition. In their place, some excellent nongovernment initiatives have emerged, but they lack the scale and reach of national programs. These initiatives include the Population Media Center's serialized radio and television dramas produced in local languages in many high-fertility countries, whose central characters model attitudinal change to a range of social issues from domestic violence, child marriage, and female genital mutilation to contraception and the benefits of small families (Jah et al., 2014).

As Bill Ryerson, founder of Population Media Center, explained, "meeting unmet demand for contraceptives is only part of the solution. The countries that have most successfully reduced population growth have emphasized changing attitudes of the people regarding the role of women, ideal family size, age of first pregnancy, and the benefits of using modern contraceptives. … [The] use of effective family planning methods will not result in population stabilization if desired family size is five, six or seven children" (Ryerson, 1993). Fig. 4 illustrates that desired family size correlates well with the actual fertility that countries achieve.

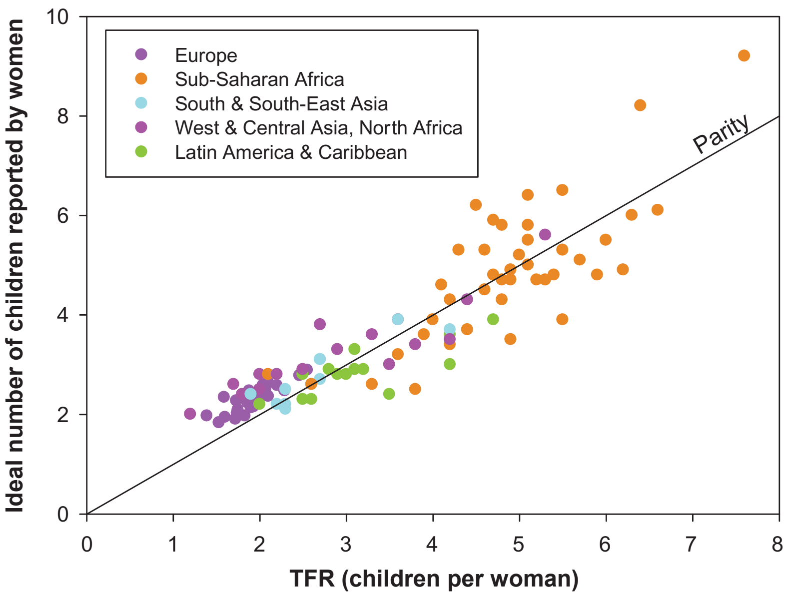

FIG. 4 The average family size that countries achieve closely follows the number of children women say they want. *Data from DHS surveys.*

The well-recognized relationship between poverty and high fertility has driven the belief that economic development is a major driver of fertility decline. This belief is bolstered by the myth that population growth is economically neutral, as this myth dismisses the other explanation for the relationship: that population growth impoverishes, and easing it promotes economic advancement. To explore which direction of causation is more influential, Fig. 5 contrasts the rate of fertility decline as a function of the prior level of wealth and, conversely, the rate of income growth as a function of the prior level of fertility. When the pace of fertility decline is presented as a function of the level of GDP per person (Fig. 5A), there is no trend: the poorest countries could reduce fertility as rapidly as any other if they implemented appropriate programs. Conversely, in Fig. 5B, we see that the level of fertility has had a very strong influence on the likelihood of economic advancement. In countries with fertility above four children per woman, only a few oil-rich states sustained significant economic growth. Over a 20-year period, all low-fertility countries advanced economically, including those with shrinking populations. Slowing the down-escalator evidently works wonders.

An interesting phenomenon occurs when we compare countries that implemented high-profile family planning programs, such as Thailand, with those that did not, such as the Philippines (Fig. 6). In 1965, both countries had around 30 million people and fertility above six children per woman. Thailand's population will peak during the 2020s at just over 70 million, whereas the Philippines has around 110 million, on its way to over 150 million before it peaks. In 1965, the Philippines was richer, better educated, and culturally more westernized, yet its fertility transition has been slow. In Fig. 6B, we see that Thailand's GDP per person only

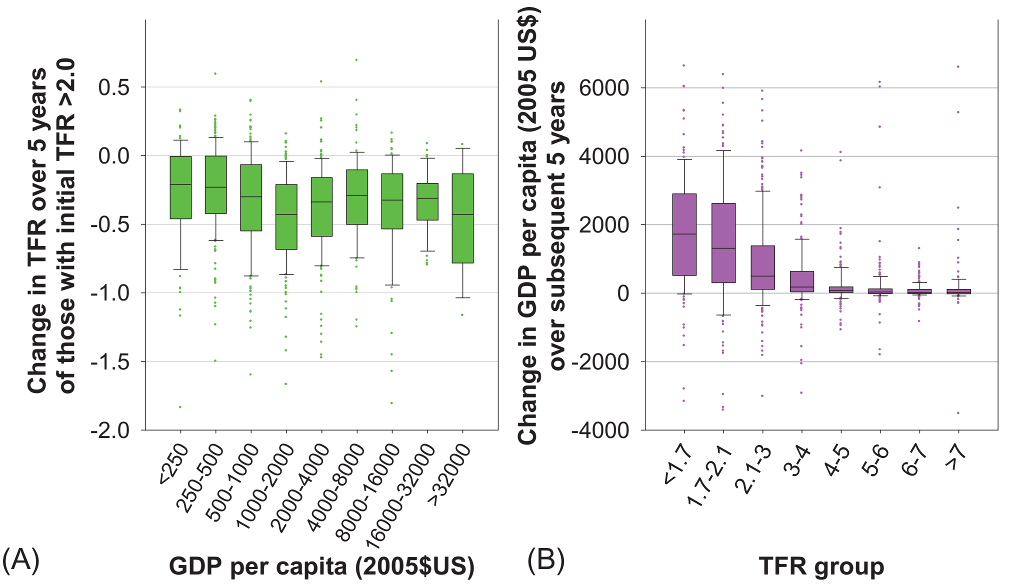

FIG. 5 (A) the rate of fertility decline as a function of the level of income, and (B) rate of economic development as a function of the level of fertility. Data points represent each country in each 5 years between 1960 and 2010. All countries and periods with available data are included. Box plots span the 25 percentile, median, and 75 percentile, and whiskers extend to the 10th and 90th percentile. GDP per capita (inflation-adjusted 2005 US$) are from the World Bank economic database and fertility data from UNDESA (2015).

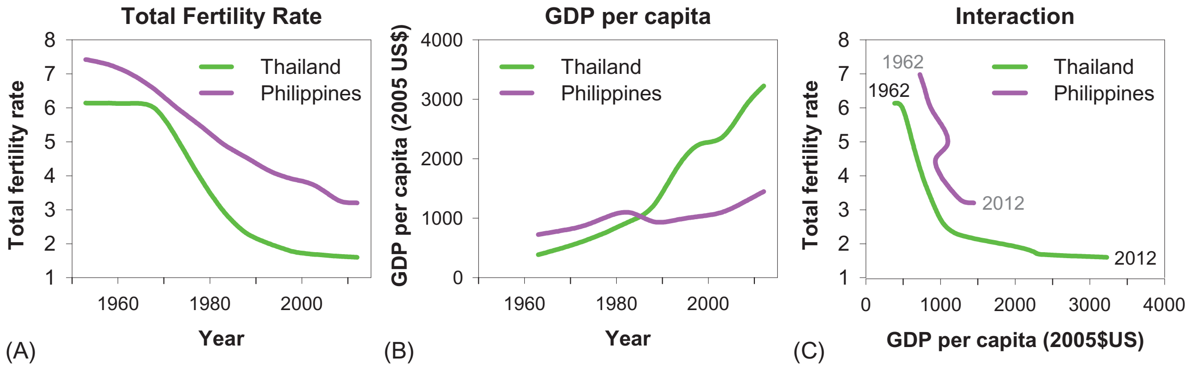

FIG. 6 Fertility and wealth time courses for Thailand, a strong family planning adopter, and the Philippines, a weak adopter. *Left*: the change in total fertility rate (TFR, average children per woman) over 5-year intervals from 1950 to 2015; *middle*: the average GDP per capita over 5-year intervals from 1960 to 2015 (adjusted to the constant year 2005 US$); and *right*: the relationship between TFR and GDP per capita.

overtook the Philippines after its fertility had fallen well below three. In Fig. 6C, the relationship between fertility and income is steeply concave: fertility fell first before income per capita accelerated. If the adage "development is the best contraception" were true, we would see convex curves, with wealth increasing until sufficient to drive fertility down. But the most interesting thing about this chart is that both countries followed parallel paths. Thailand's family planning program merely allowed it to proceed more quickly to the preconditions that allowed economic betterment.

This pattern is repeated throughout the developing world. In Fig. 7, all the countries with fertility above five in 1950 are put into one of three groups according to the rate of their fertility transition. They are synchronized with respect to the start of their transition before averaging. Fast transition countries (achieving a fall of more than 3 units over a 20-year period), all of which promoted family planning, are approaching a peak population around 2–2.5 times the population when they began fertility reduction efforts (Fig. 7B). Those with intermediate transitions (1–3 units over two decades) have not reduced fertility as fast as the number of mothers has risen, so their population growth is not yet decelerating. The population of slow-transition countries has tripled over the same period, and still has at best another doubling in store due to demographic momentum, even if they adopt strong measures from now. In Fig. 7D, we find a remarkable commonality in the relationship between fertility and GDP per capita. It appears that, unless countries have exceptional mineral wealth, fertility decline is a prerequisite for sustained economic advancement.

2.3 Trends and projections

For many decades, the UN Population Division has been collating demographic data and formulating projections of future population growth. These projections are based on the past relationships between the level of fertility and the rate at which it has fallen. As we saw in Fig. 1, countries with high fertility can initially achieve rapid declines, but the rate of decline tapers when one child fewer becomes a more significant change in a family's structure.

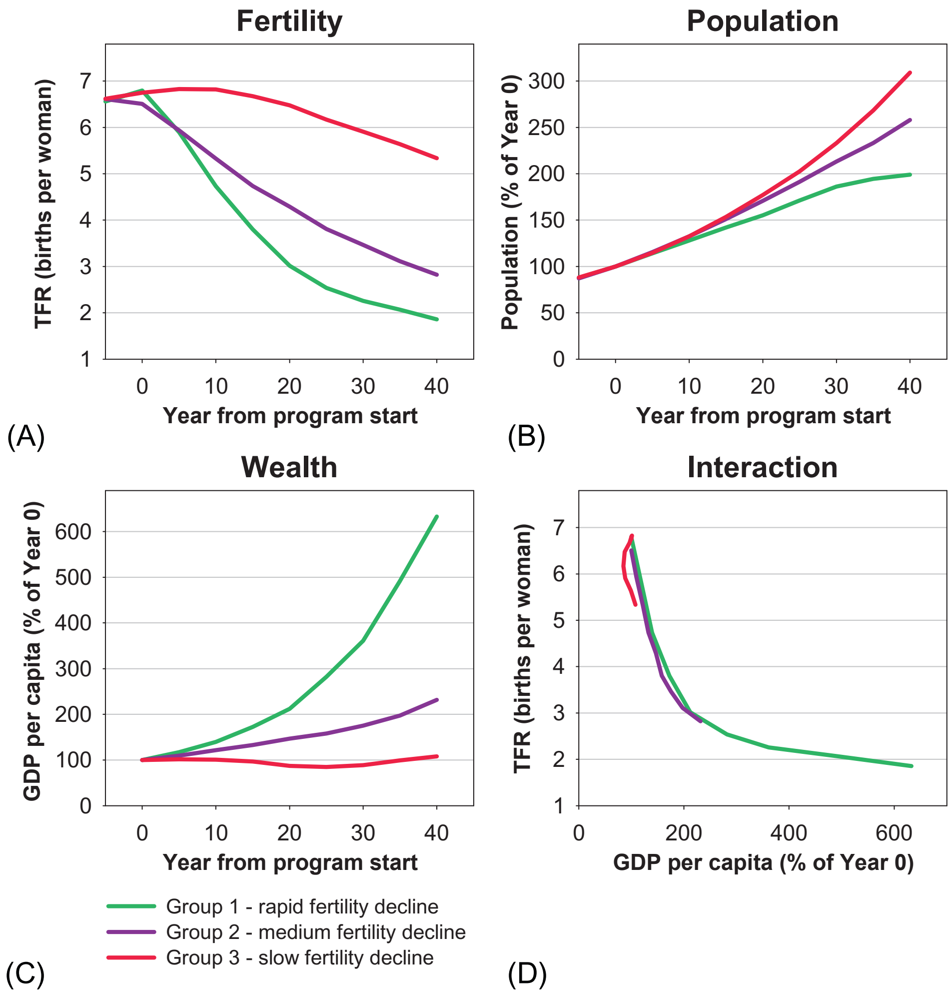

FIG. 7 The average time-course for (A) fertility, (B) population, and (C) GDP per capita (inflation-adjusted US$), and (D) the relationship between TFR and per capita GDP for developing countries grouped according to the rate of their fertility transition. Each of the rapid transition countries (Group 1) achieved a fertility decline greater than 3 units over 20 years under family planning programs. Group 2 countries had maximum falls between 1 and 3 units over 20 years. In Group 3 countries, fertility had not fallen by more than one unit in a 20-year period, up to 2010. Year 0 is the start of the fertility transition in each country or 1970 for Group 3.

However, the UN's model has trouble predicting when a country's fertility transition will take off, and does not allow for midtransition stalls (O'Sullivan, 2016).

Modeling of future climate change mitigation scenarios has been coordinated internationally by the Intergovernmental Panel on Climate Change (IPCC) through the use of a set of "shared socioeconomic scenarios" (SSPs), which imagine different potential socio-political futures as contexts within which adaptation and mitigation actions can be applied (O'Neill et al., 2014). The population projections used in the SSPs were supplied by the Wittgenstein Centre for Demography and Global Human Capital at Austria's International Institute for Applied Systems Analysis. In contrast with the UN, they emphasize the role of human capital (particularly education attainment) in driving fertility decline (Samir and Lutz, 2017). The theory behind these projections is that future fertility declines will be more rapid than in the past because the communities and particularly the women are better educated. Hence, the central projection (SSP2) lies well below the lower bound of the UN's probable range, peaking around 9.4 billion in 2070 (Fig. 9). Because fertility is assumed to be dependent on human capital, and human capital development depends on economic progress and equity, the scenarios have higher population projections (SSP3) or lower (SSP1 and SSP5) according to whether economic development is slower or faster, respectively, than the central scenario (Jiang, 2014).

More recently, the Institute for Health Metrics and Evaluation (IHME), a University of Washington unit funded by the Bill & Melinda Gates Foundation, has produced its own projections as part of its "Global Burden of Disease" program. Like the Wittgenstein Centre, it emphasizes education as a key driver of fertility decline, and predicts a global peak population below 10 billion in the 2060s (Vollset et al., 2020). However, its methodology and findings have raised concern among demographers (Ezeh et al., 2020; Gietel-Basten and Sobotka, 2020; O'Sullivan, 2020a). The IHME has come under scrutiny as a relatively intransparent, private unit at risk of politicizing analyses (Mahajan, 2019; Schwab, 2020). The IHME initially collaborated with the World Health Organization (WHO) on its Global Burden of Disease analyses, but the WHO withdrew due to its inability to validate the IHME data (Mathers, 2020). For our purposes, we should note that the SSP2 projection has substantially underestimated population growth up to 2020 (O'Sullivan, 2019), and the IHME model is already overestimating the pace of fertility decline in sub-Saharan Africa (O'Sullivan, 2020a). It would, therefore, be rash to put faith in their projections for the purpose of estimating future greenhouse gas emissions, climate change impacts, and adaptation needs.

None of these projections examine the role of family planning efforts as drivers of fertility decline. In Fig. 8, an attempt is made to do so. Two scenarios are modeled: a business-as-usual path in which failure to promote smaller families means that fertility in high-fertility countries continues on its current slow decline; and a proactive path in which all remaining high-fertility countries provide and promote voluntary family planning, and achieve the average path of fertility decline that was achieved by voluntary family planning countries in the past (the rapid transition group in Fig. 7). The latter leads to a path similar to that of the UN's "low fertility" projection and the IPCC's SSP1/SSP5 projection, without requiring fertility to fall as unrealistically low. (SSP1 expects Africa's fertility to be below 1.3 children per woman in 2100, whereas the UN's low projection assumes the average woman has half a child fewer than the medium projection in all countries, including those that already have very low fertility.)

The key to achieving such a path is greater political will to implement voluntary family planning programs that combine the provision of services with communication campaigns to change social norms about family size and contraception acceptance, as an integrated pillar of national development plans (including climate adaptation plans). For this political will to emerge, governments and aid donors would need to rediscover the profound benefits of minimizing further growth in human numbers and acknowledge the efficacy of direct, noncoercive approaches. Recent history suggests that waiting for the indirect drivers of education, urbanization, and cultural globalization to shift social norms will be too slow. The list of advantages to having fewer future people rather than more is very long. The implications for climate change adaptation and mitigation will be discussed in Sections 4 and 5.

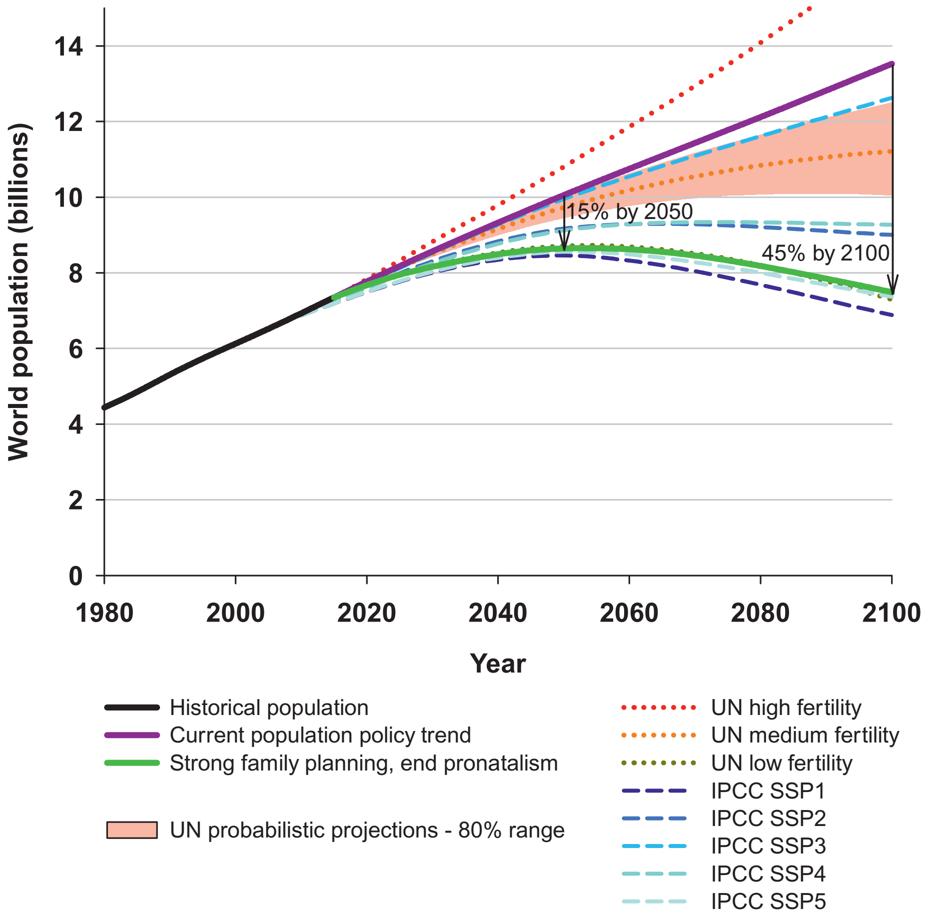

FIG. 8 Policy-based projections of the future global population, comparing outcomes if countries continue their recent trends or if remaining high-fertility countries adopt strong family planning, achieving the average path that past family planning countries achieved and assuming low-fertility countries abandon attempts to increase births. These outcomes are compared with the UN projections (UNDESA, 2015) and the IPCC's Shared Socioeconomic Pathways.

3 How will climate change affect demography?

Climate change will affect all aspects of our lives in the future, including our experience of human density. Here, we consider only the likely effects on human numbers and their distribution, not the welfare of those people, which will be covered in other chapters. Demographic effects will be through effects on deaths, births, and migrations.

3.1 Deaths

The risk of deaths from heat stress is already rising. Climate change causes a disproportionate increase in the frequency of very high temperatures in locations where they were previously very rare. This is often referred to as "shifting the bell-curve." Although the rise in

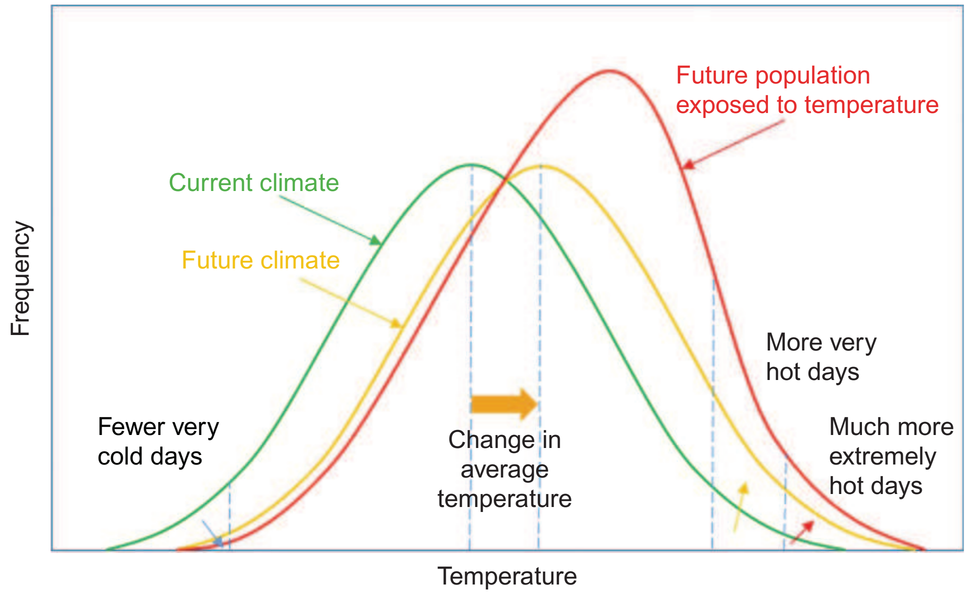

FIG. 9 Diagrammatic illustration of the effect of climate change shifting the "bell curve" of the frequency of temperature events. In addition, population growth is occurring more in hot, humid regions, skewing the impact toward more exposure to extreme heat events.

average temperature might be small compared with the usual range of variation, the frequency of extreme heat events at the tail of the curve becomes many times its previous level (Fig. 9). The effect is exacerbated because hot locations are experiencing disproportionate amounts of population growth, increasing the numbers of people likely to be exposed to future heatwaves.

The occurrence of lethal heatwaves is commonly modeled based on the wet-bulb temperature above which a healthy person could not maintain body temperature. The wet-bulb temperature allows for evaporative cooling but is closer to the ambient temperature as humidity rises. The McKinsey Global Institute (2020) defines a lethal heatwave as "a three-day period with maximum daily wet-bulb temperatures exceeding 34°C." Without greenhouse gas mitigation, they estimate that between 0.7 billion and 1.2 billion people could live in areas exposed to lethal heatwaves by 2050 (McKinsey Global Institute, 2020). Pakistan and West Africa are two regions most vulnerable to this hazard—both regions with high rates of population growth. Similarly, Im et al. (2017) modeled the occurrence of wet-bulb temperatures above 35°C and found that "the most intense hazard from extreme future heat waves is concentrated around densely populated agricultural regions of the Ganges and Indus river basins."

Owing to the high agricultural productivity of these hot, humid regions, it is no coincidence that they also have high population densities. Rural communities are particularly vulnerable to heat exposure during agricultural work, while urban populations can suffer the additional burden of the urban heat island effect.

Xu et al. (2020) took a different approach, mapping the climatic niche of human settlement, concluding that the majority of people live where mean annual temperature (MAT) ranges from 11°C to 15°C. Currently, only a few zones in the Sahara desert, comprising 0.8% of the Earth's land surface, experience a MAT >29°C. However, without greenhouse gas mitigation and in the absence of migration, by 2070 such temperatures could apply widely across the tropical latitudes, affecting one-third of the global population. This has as much bearing on agricultural production as it does on potential heat-related mortality.

These studies have focused on conditions deemed to be unsurvivable by healthy adults. Much lower levels of heat stress can contribute to the deaths of vulnerable people, such as the elderly, ill, or obese. It has been argued that heat is a much more common contributor to deaths than is currently reported on death certificates (Longden et al., 2020). Mora et al. (2017) analyzed reported incidents of excess human mortality associated with heatwaves between 1980 and 2014 to determine a weather threshold for lethality. They estimated that 30% of the world population is already exposed to such events and this could rise to 74% without climate change mitigation, but this figure could be possibly as low as 48% if greenhouse gas emissions are rapidly reduced (Mora et al., 2017).

The lethality of heatwaves can be mitigated by changes in building design, human behaviors, and availability of air conditioning. Because of this, it is not possible to model future death rates associated with the increased incidence of heatwaves. However, it does not bode well that the regions with the greatest risk of lethal heatwaves are those suffering high rates of poverty, high population density, and high population growth rate.

Flooding and related damage, such as landslides and infrastructure collapse, have a far less predictable toll. Again, it is possible to adapt the built environment and human settlement patterns to avoid some impacts of flooding. But it is unlikely that existing infrastructure and settlements will be moved merely as a precaution against rising risk, so an increasing incidence of damage seems inevitable. Again, appropriate adaptation and crisis-response systems could minimize the direct toll of human lives.

After decades of improving nutrition levels, since 2014 the number of undernourished people in the world has been once again increasing (FAO, 2020). The possibility of lethal famines is growing as regional food production fails to keep pace with population growth (Brown, 2012). Population growth is the main reason for food insecurity, but insecurity tips toward famine in extreme weather events and these will become more extreme. Increasingly volatile weather patterns will affect food production at both local and global scales. While some regions, mainly in the northern latitudes, are likely to see increased crop yields, those in the tropics and semiarid zones are more likely to suffer net negative effects. The McKinsey Global Institute (2020) estimates that the global annual harvest currently has a 10% chance of being more than 15% below average once per decade. Without mitigating climate change, this chance could rise to 20% by 2030, and by 2050 more than a third of years could yield lower than 15% below the long-term average (McKinsey Global Institute, 2020).

However, that average will be rising, as it has done for many decades because of improvements in agricultural practices, the expansion of irrigation, and, to a lesser extent, recruitment of more land. Whether this pace of improvement can continue to outpace population growth in future decades is increasingly questioned. Globally, crop yields increased by 56% between 1965 and 1985 but only 20% between 1985 and 2005 despite a substantial, and unrepeatable, increase in the area irrigated (Foley et al., 2011). Several limits are being reached apart from climate change. Major staple crops are reaching their genetic potential, barring major breakthroughs in genetic engineering which are far from guaranteed (Grassini et al., 2013).

Freshwater is already being used in unsustainable volumes, with major aquifers depleting and rivers, from the Colorado river to the Nile and Mekong, barely reaching their deltas for much of the year due to overextraction, causing seawater to invade the valuable delta soils. Fertilizers such as phosphorus and potassium could become scarce and costly as more accessible sources are mined out. The use of nitrogen fertilizer could be constrained because of its disruption of natural ecosystems and its potential contribution to global warming (Bodirsky et al., 2014). Soils are being degraded because of overuse, or lost under urban development and infrastructure. And an increasing proportion of fisheries are also in a parlous state of overexploitation (FAO, 2020). All these challenges are symptoms of population pressure.

Mortality from contagious diseases could also increase. The WHO identifies both population growth and climate change among factors contributing to the increasing risk of disease epidemics (Global Preparedness Monitoring Board, 2019). Climate change is likely to spread the geographical range of major vector-borne diseases such as malaria (Caminade et al., 2014). Increased incidence of environmental crises leading to damaged infrastructure and displaced people create situations in which hygiene standards are compromised, leading to outbreaks of diseases, such as cholera. Heat and nutritional stresses lower human resistance to the diseases already in circulation. The increasing stress on wild animal populations could contribute to more novel zoonotic diseases passing to humans.

Mortality attributable directly to climate change is unlikely to affect local and global populations greatly. The majority of these extra deaths are likely to be among the old and frail. This does not make them less tragic but does mean that they have less impact on populations as few life-years are lost and they do not affect the number of potential parents. Between 2030 and 2050, the WHO estimates that climate change will cause approximately 250,000 additional deaths per year, from malnutrition, malaria, diarrhea, and heat stress (WHO, 2018a). This represents only around 0.3% of all deaths.

The climate change response could reduce mortality associated with air pollutants, which kill more than 7 million people per year: the largest environmental cause of ill-health globally, and the second leading cause of deaths from noncommunicable diseases (WHO, 2018b). Indoor smoke affects the respiratory health of roughly 3 billion users of biomass-fuel cooking. Cooking smoke is estimated to lead to 4.3 million premature deaths per year, particularly of women and small children (Bruce et al., 2015). Efforts to introduce improved stoves to reduce smoke exposure have been given a boost by climate finance, as this also reduces emissions of black carbon, a potent, if short-lived, climate forcing. Smog (comprising ozone, nitrogen oxides, and fine particulate matter), a rapidly increasing health hazard in burgeoning Asian cities, will also be eased by the electrification of transport. Coal-fired electricity generation is a major source of fine particulates ($<2.5\,\mu m$). However, even when the electricity to recharge vehicles is generated from coal, lower urban ozone levels yield positive net health effects (Schnell et al., 2019). Replacement of coal-fired electricity with renewables substantially reduces fine particulate pollution. Fine particulates have been associated with a range of health impacts, including an estimated 1.37 million cases of lung cancer per year (Lin et al., 2019). It is quite likely that more deaths will be averted through climate change mitigation efforts than will be caused by intensified weather events.

A cataclysmic escalation of deaths this century is a real risk, but climate change would be only an exacerbating factor in a complex of stresses generated principally by population pressure. For global population growth to be reversed through more deaths rather than fewer births, premature deaths would need to increase by more than 80 million per year—around 40 times the death rate experienced in the first 6 months of the COVID-19 pandemic, sustained for many years. The projected deaths from climate change are trivial by comparison with such a calamity. As an infinitely large population is not possible, avoiding this outcome depends on population growth ending through fewer births before environmental strains cause system collapse. Climate change adds to these strains and hence increases the urgency to minimize further population growth.

3.2 Births

Human fertility is less likely to be affected directly by climate change. Heat exposure has been found to reduce conception rates (Lam and Miron, 1996) and to marginally increase the risk of preterm delivery, low birth weight, and stillbirths (Bekkar et al., 2020; Grace et al., 2015). While this is detrimental to the health and well-being of individuals, such effects are unlikely to change birth rates significantly at the population level. If opportunities for conception are frequent, then the loss of a single pregnancy has little impact on parents' prospects for achieving their desired family size. Countries in West Africa have long maintained fertility levels above six children per woman despite the frequent separation of sexual partners when men undertake temporary migration for work or herding stock, and despite women farmers routinely working under conditions of heat stress. High fertility has persisted even in the presence of chronic undernutrition evident in the stunting of a high proportion of children. Where these fertility rates are declining, this is not due to health constraints but associated with changing attitudes to family size combined with improved health services and family planning.

It is possible that climate change will provide an additional incentive for couples to limit childbearing. This could be in response to specific natural disasters or gradual worsening of circumstances or the anticipation of future environmental challenges. There is some evidence that communities in Ethiopia and Bangladesh see smaller families as a means of adaptation to deteriorating environmental conditions (Rovin et al., 2013; Thompson and Sultana, 1996). Researchers in Pakistan attributed increased family planning use by flood-affected communities to women having greater contact with international agencies providing crisis health services (Sathar et al., 2018).

In developed countries, reducing births or even childlessness is increasingly discussed as a climate change response, emphasizing both the moral dilemma of bringing children into such troubling times (Overall, 2012; Conly, 2016; Hedberg, 2019), and the practical reality that having one child fewer than otherwise intended avoids more future greenhouse gas emissions than any other behavior change available to individuals (Murtaugh and Schlax, 2009; Wynes and Nicholas, 2017). However, to date, such sentiments are too rare to alter national fertility appreciably. Indeed, other cultural influences are operating in the other direction, including government promotion of births as a misconceived attempt to avoid population aging (Lee et al., 2014; Götmark et al., 2018) and an increasing tendency of celebrities to have large families (The Guardian, 2019).

More concerning is the risk of increased fertility if the availability of contraception were to deteriorate in situations of climate-related crises, or more generally if economies are strained by the burden of climate change. The COVID-19 pandemic has provided a salient example of how reproductive health care and contraception access can be disrupted in crises (Bateson et al., 2020; Makins and Arulkumaran, 2020). Two-thirds of countries surveyed by the WHO reported disruptions to family planning and contraception services due to the pandemic, and the UNFPA warned of up to 7 million additional unintended pregnancies worldwide (Associated Press, 2020). Reproductive health service provider Marie Stopes International estimated that globally the pandemic would cause an additional 1.5 million unsafe abortions and 3100 additional maternal deaths (Marie Stopes International, 2020). There are reports of increased child marriage as school closures leave youth idle and impoverished families seek to off-load daughters (Aljazeera, 2020). These experiences emphasize the importance of giving priority to women's reproductive health services throughout crisis responses.

3.3 Migration

The biggest demographic impact of climate change is likely to be on migration. The term "climate change refugees" has been widely used in anticipation of many millions of people having to relocate from areas affected by sea-level rise, drought, or flood. However, there is a tendency to overuse the term, applying it to any migrant whose previous life has been impacted in any way by climate change, regardless of whether this was the main cause of their migration.

A review of climate migration literature argued that both household capacity to leave and household vulnerability in staying can be affected by climate change or extreme weather events (Kaczan and Orgill-Meyer, 2020). The interplays between these influences, according to the authors, "help explain four key patterns seen in the empirical literature: (1) climate-induced migration is not necessarily more prevalent among poorer households; (2) climate-induced migration tends to be more prevalent for long-distance domestic moves than local or international moves; (3) slow-onset climate changes (such as droughts) are more likely to induce increased migration than rapid-onset changes (such as floods); and (4) the severity of climate shocks impacts migration in a nonlinear fashion, with impacts influenced by whether the capability or vulnerability channel dominates."

A World Bank study estimated that in sub-Saharan Africa, South Asia, and Latin America, by 2050 more than 140 million people could relocate within their country due to the effects of climate change (Kumari Rigaud et al., 2018). The authors suggest that strong climate change mitigation measures could reduce this flow to around 50 million. While sudden crises such as floods displace people temporarily, the slow-onset changes, including decreasing crop production, water shortages, and rising sea levels, have more lasting effects. The report suggests that if climate migration is anticipated and is embedded in development planning, it can play a role as a constructive adaptation rather than being a crisis response.

Nawrotzki et al. (2016) challenge the idea that climate migration is predominantly internal. Where communities have an established history of international migration, this can be their dominant response to climate-related crop failures (Nawrotzki et al., 2016). Lustgarten (2020) described a study using the same modeling framework as the World Bank report, which found that unmitigated climate change could increase international migration from Central

America to the United States by more than 1 million people between 2020 and 2050. However, this represented less than 5% of the total migrant flow of 30 million anticipated over that period. This flow was expected to increase each year regardless of climate change (Lustgarten, 2020).

Likewise, the 50–140 million internal climate migrants modeled by the World Bank represent a small proportion of the anticipated rural-to-urban migration due mainly to demographic pressure. UN projections suggest that well above 800 million people will move from rural to urban settings between 2020 and 2050, just in the three regions included in the World Bank study (United Nations Population Division, 2018).

Kirezci et al. (2020) modeled the impact of climate change and sea-level rise on the land area exposed to coastal flooding events. Only some of these areas would require permanent evacuation. They estimated that by 2100, under the worst-case climate scenario, the population exposed to such flooding events would increase by 52%, from 148 million currently to around 225 million, based on current population distribution (not allowing for population growth). They emphasize that these figures could be lowered by the construction of protective infrastructure such as sea walls. Again, population growth on the most vulnerable islands and river deltas, particularly in South and South-East Asia, will likely expose more people to this hazard than will climate change. Although coastal lowlands (less than 10 m above sea level) occupy only 2% of global land area, they contain 10% of the global population and more than 20% of the urban population of least developed countries—cities whose populations are doubling every few decades (McGranahan et al., 2007).

These studies demonstrate the close interactions between climate change and other drivers of migration, making it difficult to differentiate climate migration from economic migration. Baez et al. (2017) found that droughts increased the flow of youth migrants from rural to urban centers in Latin America. But such studies are unable to show whether this increases the cumulative flow, or merely shifts a portion of it from better growing seasons to worse. For instance, a larger than average exodus in a drought year might make it easier for the next year's cohort of youth to find employment locally.

Migration literature, particularly under the "new economics of labor migration" (NELM) theory, tends to ignore population growth as a driver of migration. Analyses typically present the decision of a household to send migrants as one of income diversification and self-insurance. Taylor (2002) sees rural-urban migration as a phenomenon driven by GDP growth and its implicit link with economic diversification, and suggests that constraints on local production and livelihoods are due to "market failures" such as inadequate market access, finance, and insurance systems. The presumption is that, without climate change or other exogenous factors undermining livelihoods, the economic situation would be stable or gradually improving due to development, and migration offers a means to enhance development. But nothing is stable where populations are growing. The climate migration literature does not discuss the common reality that the alternative to out-migration from rural areas is an ever-dwindling allocation of natural resources per household (arable land, water, or access to communal forest, pasture, or fishing resources) (Garedew et al., 2012), and the inevitable degradation of those resources due to overuse (Taddese, 2001). Equally absent is any recognition that such subdivisions and degradations over the past two generations have contributed to the impoverishment of households and their vulnerability to climate change.

A test for genuine climate change migration would be that the sending area should permanently decline in population, and this must be due to changed environmental circumstances attributable to climate change, rather than to other impacts of human behavior. These other impacts are often attributed to climate change, especially when they occur at a distance from the activity causing them. For instance, deforestation not only changes the hydrology of river catchments, increasing flooding and the seasonality of flows, but also reduces rainfall downwind across whole continents (Lawrence and Vandecar, 2015; Ellison et al., 2017; Pearce, 2018). Overextraction of groundwater is causing widespread land subsidence, in some places more than 2 m per decade, affecting agricultural lands and coastal cities (Herrera-García et al., 2021). In addition, groundwater depletion (transferring water from aquifers ultimately to oceans) contributed 13% of sea-level rise between 2000 and 2008 (Konikow, 2011). Climate change-related sea-level rise is often cited as the cause of saltwater intrusion into the groundwater of deltas and coastal plains (Chen and Mueller, 2018), where overextraction of groundwater and expansion of aquaculture are mostly responsible (Mabrouk et al., 2018; Chang et al., 2011). This is not to belittle the vulnerability of atolls and coastal lowlands to inundation from sea-level rise and increased storm surge. But we should be mindful that climate change is not the only, and often not the biggest, cause of loss of livelihoods due to environmental change.

An absence of population decline does not mean that a community is not impacted by climate change, but it means that the community has been able to adapt to live with that change. In the meantime, hardships caused by climate change and extreme weather events would likely have contributed to many households' decisions to leave, but their place has been filled by local population growth. Without climate change, perhaps the region could have sustained an even bigger population thanks to other advances that increase opportunities for local livelihoods. But without the population growth, the same advances would increase incomes and climate resilience. Such speculative hypotheticals are impossible to quantify. It is therefore not justifiable to claim climate change migration if the sending region's population does not decline.

We are left with the conclusion that climate change will be a contributing factor in net migration flows which are largely driven by population pressure. In the past, emerging economies such as Japan and South Korea, like Europe earlier, have also seen rural-urban migration to the extent that rural areas depopulate. This was driven by economic diversification providing more jobs in the cities, while the modernizing agricultural sector became less labor-intensive. But this was only possible after fertility levels fell, preventing those leaving from being instantly replaced. In the postindustrial, internet-connected future, it is not clear whether large cities will continue to be the focus of employment growth, or whether rural towns will also have more opportunity to diversify. Regional towns in Japan are achieving some rejuvenation by developing information technology and ecotourism industries (Matanle, 2017). But wherever fertility rates remain high, net migration to cities will continue, driven by a lack of rural opportunities rather than a surfeit of urban opportunities.

The total volume of international migrations will depend on the willingness of countries to receive migrants, more than on the factors motivating people to move. This is because those motivated to move already greatly overwhelm the capacity of destination countries to absorb them. Gallup polls regularly assess intentions to migrate across the world. In 2018, they reported that more than 750 million people would migrate if they could—around 15% of the world's adults (Esipova et al., 2018). This included a third of all adults surveyed in sub-Saharan Africa and more than a quarter of those in non-EU Europe, Latin America, and the Caribbean. A number of destination countries, including Australia, Canada, New Zealand, Singapore, and Switzerland, were named as a first preference by more would-be migrants than their current population. In reality, only around 3% of people live outside the country of their birth, and only around 1% have migrated from poor to rich countries (Abel and Nikola Sander, 2014). With such a constraint on flows, the demographic pressure for migration will likely persist for a long time even after national population growth ends. Climate change is likely to have some influence on who migrates, but little effect on the volume of international flows. Most people displaced due to climate change will move within their own country.

4 Demographic influences on vulnerability to climate change impacts

It is widely acknowledged that poor households in poor countries are most vulnerable to the impacts of climate change. This is partly because of their high reliance on the natural environment for their livelihood (Stern, 2006), and partly because they live predominantly in equatorial zones likely to incur the greatest negative effects of climate change, from extreme heat (Bathiany et al., 2018) and disrupted rainfall patterns to intensified cyclones and flood events. But high population densities and growth rates are also contributing to vulnerability (Das Gupta, 2013). With natural resources and human services stretched to their utmost to meet the needs of increasing numbers of people, the capacity to respond to crises is diminished and small disruptions to weather patterns can have large and cascading effects.

Much has been written on the threat of climate change to food and water security, but the role of population growth, and the potential to influence future population growth, often goes unmentioned (Beddington et al., 2011; Steiner et al., 2020), even when the focus is on reducing food demand (Bajželj et al., 2014; Tilman et al., 2011). Indeed, the population taboo is evident in the disappearance of population as a focus in food security literature, from a central theme half a century ago to relatively rare today (Tamburino et al., 2020). There is no doubt that the current food system is overreaching several planetary boundaries for sustainable impacts—by one estimate, current production and consumption patterns could sustainably provide a balanced diet for only 3.4 billion people (Gerten et al., 2020). Heroic shifts in production systems and dietary choices would be needed to allow sufficient food for our current population to be produced sustainably (Conijn et al., 2018). A study commissioned by The Lancet concluded that global food systems could provide healthy diets for up to 10 billion people by 2050 and remain within environmental boundaries, but it would take a global transformation of production systems, halving of food loss and waste, and red meat consumption reduced to about a third of current levels globally—all formidable challenges with low likelihood (Willett et al., 2019). The authors conclude that, on current trends and production systems, emissions from food production will nearly double by 2050.

The regions most vulnerable to critical shortages of food and water tend to be those with high population densities and growth rates. In these regions, population growth is a much greater driver of water and food insufficiency than climate change. Modeling by Gunasekara et al. (2013) concluded that small reductions in population growth could have large effects on the numbers of people exposed to acute water stress. Carter and Parker (2009, p. 676) evaluated threats to groundwater access in Africa, concluding, "The climate change impacts [on groundwater] are likely to be significant, though uncertain in direction and magnitude, while the direct and indirect impacts of demographic change on both water resources and water demand are not only known with far greater certainty, but are also likely to be much larger. The combined effects of urban population growth, rising food demands and energy costs, and consequent demand for fresh water represent real cause for alarm, and these dwarf the likely impacts of climate change on groundwater resources, at least over the first half of the 21st century" (Carter and Parker, 2009).

Fig. 10 demonstrates how dramatically the projected increase in population will affect African countries' ability to feed their own populations, in comparison with the modest changes in rainfall anticipated. The *dashed lines* in Fig. 10 demonstrate how much this challenge could

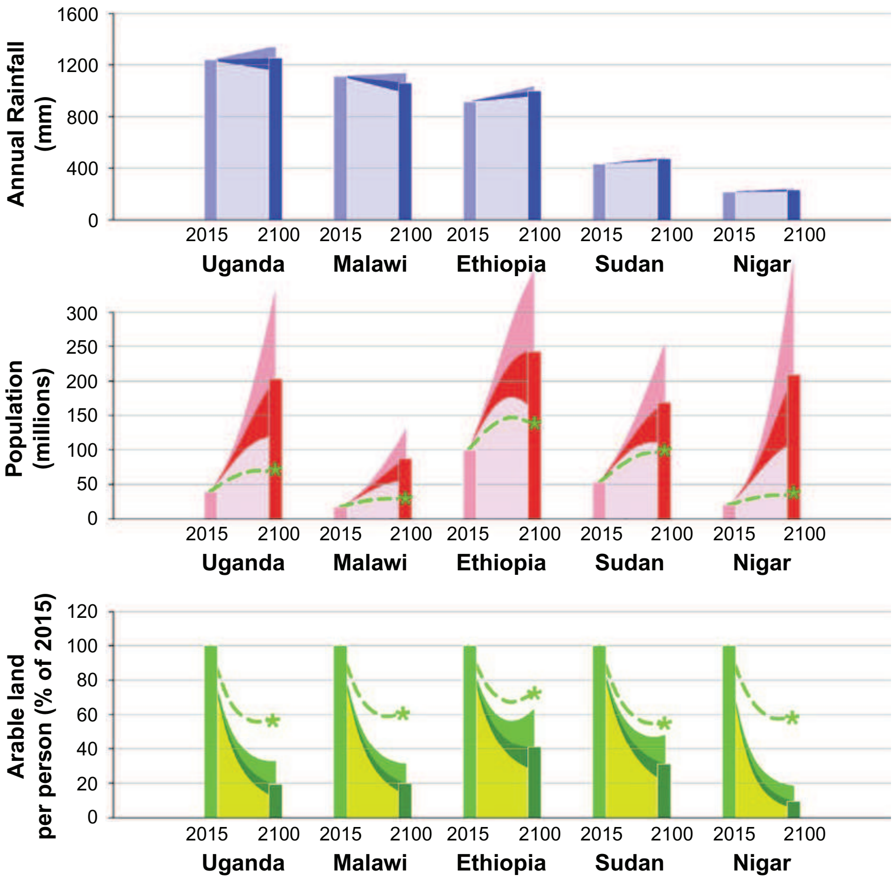

FIG. 10 Projected change in rainfall due to climate change (from Carter and Parker, 2009) and in population (UNDESA, 2015) in five sub-Saharan African countries. Histogram bars give the central projection, and shaded areas between the bars indicate the likely range (for population, this is the 80% range using UN probabilistic projections, UNDESA, 2015). Arable land per person is calculated as a percentage of that currently available. The *dashed-line* pathways are those that would be achievable if the proactive scenario described in Fig. 8 were rapidly initiated (approximately emulating outcomes in the SSP1 and SSP5 scenarios).

be alleviated if these countries emulated the voluntary family planning successes of the past (using the same model described for Fig. 8).

Of course, these changes in annual rainfall do not do justice to the increasing unpredictability of rainfall patterns, including increasingly severe droughts and floods. Nevertheless, population growth is clearly a greater threat. Hall et al. (2017) modeled climate and population drivers of future food insufficiency, and concluded, "Very little to no difference in undernourishment projections were found when we examined future scenarios with and without the effects of climate change, suggesting population growth is the dominant driver of change." Moreland and Smith (2012) found that even a modest increase in the rate of fertility decline in Ethiopia would negate the anticipated impacts of climate change on food insecurity in that country. Thankfully, Ethiopia has since made considerable progress in extending and promoting family planning, as have Rwanda and Malawi, but most other tropical African countries are progressing more slowly.

In many areas, water scarcity will limit the further intensification of agriculture, leaving imports as the main source of increasing food supply. Food import dependence is growing in many high-fertility countries already. In terms of calories, internationally traded food has more than doubled in the past three decades (D'Odorico et al., 2014), and an increasing number of countries depend on imports for more than 25% of their cereal needs (Gardner, 2015). In years with below-average yield, the price of internationally traded cereals spikes up, placing severe stress on poor countries that depend on imported food. A flood or drought affecting major rice exporters such as Thailand and Vietnam could make food sufficiency unaffordable for hundreds of millions of West Africans: it was estimated that a 5% fall in the volume of traded rice could lead to prices rising by 17% (Bren d'Amour et al., 2016). A strong relationship exists between the global food price index and the incidence of violent unrest (Lagi et al., 2011). There is also the threat of countries banning exports in bad years to ensure domestic needs are met first (Bren d'Amour et al., 2016). Consequently, the adverse weather events caused by climate change, which might have caused ripples of hardship when most countries were self-sufficient, could turn into tidal waves of famine and violent conflict.

The relationship between natural resource scarcity and violent conflicts has been documented over many decades, in many countries (Homer-Dixon et al., 1993). Both the direct effect of population growth on the amount of land and water available per person and the indirect effect of land degradation and water depletion due to overuse contribute to this instability. Often the situation is inflamed by inequitable land titling and water access, with elites capturing the benefits of development such as irrigation infrastructure, disenfranchising communities who held traditional access. The Rwandan genocide was a case in point, escalating from severe land scarcity and power imbalances (Gasana, 2002). A 2003 study found that the risk of civil conflict was particularly elevated when land and water scarcity coincided with a youth bulge (a high proportion of those aged 15–29 in the adult population) and high rates of urban population growth (Cincotta et al., 2003). Both of these stress factors are products of rapid population growth outpacing the growth in livelihood opportunities. These researchers found that "a decline in the annual birth rate of five births per thousand people corresponded to a decline of just over 5 percent in the likelihood of civil conflict."

This nexus between population growth and climate change has already been evident in the recent unrest in the Middle East. High levels of population growth and unemployment heightened distrust between ethnic groups, laying the kindling for conflict (Friedman,

TABLE 1 Biophysical challenges (water scarcity, peak oil, population) for selected oil-producing nations. High water and energy insecurity are indicated in bold text. Moderate water shortage is deemed to occur when availability drops below 1700 m^3 cap^{-1} yr^{-1}, and severe water shortage is deemed to be below 1000 m^3 cap^{-1} yr^{-1} (Kummu et al., 2016).

Nation	x-fold population increase 1960–2014	1962 Renewable freshwater per capita (m^3 yr^{-1})	2014 Renewable freshwater per capita (m^3 yr^{-1})	Peak oil year	2015 Barrels oil produced (1000s per day)	2015 Barrels oil consumed (1000s per day)	2015 Oil import dependence (%)
Egypt	3.4	**63**	**20**	1995	493	**824**	**63**
Iraq	5.3	4587	**998**		4480	818	
Nigeria	4.2	4690	1245	2005	1943	271	
Saudi Arabia	8.0	**550**	**98**		12,014	3895	
Syria	4.1	1456	**380**	1996	27	**219**	**88**
Yemen	5.5	**393**	**86**	2002	22	**168**	**88**

Source: Ahmed (2017), extra data from the World Bank series EG.USE.PCAP.KG.OE.

2013). Climate change played its role in a severe drought in Syria from 2007 to 2011 (Kelley et al., 2015), which saw food imports rise steeply and prices with them. This occurred at the same time as depleted groundwater was driving many farmers from their land, and as Syria's declining oil revenue was overtaken by its oil import needs. Oil revenues have enabled countries to increase their dependence on imported food, but they have a habit of running out. Middle East analyst Nafeez Ahmed argues that the converging effects of population growth, climate change, and fossil energy depletion in these chronically water-scarce countries are setting the stage for violent upheavals and failed states (Ahmed, 2017) (Table 1).

The "Fragile States Index" scores countries on a range of political, social, and economic indicators of vulnerability to political instability. The countries that scored highest for state fragility are all experiencing high rates of population growth (Population Institute, 2015). Population density and growth rate have been described as challenge multipliers, as they exacerbate all environmental and social stresses. The stresses associated with climate change are one dimension of this convergence of vulnerability in countries suffering high demographic pressure.

Greater resilience to the impacts of climate change is often argued as a cobenefit of measures intended to promote women's reproductive rights through family planning services (De Souza, 2014). Women are particularly vulnerable to climate change impacts, and the ability to regulate their childbearing enables their greater participation in livelihoods, natural resource management, and community activities that build resilience (UNFPA, 2009). Community-level effects of smaller families are also important, such as reducing pressure on natural resources, improving child nutrition and access to education, and simply adding fewer people to the numbers exposed to environmental crises (Mogelgaard, 2018; PRB and Worldwatch, 2014).

Population, Health, and Environment (PHE) projects emphasize multisector, community-driven approaches to integrate natural resource management with livelihood diversification, gender equity, health and hygiene, and family planning (Oglethorpe et al., 2008; Gonsalves et al., 2015). PHE projects have been reported to improve climate change resilience through a number of channels, such as by strengthening social participation and cohesion, raising awareness of environmental change and conservation measures, improved hygiene and health management and income diversification, in addition to more direct effects of fewer, more widely spaced births on women's health, children's nutrition, and lessening demands on natural resources (De Souza, 2014; Hardee et al., 2018; Mohan et al., 2020). Relating family size to environmental limits has proven compelling in increasing men's support for family planning (Kock and Prost, 2017). PHE projects also tend to build male support for women's roles in livelihood enterprises and natural resource management, and greater gender equity in household decisions (Wilson Center, 2013). However, these projects have depended on short-term donor funding and rely on building relationships with existing community and sectoral organizations, creating challenges for scaling up (De Souza, 2009). Access to climate adaptation finance could magnify the impact of such projects (Mogelgaard, 2018; Patterson et al., 2019).

As part of the Least Developed Countries (LDC) Work Program of the United Nations Framework Convention on Climate Change (UNFCCC), LDCs were invited to prepare national adaptation programs of action (NAPAs) to identify priority activities for adaptation funding under the Least Developed Countries Fund (LDCF) and other mechanisms. Among the 41 NAPAs submitted by 2009, 37 highlighted population growth and density as factors increasing vulnerability. However, only two proposed projects included a population component, and none were funded (Bryant et al., 2009; Mutunga and Hardee, 2010). The sectoral structure of the framework set out for NAPAs made it difficult for a crosscutting issue such as population growth to be acknowledged. A decade later, avenues for climate adaptation funding to flow to family planning activities are yet to be opened (Patterson et al., 2019). Within the UN negotiations, inclusion of family planning is actively denounced by some agencies, with the false arguments that family planning is about control rather than choice, and that any focus on population in the climate change agenda is a denial of the responsibility of rich-world consumption patterns (CARE, 2014). Thus, the lack of attention given to population in climate adaptation activities reflects politics and ideology rather than evidence.

5 The influence of population change on climate change and its mitigation

Population size is a multiplier of all human impacts on the environment, including greenhouse gases. However, different people in different places have different levels of impact. In terms of greenhouse gas generation, people in developed countries and emerging economies with high fossil fuel use clearly have a much greater impact per person than the average person in India or Ethiopia. When a person in a rich country decides to have one child fewer, that decision avoids more future emissions than any other lifestyle choice they could make (Fig. 11) (Murtaugh and Schlax, 2009; Wynes and Nicholas, 2017).

As we have seen above, for people in underdeveloped countries, the decision to limit childbearing has substantial benefits for climate change adaptation, as well as for reducing poverty

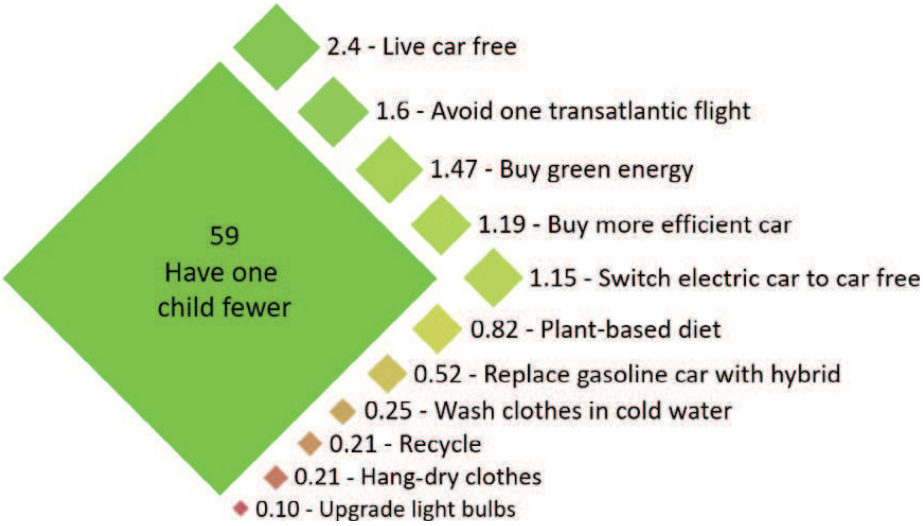

FIG. 11 The emissions reduction (tons CO_2e per year) achievable from various individual actions—the mean value of developed countries. Emissions avoided by having one child fewer assumes each parent is responsible for half the lifetime emissions of their child, a quarter of a grandchild, etc., divided among the parent's remaining years of life. *Data from Wynes, S., Nicholas, K.A., 2017. The climate mitigation gap: education and government recommendations miss the most effective individual actions. Environ. Res. Lett. 12, 074024. https://doi.org/10.1088/1748-9326/aa7541.*

and ultimately avoiding violent conflicts or famines. But the benefit for greenhouse gas emissions reduction is also significant.

Some writers have argued that people in high-fertility countries have such low per capita impact that their population growth does not matter for climate change. Advocates of this position claim that including population in the climate mitigation discourse is a means of deflecting attention from consumption behaviors of the rich, and "blaming the poor" for climate change (Monbiot, 2020). Unfortunately, they are doing the poor a disservice by reducing the political will for much-needed family planning programs. There is no trade-off between addressing fertility decline and addressing per capita emissions, as family planning programs tend to save more money than they cost. Among 16 sub-Saharan African countries, a USAID study found that fulfilling the unmet need for family planning would not only contribute materially to a range of development goals, but each dollar spent on family planning saved between two and six dollars on unneeded services for mothers and children (Moreland and Talbird, 2006). Even in the United States, where each avoided birth reduces far more emissions, a program to reduce unwanted pregnancies in teenagers and youth saved the health system around $5.85 in perinatal care for every $1 invested (Colorado Department of Public Health and Environment, 2015).

A study by the Global Center for Development asked whether providing much-needed additional funding for female education and family planning would be competitive with other options for climate change mitigation. Based on country-by-country estimates of emissions per person and costs per averted birth from family planning and female education, they found that "the population policy options are much less costly than almost all of the options for low-carbon energy development, including solar, wind, and nuclear power, second-generation biofuels, and carbon capture and storage. They are also cost-competitive with forest conservation and other improvements in forestry and agricultural practices" (Wheeler and Hammer, 2010). In most of the 106 developing countries studied, the cost per ton of carbon abated was less than $10. Interestingly, although expenditure on family planning averted more births per dollar than expenditure on education, the strong synergy between these two activities meant that dividing funding between them produced the lowest cost emissions reductions.

Similarly, Wire (2009) estimated that providing family planning services to all women with an unmet need (then estimated at 215 million women globally), and thereby avoiding 75% of unintended births, would avoid 34 billion tons of carbon dioxide between 2010 and 2050 at a cost of less than $7 per ton.

There is a fly in the ointment for these calculations, and that is the economic stimulus that reduced fertility levels are likely to promote. Extra consumption per person, particularly of fossil fuels and the products of their use, could counteract the emissions reductions from fewer births. Taking account of various ways that lower fertility might change economic growth, Casey and Galor (2017) estimated that moving from the medium to the low variant of the UN global population projection could reduce emissions from fossil fuels and industry by 10% by 2050 and 35% by 2100, despite increasing income per capita. For a similar shift in population trajectory, O'Neill et al. (2010) estimated emissions reduction around 15% by 2050 and 35%–42% by 2100, factoring in emissions from the food system as well as effects of urbanization, household size, and age structure, on a country-by-country basis, but not those resulting from economic stimulus. Neither of these studies considers the possibility that emerging economies might leapfrog fossil-fueled technologies to build postcarbon economies, and thereby avoid raising emissions per capita as incomes increase. We can conclude that providing the resources to avoid unwanted births and promote smaller families is a highly cost-effective means of reducing emissions, even when the avoided births are in communities with very low emissions per person.

Climate mitigation modeling using the SSPs has shed only indirect light on the contribution of population growth to greenhouse gas emissions. As we saw in Fig. 8, each of the five "shared socioeconomic pathways" (SSPs) has a different population projection, but it is not possible to isolate the effect of lower or higher population because many other parameters also differ between the scenarios (Samir and Lutz, 2017). Within the model, fertility decline is assumed to be driven by investments in education and health, assuming that economic development is causal on fertility but not the other way around (Jiang, 2014). Hence, the SSP framework does not lend itself to exploring the impacts of more direct investments in family planning.

However, SSP modeling does provide strong evidence that bending the population curve downward is an essential component of successful climate change mitigation. A review of scenario modeling by six separate research groups using the SSPs found that even the most extreme emissions reduction methods could not achieve less than 2°C of global warming using SSP3. This is the SSP with the highest projected population and the lowest economic development (Riahi et al., 2017). It should be noted that, since the publication of the SSPs, global population growth has most closely followed the SSP3 path.

A major contributing factor preventing strong climate change mitigation under SSP3 was the infeasibility of reversing deforestation due to increasing population pressure and demand for food (Riahi et al., 2017). Agricultural expansion is the largest driver of deforestation

(Carter et al., 2018), and forest loss is closely correlated with the increase in rural populations (FAO, 2016). In Africa, patterns of forest loss indicate that shifting agriculture, in which land was infrequently cropped and allowed to revert to forest, has seen land cropped increasingly frequently so that forest remnants shrink and become degraded before being permanently cleared (Curtis et al., 2018). Elsewhere, "commodity agriculture" predominates, but this too is largely undertaken by rural smallholders migrating into the forest frontier to produce cattle, rubber, palm oil, rice, and other cash crops, as well as illegal logging and charcoal production (Carr, 2009). Globally, population growth has been the greatest driver of the expansion of agriculture, although diet change in emerging economies (through more meat consumption) is also significant (Alexander et al., 2015; Henders et al., 2018). Thus, although only a tiny proportion of the world's population is directly involved in deforestation, regional population pressure is a push-factor, and global growth in food demand is a pull-factor, both acting to incentivize land clearing.

Designation of protected areas is less effective at preventing forest encroachment by smallholders than by industrial projects (Jayathilake et al., 2020). In regions of acute land scarcity due to population growth, such as Kenya's Chyulu Hills National Park and Tanzania's Southern Highlands, it is not politically feasible to evict squatters from conservation areas (Muriuki, 2016). In the north-western uplands of Cambodia, a 60% increase in the agricultural area occurred between 2006 and 2016 (Konga et al., 2019). In Latin America, forest frontier migrants tend to have particularly high fertility, and their children are much more likely than other rural people to become frontier migrants themselves (Lopez-Carr and Burgdorfer, 2013). The construction of new roads into forests, often associated with mining or dam projects, provides access facilitating colonization by farmers (Laurance et al., 2014). Such infrastructure development has accelerated rapidly in recent years (Laurance et al., 2015).

Greenhouse gas emissions from agriculture-related deforestation were around 1.6 Gt CO_2 yr^{-1} in 2010–2015, and increasing rapidly in Africa (Carter et al., 2018). The rapid growth of urban populations in Africa has also greatly increased demand for charcoal, which consumes several times more wood for the same cooking fuel than direct use of wood fuel, and generates significant amounts of methane, nitrous oxide, and black carbon emissions in its production (FAO, 2017). In addition, the exposed soil continues to lose carbon, and this is exacerbated by more frequent cropping and overgrazing resulting from population growth. The combination of soil carbon loss and deforestation contributed to a net loss of 1.65 Gt of carbon from Africa's tropical zone in 2016 (Palmer et al., 2019). An estimated 116 Gt of carbon (425 Gt CO_2) has been released from soils over the history of agriculture (Amundson and Biardeau, 2018). Although increasing soil carbon has been widely promoted as a means of climate change mitigation, there are formidable social and logistical challenges to reversing soil carbon loss even in developed countries, and the prospects for net gains on a global scale are severely undermined by the growth in food demand (Amundson and Biardeau, 2018).

As mentioned earlier, deforestation and other reductions in vegetation also directly increase regional temperatures and alter rainfall patterns locally and over substantial distances, as well as contributing to the seasonality of river flows and the severity of flooding (Ellison et al., 2017; Lawrence and Vandecar, 2015; Mahmood et al., 2014; Pearce, 2018). Deforestation in the Amazon could reduce rainfall in the Midwest of the United States, a vital grain exporter to the world (Lawrence and Vandecar, 2015). The drying already experienced in Africa's Sahel region is due more to deforestation in East and Central Africa than to the global greenhouse effect (Zeng et al., 1999; Zheng and Eltahir, 1998).

The World Resources Institute estimated the extent to which various actions could reduce emissions from the global food system by 2050. Among the options considered was enhancing family planning to achieve replacement-rate fertility throughout Africa by 2050. This measure was estimated to contribute almost 1 Gt CO_2e yr^{-1} of reductions (Searchinger et al., 2018). While this was less than a tenth of their full menu of options, it was the only one offering much greater reductions, for no additional investment, in the latter half of the century. Other options, such as reducing meat consumption or lowering methane emissions from cattle, manure, and rice paddies, are one-off changes that cannot be repeated. Similarly, Project Drawdown found that providing the health and education services needed to reduce the projected global population by 1 billion could cause more emissions reduction than any other single technology deployment the project analyzed, estimated at 119 Gt between 2020 and 2050 (Hawken, 2017).

Because population growth is occurring mainly in the world's poorest countries, reducing birth rates is far from being a remedy for climate change on its own. It is nevertheless an essential component of successful climate change mitigation. Given that a dollar spent on family planning services and promotion achieves cheaper greenhouse gas emission reductions than almost all other options, and the same dollar simultaneously empowers women, saves lives, improves child nutrition and survival, reduces environmental degradation, stimulates economic development in the world's poorest communities, reduces the extent to which other climate change responses are needed, and directly saves several dollars in unneeded health services, this surely represents the climate response's low-hanging fruit.

6 Conclusions

Climate change is likely to have only modest impacts on the size and distribution of populations, other than in specific locations that are severely affected. In contrast, the extent of future population growth will have large impacts on both the vulnerability of communities to climate change and the emission of greenhouse gases. With or without climate change, the security and prosperity of the world's poorest countries depend on minimizing further growth in their populations.

Policies and programs are available that would accelerate the reduction in fertility in those communities where it is still high, through voluntary measures that empower women and couples to take greater control over their lives and their children's well-being. If widely supported, they could lower the global population by several billion people by the end of this century. These interventions are both highly cost-effective (generally saving more money than they cost) and widely beneficial for community development and relieving local environmental strains. The cost is modest: a doubling of current resourcing, from 1% to 2% of international aid, would make a substantial difference if supported with the political will to promote the benefits of small families and address barriers to uptake (Bongaarts, 2016). That such programs are, to date, absent from national and international climate change responses can best be explained by the prevalence of an irrational taboo against identifying population growth as a problem.

Inclusion of population issues and responses in climate change discourse is often actively denounced, and presented as morally deplorable (Monbiot, 2020). By others, it is simply dismissed as not having policy relevance, as (they argue) it is best addressed—and is being addressed—indirectly through attention to girls' education, child survival, and poverty alleviation (Rosling et al., 2018). While less accusatory, the latter commentary is similarly judgmental of population discourse as both "blaming the poor" and abetting human rights abuses in the form of involuntary population control measures. These positions are ill-informed and very damaging, not only to the prospects of communities in high-fertility countries but also to the chance of avoiding severe impacts of climate change globally.

Ending population growth is only one of many important dimensions of a successful climate change response, but it is nevertheless essential for success. If global population growth meets or exceeds the UN's current medium projection, integrated assessment models suggest no feasibility of avoiding greater than 2°C warming (Riahi et al., 2017). Lower projections, such as the IPCC's SSP2 projection, let alone SSP1, are very unlikely to be realized without substantially greater efforts to reduce desired family size and extend reliable and affordable access to contraception. The moral hazard of maintaining the population taboo has never been greater.

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