Chapter 2

Drivers of Environmental Change

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Executive summary

Population growth will be highest in countries that are very poor, have a low carbon footprint per capita and high gender inequity in terms of access to education, work, and sexual and reproductive rights *(well established)*[1]. It will also remain important in countries going through their early or late demographic dividend (most middle-income and upper middle-income countries). These are also the countries that have presented the highest increases in carbon footprints per capita – and in ecological footprints more broadly. {2.3.1}[2]

The world's population will become older, including in the global South, more urban and will live in smaller households *(well established)*. In a business-as-usual scenario, all these trends will contribute to higher levels of emissions. This is true even if, in some cases, urban milieux show a more efficient relationship between welfare improvement and environmental footprint. {2.3.3}

Between today and 2050, the global urban population will continue to increase *(well established)*. Around 90 per cent of the growth of cities will take place in low-income countries, mainly in Asia and Africa, which are the world's most rapidly urbanizing regions. {2.4}

Serious social and environmental challenges of urbanization remain unsolved in many urban areas, particularly but not solely, in the global South *(well established)*. These challenges can be exacerbated by climate change and rapid urban growth in regions and cities that currently lack the capacity to face these mounting pressures. {2.4.1, 2.4.2}

On the other hand, urban population growth can represent an opportunity to increase citizens' well-being while decreasing their ecological footprint *(established but incomplete)*. Urbanizing areas can therefore be seen as an opportunity for the reduction of greenhouse gas (GHG) emissions through the appropriate planning and design of urban form and infrastructure. {2.4.4}

Economic development in the past has been a driver of increased resource use and environmental damage *(well established)*. The production of internationally traded goods accounts for about 30 per cent of all CO_2 emissions. The household consumption, meanwhile, of goods and services over their life cycle, accounts for about 60 per cent of the total environmental impact from consumption (UNEP 2010). Economic development continues to be the number-one policy priority in most countries, because of its material benefits and its potentials for poverty eradication, for narrowing inequalities in income and wealth between and within countries, and for providing win-win scenarios that can facilitate collective action and global solidarity. At the same time, economic development must coincide with sustainable consumption and production. {2.5.1, 2.5.4}

Achieving the SDGs will require that the fruits of sustainable economic development are predominantly used to increase the capacity, capabilities and opportunities of the least-advantaged people in societies *(well established)*. Educating girls, improving the status and opportunities for women, and enabling poor people to achieve full participation in society will strengthen both sustainable economic growth and sustainable economic development, and reduce alienation and conflicts in society. {2.5.2, 2.5.3}

Technological advances have resulted in both positive as well as negative impacts *(well established)*. Oil and other fossil fuels have accelerated economic development and lifted the standard of living for billions of people in both industrialized and developing countries, but they have also contributed to climate change. At the same time, there are current and emerging technology business models, which are building a more circular economy, creating less resource-intensive processes, and accelerating more effective resource innovation cycles. {2.6.1, 2.6.2}

Technological advances have created unintended consequences that make it difficult to determine whether the advances have long-term positive and/or negative impacts *(established but incomplete)*. Scientific analyses of technology issues often fail to capture the important negative and rebound effects of technologies as well as the complex policy and market challenge of diffusing sustainable technologies to developing countries. {2.6.3, 2.6.4}

Climate change has become an independent driver of environmental change and poses a serious challenge to future economic development *(well established)*. Regardless of human action, or even human presence on the planet, impacts will continue to occur. Climate change thus poses a challenge to growth and development. {2.7.1, 2.7.2}

Climate change poses risks to human societies through impacts on food, and water security *(established but incomplete)*, and on human security, health, livelihoods and infrastructure. These risks are greatest for people dependent on natural resource sectors, such as coastal, agricultural, pastoral and forest communities; and those experiencing multiple forms of inequality, marginalization and poverty are most exposed to the impacts. {2.7.3}

Climate change will amplify existing risks and create new risks for natural and human systems *(well established)*. Risks are unevenly distributed and are generally greater for developing countries (mainly for SIDS) and for disadvantaged people and communities in countries at all levels of development. Risk of climate-related impacts results from the interaction of climate-related hazards with the vulnerability and exposure of human and natural systems, including their resilience and ability to adapt. {2.7.4}

1 This assessment uses confidence statements to better inform policy makers of the extent of evidence on a particular subject and the level of agreement across this evidence. The various confidence statements used include: "well established" (much evidence and high agreement), "unresolved" (much evidence but low agreement), "established but incomplete" (limited evidence but good agreement) and "inconclusive" (limited or no evidence and little agreement). Annex 1-4 provides more information on the use of confidence statements.

2 Statements in the Executive Summaries of different chapters are referend to the subsections of the chapter where the underlying analysis and evidence for the statement can be found.

There is an important need to limit the potential negative sustainability impacts of drivers of population, economic development and climate change *(established but incomplete)*. Whether these three drivers serve as catalysts of positive (rather than negative) transformative response in the form of social equity, environmental resilience, and poverty eradication is likely to be determined by uncertain long-term impacts of drivers of urbanization and technology. {2.8, **Figure 2.23**}

2.1 Introduction and context

The environmental movement has gone through many phases. Initially the movement consisted broadly of the conservation school, which emphasized husbanding of both renewable and non-renewable resources (especially forests) for future development, and the preservation school, which saw nature as intrinsically valuable (Eckersley 1992). In addition to these economic and aesthetic concerns, the modern environmental movement is now more about risk, the risk that environmental degradation poses to human health and well-being (Carson 1962; Rees 1995; Guha 1999; Lenton *et al.* 2008; Rockstrom *et al*. 2009a; Diamond 2011). Increasingly, there are concerns that the enormous gains in life expectancy and quality of life since the industrial revolution are in danger of being reversed (GBD 2015 Mortality and Causes of Death Collaborators; Harari 2017).

The five drivers reviewed in this chapter — population growth and demographics, urbanization, economic development, new technological forces, and climate change — have led to an unprecedented expansion of wealth for many but have also left many behind and could produce trouble for the future. If current trends in inequality continue, the top 0.1 per cent of the population will own more wealth than the global middle class by 2050 (WID 2018).

2.1.1 Overview of the Drivers

As noted in Section 1.6, the analysis conducted in the GEO-6 uses the DPSIR framework, where DPSIR stands for Drivers, Pressure, State (of the environment), Impact (on the environment and human well-being), and Response[3]. 'Drivers' are anthropogenic *inertial* forces – social, economic, ecological, technological, and political. They are inertial forces, in the sense that they have their own rules of motion and reversing them will require time and effort. GEO-5 referred to two drivers – population and economic development – to which GEO-6 adds three more, urbanization (previously covered under population), technology and climate change.

Three of these drivers – population, economic development, and technology – are ubiquitous in the DPSIR literature (Nelson 2005) and represent the disaggregation into three components of aggregate human consumption, and therefore of what is necessary for meeting survival as well as other welfare needs.

- *Population*: Other things being equal, more people will mean a proportionally higher pressure on the environment. In such a scenario, long-term sustainability is incompatible with growing populations, which the literature indicates will continue to grow at a global scale throughout this century. It is imperative in the present, therefore, to attend to how key population dynamics – including fertility rates, ageing populations, displacement and gender inequality – interact at multiple scales and impact environmental sustainability.
- *Economic development*: This refers to an increase in human welfare, which depends on material consumption and many other factors, including the environment. While economic development has been highly correlated with economic growth in the modern era, the two are quite distinct, empirically as well as conceptually. Per capita consumption is expected to continue increasing in the foreseeable future (because of the unfinished agenda of eradicating poverty, meeting survival needs and enabling individuals to pursue prosperity). To decouple growth from negative environmental impacts, resource-efficient, sustainable patterns of consumption are needed.
- *Technology*: Technological change is well understood as a driver of change, both negative and positive. Negatively, it provides an opportunity to accelerate, with incentives, the harnessing of natural resources for human ends; in times of crisis, incentives strongly favour adoption of riskier options and elimination or minimization of safeguards. Positively, technological progress also creates more efficient options, which can meet human needs at lower resource costs.

3 Note that The DPSIR framework has come under some criticism, especially on the elision over the interdependence between the drivers. In this assessment, we include an explicit examination of this interaction.

In this assessment, urbanization and climate change are added as independent drivers because of their importance in socioeconomic change.

Urbanization has been going on throughout history, but its pace, scale and impact have accelerated sharply in recent decades. As such, it is included independently as a fourth driver.

Likewise, climate change has been added as a fifth driver, even though, in principle it could be represented as an outcome of the other drivers. According to the Fifth Assessment Report (AR5) (Intergovernmental Panel on Climate Change [IPCC] 2014), the world is on the threshold of entering the era of 'committed climate change', namely that some impacts of climate change have now become irreversible (such as extinction of species and loss of biodiversity) and regardless of future mitigation or adaptation actions. In other words, even if all human activity were to cease, the impacts of climate change would continue to manifest themselves over the next few centuries.

Taken together, these five drivers are bringing about changes in natural as well as social systems. These impacts range from resource depletion to biodiversity loss, water scarcity, changes in the hydrological cycle, health impacts, and ecosystem degradation as well as pollution. In the absence of an adequate response, a changing climate could lead to a pre-modern world of famine, plague, war, and premature death.

2.2 Changes since the last assessment

A number of changes, summarized as follows, have taken place since the fifth Global Environmental Assessment (GEO-5).

- *Population*: With the 2018 world population estimated at 7.6 billion people, estimates by the United Nations indicate that the peak human population is likely to be higher than had been projected earlier. The world has also seen an increase in the number of migrants and refugees, in part as the result of heightened conflict and increased environmental degradation. Other demographic variables remain on track.
- *Urbanization*: Having passed the symbolic 50 per cent of population living in urban areas, trends indicate that rural-to-urban migration will continue, with acceleration in the global south. This represents both an increased driver of environmental pressure and an opportunity to enhance sustainability.

- *Economic development*: The global economy is coming through a slow recovery from the 2008 recession, and there are concerns about the persistent debt crisis, the increase in income inequality, and emerging instability due to trade wars. Offsetting factors include the increasing role and contribution of emerging economies, and the adoption of the Sustainable Development Goals (SDGs) as a new global aspiration and orientation for development (Section 2.5.1).
- *Technology*: The environmental crisis is creating perverse incentives for countries and businesses to resort to environmentally riskier technological options, including geo-engineering and nuclear technology. Yet it is also providing sound incentives for such technologies as renewable energy, energy efficiency, energy storage, and expanded application of information and communications technologies (ICTs).
- *Climate change*: The IPCC-AR5 states that 'the warming of the climate system is unequivocal, as evidenced by observations of increases in global temperatures, widespread melting of snow and ice and rising sea level'. IPCC also notes that human influence on the climate system is clear, and that 'many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped' (IPCC 2014, p. 16).

Besides the drivers themselves, various policy developments since GEO-5 also need mention. A number of global agreements were reached to address key issues pertinent to this assessment, including a new comprehensive treaty to address climate change, an agreement on the new development agenda, including the adoption of the SDGs, and agreements on mobilization of finance for development as well as climate action. In addition, several countries adopted national policies on disaster risk management, renewable energy, urbanization, transport, and water and sanitation.

Recent years have also seen increased interest in technologies that can accelerate social and environmental benefits and enable people, institutions, and communities to achieve their needs at lower resource costs. Section 2.7 focuses on the interactions across the five selected drivers and how actions on one driver may affect the others.

2.3 Population

Rapid population growth can undermine economic development at the national level and is associated at the local level with lower status and opportunities for women (Casey and Galor 2017; Kleven and Landais 2017). Other things being equal, a larger population means higher consumption, which in the long run puts increased pressure on natural resources. This is in spite of the fact that the short-run effect of a higher population growth rate does not imply a higher growth rate of consumption or resource use.

Box 2.1: Relationship between higher population and growth rate of consumption and resource use

Countries with higher population growth rates are typically also poorer, have lower carbon footprints per capita and experience slower growths in income per capita. For this reason, increased population does not always lead to increased consumption or resource use. High inequality and population growth are also inextricably linked. Inequality is a root cause of both rapid population growth and environmental degradation. To moderate population growth in high-growth regions, people need access to voluntary family planning and other reproductive health services, as well as to educational and employment opportunities.

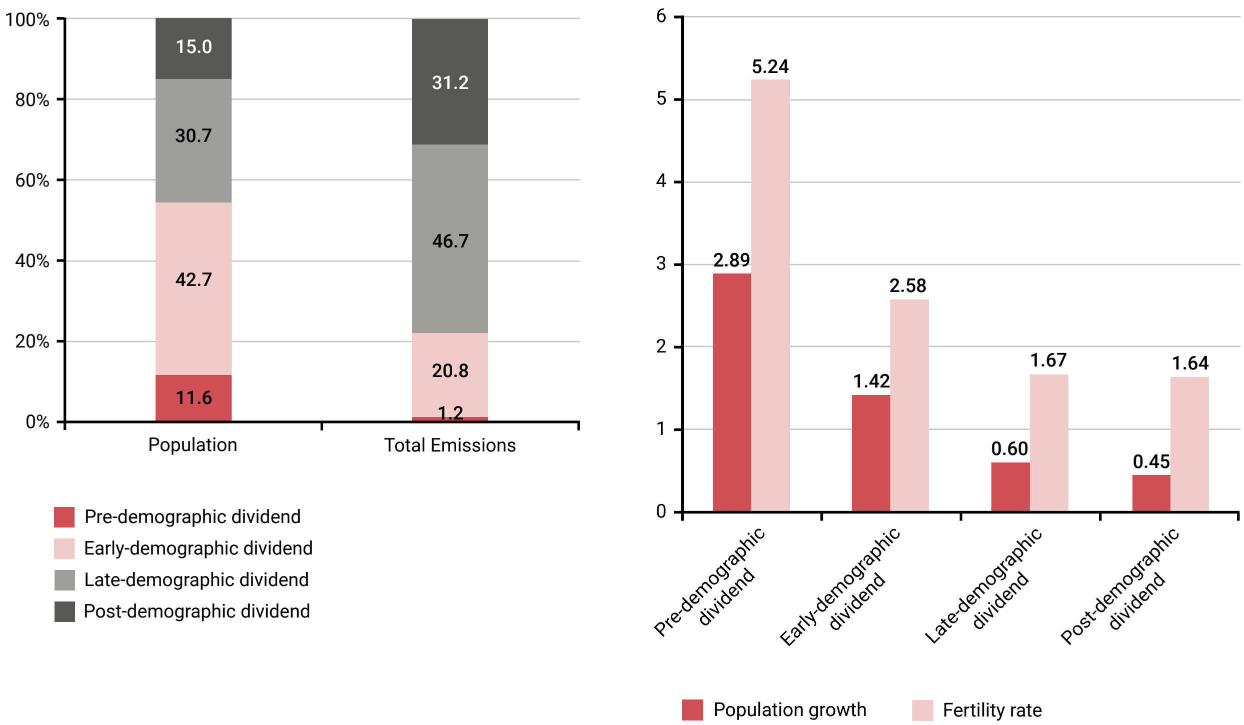
While the most important source of environmental pressure comes from the global North and its high carbon footprint per capita, high population growth in the global South is expected to– under current conditions – reinforce environmental pressures and enhance global inequality. Here, countries are transitioning to early and late demographic dividend stages.

Equally, high population growth rates constitute a drag on the development process. Whereas most countries that have been able to make the transition to developed status have seen massive reduction in their fertility rates (Sinding 2009), at the level of families and individuals, poverty, conversely, is typically associated with having many children (Gillespie *et al.* 2007).

Box 2.2: The demographic dividend

The demographic dividend takes place when the dependency ratio goes down – because of lower fertility and the fact that societies have not aged yet. Post-dividend societies are those that are already starting to increase their dependency ratio, led now by older people. Countries going through their demographic dividend – also called the window of demographic opportunity – benefit from increasing numbers of active-age population (15-64 years), decreasing numbers of young dependents (0-14 years) and small numbers of older people (64 years and over). In schematic terms, pre-dividend countries are the poorest, early dividend ones are the low- to middle-income countries, and late demographic dividend countries are mostly upper middle-income countries. Post-dividend countries are almost always rich countries with some upper middle-income countries from the former socialist block. Pre-dividend countries and those in early stages of the demographic dividend are expected to increase their population quite strongly, late-dividend societies are expected to grow still, but more moderately, and post-dividend societies will increase their populations in the years to come at a much slower rate or, in some cases, might even decrease their absolute population, and will continue to increase their older population. Pre-dividend countries and those in early stages of the demographic dividend have a smaller carbon footprint per capita and GDP. Yet as can be seen in this chapter, both early- and late-dividend countries (where both population and GDP should be expected to grow) have increased their carbon footprint per capita substantially.

Figure 2.1: World population, emissions and fertility



Source: Own elaboration based on World Development Indicators (2017 (https://data.worldbank.org/products/wdi)

Finally, countries with high population growth rates are often characterized by adverse conditions for women, including lack of access to education and health services, lower levels of literacy and life expectancy, higher rates of maternal and child mortality, significant barriers to participation in the labour force, and other discriminatory factors (Iversen and Rosenbluth 2010).

Sexual and reproductive health is often thought of as a universal right. While no single human right is framed in such terms, in the words of the United Nations Population Fund [UNFPA], "no country today – even those considered the wealthiest and most developed – can claim to be fully inclusive, where all people have equal opportunities and protections, and fully enjoy their human rights" [UNFPA 2017, p. 10.) Not only are sexual and reproductive inequalities and economic inequality strongly correlated, but the literature demonstrates they may be mutually reinforcing (UNFPA 2017). Poor women, particularly those who are less educated and live in rural areas, are often least able to access sexual and reproductive health services. Lack of access to these services, including contraception, places a woman at heightened risk of unintended pregnancy, which results in greater health risks and lifelong negative economic repercussions for herself and her children (UNFPA 2017).

Population growth can affect the environment not only through consumption and use of natural resources, but also through its impact on other factors. This includes the strain it can create on governance, its effects on the probability of conflict over limited resources, and its impact on rapid and unplanned urbanization (Organization for Economic Cooperation and Development [OECD] 2016).

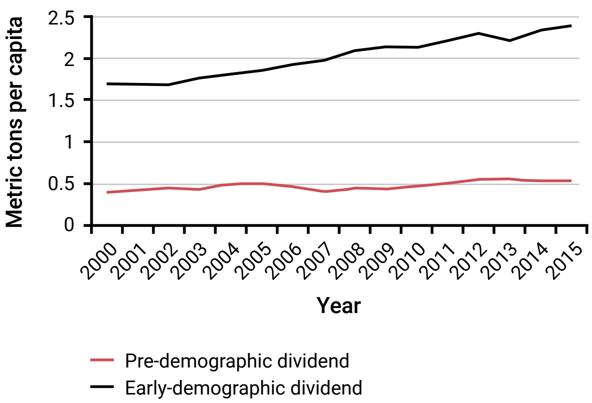
As an example, consider the experience of Latin America. As one of the regions with the highest inequalities, it experienced rapid urbanization and the formation of megacities far too rapidly for governing systems to cope. The result was inequality within dysfunctional urban milieux, rendering them segregated, unsafe and violent, in turn starving them of public resources, dampening economic growth, shrinking civic spaces, weakening public and merit goods, and undermining the quality and availability of collective services (Filgueira 2014). This reinforces inequality by encouraging private, segregated solutions for leisure, education, security, transport and housing.

The following analysis focuses on global population trends and global effects on environmental sustainability with some discussion of impacts on a subregional, national and local level.

The expected trends show that global population growth rates will slow but will continue to be positive in all regions except Europe, at least until 2040 – even in the most conservative estimates (United Nations Department of Economic and Social Affairs [UN DESA] 2017). This means that population growth will remain quite strong in many developing regions. These regions will also rapidly increase gross domestic product (GDP) and consumption per capita given both historical trends and accepted projections. The rapid increase in the carbon footprint per capita of countries sitting in the middle of the demographic transition (early- and late-demographic dividend) clearly illustrates the likely effects of high population growth on CO_2 aggregate emissions under current circumstances **(Figure 2.2)**.

Migration will probably move a large part of the population born in areas of low carbon footprint per capita (rural areas, the

Figure 2.2: Emissions per capita according to demographics



Source: Own elaboration based on World Development Indicators (2017 (https://data.worldbank.org/products/wdi)

global South) to areas of higher carbon footprint (O'Neill *et al*. 2012; OECD 2016). These are shifts that can increase the efficiency of carbon production per unit of output (technology or agglomeration reduces pressure for a given level of welfare). These shifts also increase consumption, however, and so increase aggregate CO_2 emissions in the process.

Finally, the still-growing world population will become older and is living and will live in smaller households (Dalton *et al.* 2008; O'Neill *et al*. 2012; UN DESA 2017).

These trends imply – on average, and again, with other things being equal – a higher carbon footprint per capita. In most cases, this simplified logic of population growth, dynamics and growing carbon emissions (assuming a business-as-usual scenario – see Chapter 21) also applies to the national and local levels and to other environmental variables such as water and air pollution, soil degradation, desertification and deforestation.

It should be stressed that population dynamics and population growth do not in themselves lead to an unsustainable environmental path. Rather, this path is the result of population growth happening with the current consumption and production patterns. Unsustainable consumption and production are each largely fuelled by heightened inequality. Both within and between countries, inequality remains one of the largest obstacles to environmental sustainability (Chancel and Piketty 2015; Oxfam 2015).

There are two detrimental effects against sustainability that are produced directly by heightened inequality:

1. because of the highly uneven distribution of resources, the level of growth required to lift people out of poverty is far larger than it would be in a more egalitarian distribution (Ravallion 2001; Bourguignon 2002; World Bank Group 2004). Put another way, the world would not have to grow at very high rates to improve the lives of those worse off if the distribution of those gains was more equally distributed.
2. high inequality is associated with a preference for overconsumption of private and positional goods, weakening public and merit goods (López and Palacios 2014; Samaniego *et al.* 2014).

Because public and merit goods usually mean collective consumption and lower marginal costs per unit consumed, because they are built on with economies of scale, they are far more efficient than private and positional goods in terms of their environmental footprint needed for their production and consumption. In particular, as societies become more urban, there is a unique opportunity for expanding collective goods (both public and merit goods) such as public transport, common utilities, green public spaces for recreation, bike lanes for mobility, and collective food preparation in full-time schools and work environments (Samaniego *et al.* 2014). A collective meal, a bus, a bike or a public park has the potential to satisfy needs (mobility, food, leisure) with a significantly lower footprint than private cars, individual food preparation, or an enclosed shopping mall (Jorgenson *et al*. 2015). Yet high inequality leads precisely to a preference for the private goods and services and not the former, because of fear, fragmentation, status competition and segregation.

It is because of the inevitability of population growth and other demographic dynamics (urbanization, smaller households and ageing populations) that it is critical to decouple these trends from unsustainable environmental pressure, by changing current consumption and production patterns.

2.3.1 Global population growth and composition

Four trends can be predicted with confidence: the world population will continue to grow (until at least 2050; **Figure 2.3)**, average age will increase, populations will become more urban, and household sizes will become smaller (United Nations 2015a). These trends are the inevitable results of underlying processes: industrialization, the agricultural technological revolution and resulting landholding patterns, the shift from extended households towards nuclear ones, and the dramatic drop in mortality due to the epidemiological transition (Lopez and Murray 1996; GBD 2015 Mortality and Causes of Death Collaborators 2016).

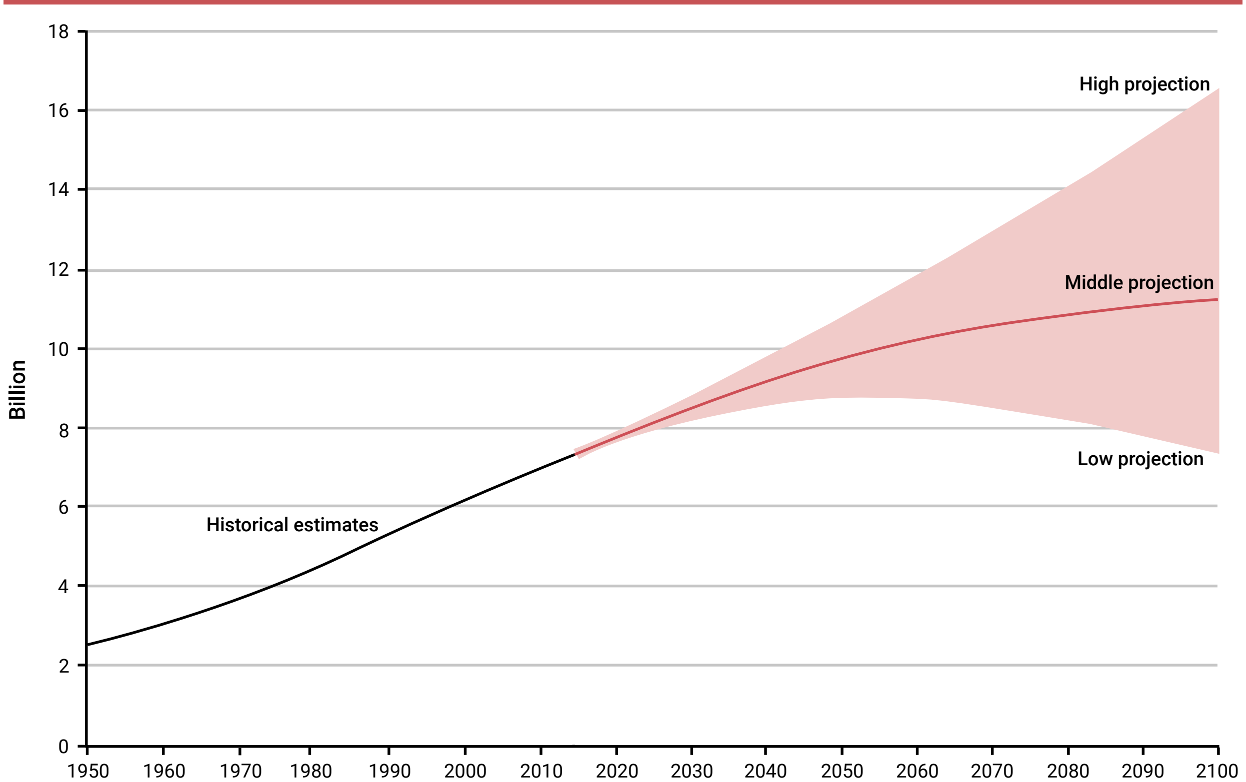
Policy and behavioural changes could moderate the rate at which these changes occur, but not reverse them. All other things being equal, smaller households, urbanization and ageing will generate more environmental impact per capita. Given that such trends are inevitable – to a larger or lesser extent – there are only three possible courses of action.

1. when possible and desirable, such trends can be moderated. For example, lower fertility (due to improved access to contraception and improved economic and social empowerment for women) is positive for economic development, moderating inequality, combating poverty and decreasing environmental pressure.
2. avoiding rapid surges in unplanned urbanization due to expulsion from rural areas provides a win-win scenario, allowing for national trajectories and urbanization processes that are more balanced and welfare-enhancing, which could enhance green cities and improve ecosystem connectivity. (rural expulsion is due in part to underinvestment in sustainable farming techniques and overexploitation in the depletion of natural resources, among other causes.)
3. patterns of consumption and production remain highly inefficient in terms of CO_2 production and other environmental pressures. Both hard and soft technological innovations (substitutes for fossil fuel energy sources, soil management, urban planning, collective care services in urban centres, public transportation, etc.) can drastically change the elasticity of consumption and production to units of environmental pressure.

2.3.2 Population growth estimates

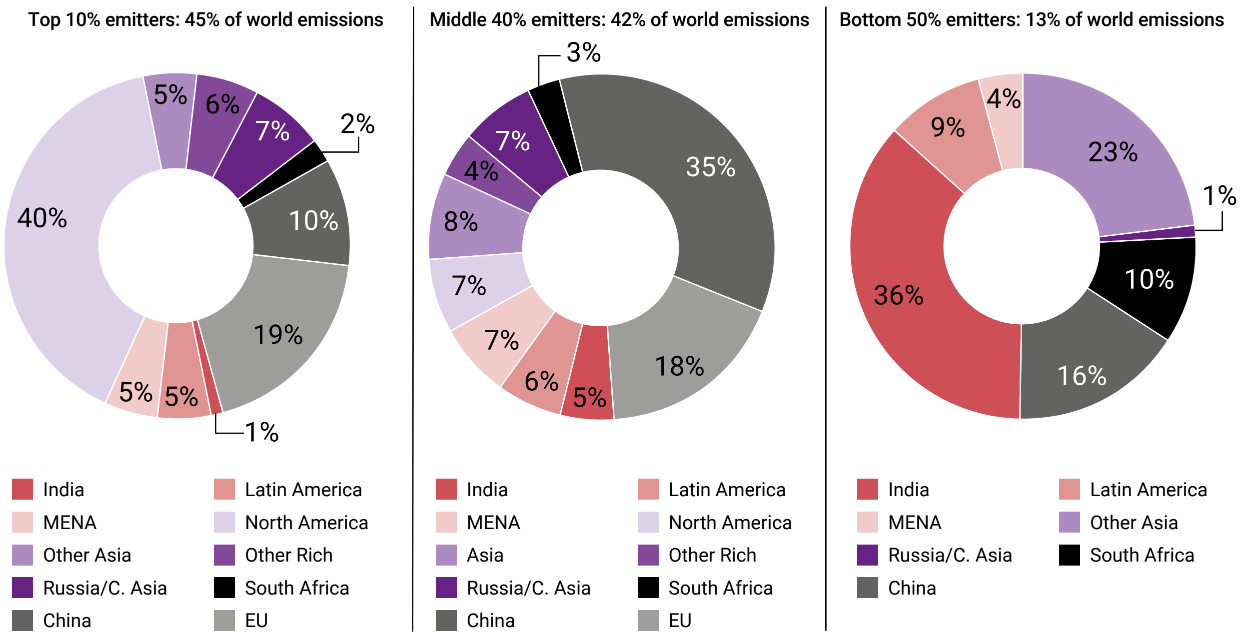
In 2017 (UN DESA 2015a), the total world population was 7.55 billion, growing at 1.10 per cent annually, a decline from a decade earlier, when it was growing at 1.24 per cent. Under middle projections for fertility, there will be 8.55 billion people by 2030, and almost 10 billion by 2050 (9.77 billion). However, any forecast looking a century into the future comes with significant caveats. Depending on the rate of decline in fertility rates, the global population could rise as high as 13.2 billion by the end of this century or reach 9.4 billion by mid-century and stay around those levels until 2100 (see Section 21.3.1).

Figure 2.3: Projected world population



Source: United Nations Population Fund (2017)

Figure 2.4: Consumption and associated environmental pressures are unequally distributed between nations



Note: In order to better represent the contribution of different groups of emitters to total CO_2 emissions, the charts split the world in three groups: top 10 per cent, middle 40 per cent and bottom 50 per cent CO_2 emitters in each country. For each of these groups, the chart presents the percentage of the group's emissions stemming from each region of the world.

Source: Chancel and Picketty 2015.

The key points to take away from this projection are:

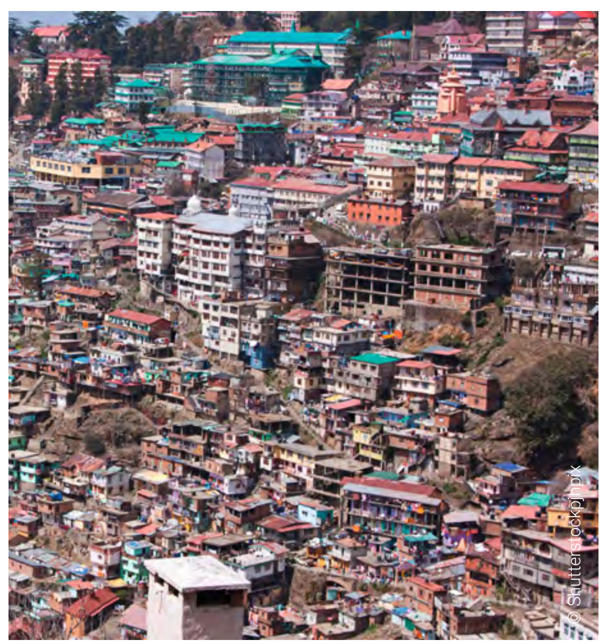
a. that the population will continue to rise until at least the middle of the century, and perhaps longer,
b. that there are significant uncertainties about long-term trends, and
c. that population control is not responsive to direct policy intervention, but rather indirectly to policies that, for example, lower fertility rates through women's control over reproductive choices.

Population growth depends on the numbers of births and deaths in a given year, and these in turn depend on three interrelated factors – fertility, mortality and the age and sex structure of the population. These last three depend on human behaviour, health conditions and demographic inertia, respectively. While age and sex structures change slowly, there are uncertainties about the rate of decline of fertility rates, as well as future trends in mortality rates. Also, while changes in fertile behaviour result in a lower rate of population growth, they do so only eventually, after considerable lags.

Mortality rates are declining rapidly in almost all developing countries, but fertility rates remain high in the least developed group, where the average is above 4 children per woman, almost twice the replacement level of fertility of 2.1 children (UNFPA 2017). Fertility rates can respond to gender policies, but if emerging medical technologies result in a dramatic extension of lifespans, population growth would be closer to the higher-end estimates, and ageing of the world population would be far more pronounced.

2.3.3 Population composition and distribution

There is increasing evidence of the complex interactions between the environment and the distribution and composition of the population (age, urban/rural residence, and household structure) (see Jiang and O'Neill 2007; Dalton *et al.* 2008; O'Neill *et al.* 2012; Liddle 2014).



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Population growth is distributed unevenly around the globe and within nations, as a result of differences in fertility patterns and migration trends. Countries with high fertility rates, young populations and steeply declining mortality rates will grow more rapidly than others. In the coming decades **(Figure 2.5)**, According to current trends Africa is projected to grow the fastest, followed by Asia, Latin America, North America, Oceania and Europe (United Nations 2015b, 2017).

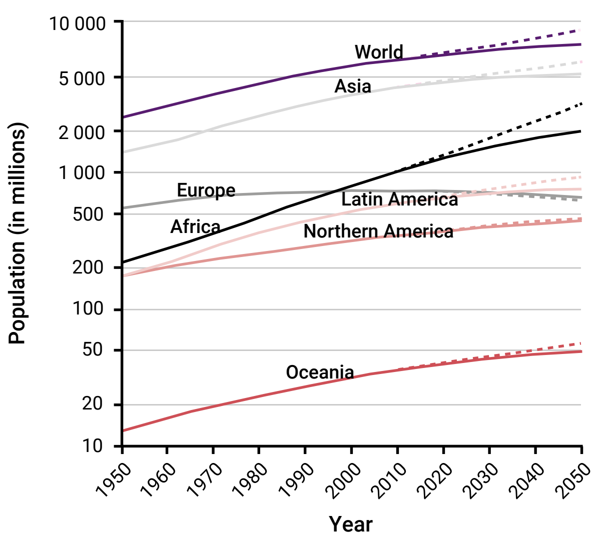
The impact of natural population growth is partially mitigated by migratory patterns, which will lead to shifts in population from less developed regions to more developed ones, and from rural to urban areas (OECD 2016). The pace of migration has increased in the last 50 years and will continue to do so in the next 30 years (Massey and Taylor 2004; International Organization for Migration [IOM] 2015). This is driven by the persistence of the underlying push-and-pull causal factors:

- the push effects of global inequality, poverty, conflict-ridden regions, and
- the pull effects, such as already established migrant communities in more developed regions sometimes attracting others from less developed regions.

South-South international migration has also increased along the same patterns as South-to-North migration (Hujo and Piper 2010). In many cases, migration is actually fuelled by environmental degradation that makes life unsustainable in the original locations (Leighton 2006).

Migration tends to dampen population growth, as data show that migrants typically have lower fertility rates in their new contexts (Majelantle and Navaneetham 2013). The net impact on the environment can still be adverse, however, given that migrants access higher levels of income and consumption than they had in their previous milieux. Given that one of the objectives of development, as well as of migration, is less poverty, increased income and consumption are desirable outcomes.

Figure 2.5: World population distribution and composition



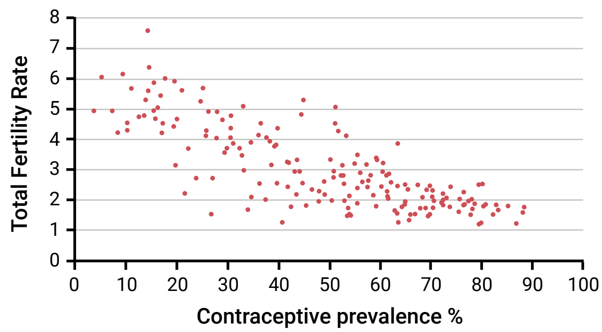
Source: United Nations Population Fund (2017)

Increased per capita consumption of resources may not be the only impact of migration on the environment and natural resources; resource efficiency may also change – for example, energy and materials use per unit of consumption may decline.

2.3.4 From population programmes to gender equality and women's empowerment

Population programmes, which were a major policy focus in the 1960s and 1970s, have since been discontinued in many countries, even though their benefits are widely recognized (UNFPA 2017). Part of the explanation for their decline was the systematic violation of basic rights that some of these programmes entailed through mass sterilization or forced and coercive policies limiting women's reproductive choices.

Figure 2.6: Contraceptive prevalence and total fertility



Source: Own elaboration based on World Development Indicators (2017) (https://data.worldbank.org/products/wdi)

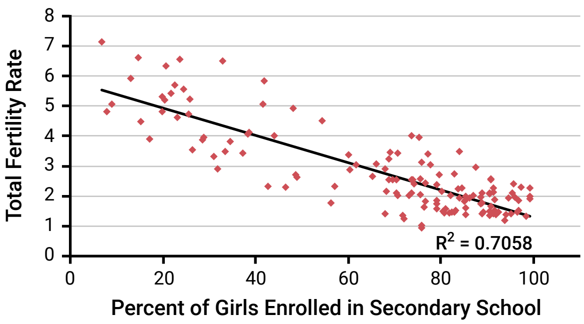
The United Nations International Conference on Population and Development in Cairo in 1994 and the Women's Conference in Beijing in 1995 contributed to the view that population policies should respect the rights of women and their choices, moving from population targets to a rights-based approach that places reproductive control in the hands of women. There is little doubt that existing population policies in Africa, Asia and parts of Latin America can contribute markedly to moderating the rate of population growth while respecting gender equality and empowering women. In turn, this seems likely to contribute to more robust economic growth, through higher female labour-force participation in the market economy, and improved health for mothers as well as children (UNFPA 2017).

These policies comprise a suite of actions, including access to modern contraceptive methods **(Figure 2.6)**, improved access for women and men to voluntary family planning and other reproductive health services, investment in women's education, removal of barriers to female labour-force participation, institution of legal penalties for discriminatory practices associated with traditional patriarchal behaviour, and investment in the social and economic uplift of less developed areas within countries, and of developing countries more generally.

2.3.5 Gender and education

Placing reproductive choices as much as possible in the hands of women has proven to have a definite impact on timing and quantity of childbearing (UNFPA 2017; United Nations Entity for Gender Equality and the Empowerment of Women [UN Women] 2017). This is affected, in part, by access to education and employment. One of the main contributing factors to high fertility rates is lack of women's access to education and employment opportunities. In least developed countries, where fertility rates are highest, access to education for girls tends to be lowest. Causal relations run both ways. **(Figure 2.7)**.

Figure 2.7: Female secondary education and total fertility rates



Source: Earth Policy Institute (2011)

2.3.6 Inequality, migration and cities

North-South inequality and international inequality in general is a major driver of migratory patterns. Closing international welfare gaps and promoting growth in the South has proven to help moderate migratory flows, which can allow for slower and eventually less CO_2 intensive welfare enhancing trajectories.

Similarly, within-country migration is driven by inequalities, especially between rural and urban areas, leading to rapid – and sometimes environmentally unmanageable – urbanization. Again, adequate developmental support for rural areas helps moderate such pressures. (IOM 2015).[4]

2.4 Urbanization

A distinct channel through which demographic trends affect environmental resources is through urbanization (also analysed as a cross-cutting issue in Section 4.2.5 of this report). The facts about urbanization are well known. Urban areas have higher incomes and consumption, greater access to political power, higher rates of economic growth, and, per capita, place a higher pressure on natural resources. On the other hand, cities exhibit greater efficiency in the use of resources per unit of income generated and better potential for energy efficiency (Dodman 2009; Bettencourt and West 2010; Barrera, Carreón and de Boer 2018; Cottineau *et al.* 2018). Cities are also the engines of economic growth. No country has made the transition from poverty to middle-income status without experiencing a period of rapid urbanization. Managed effectively, though, urbanization can help in the achievement of SDGs, efficiently and sustainably. Finally, urbanization is generally associated with a lowering of fertility rates (Martine, Alves and Cavenaghi 2013).

Slightly more than half of the world's population is currently living in urban areas, a share that is expected to rise to 60 per cent by 2030 and 66.4 per cent by 2050 (Brenner and Schmid 2014; United Nations 2014; Melchiorri *et al.* 2018). It should be noted that urban areas are defined in different ways worldwide, so UN DESA information is based on heterogeneous data sources. Using a globally harmonized definition of urban areas that combines demographic characteristics and density grids, Melchiorri *et al*. (2018) place global urban population at 85 per cent in 2015. Alternative understandings of the urban condition (Brenner and Schmid 2014) that can benefit from these new methodologies, and from an analysis of the transboundary ramifications of cities (Section 4.2.5), could represent an important tool for policy analysis and environmental governance.

Around 90 per cent of the growth of cities will take place in low-income countries (United Nations Human Settlements Programme [UN-Habitat] 2014). Africa is the world's most rapidly urbanizing region, while European cities grew the least in the 1995-2015 period (UN-Habitat 2016). The critical factor accounting for these trends is neither fertility nor age structure (which are, respectively, lower and older in urban areas), but migration (UN-Habitat 2016).

The coming decades are crucial. It took 200 years for the urban share of the world's population to rise from 3 per cent to 50 per cent, to 3.5 billion people in 2010 (United Nations 2014). This population is set to more than double over this century, but in all the centuries that follow, we may add, at most, another billion or so. This makes the current global urbanization era not just immense, but also brief (Fuller and Romer 2014). The choices around investment and design of new and existing cities are effectively determining the infrastructure, technologies, institutions and patterns of behaviour that will define the functioning of our cities and the future of the planet for the foreseeable future. This suggests there is a very narrow window of opportunity to help plan and design this future. The world's infrastructure will more than double in the next 20 years (Bhattacharya *et al.* 2016).

2.4.1 Cities of different sizes face different challenges

The pattern of urbanization is also relevant for understanding both the potential for growth and the impact on natural resources. At the high end of urbanization are megacities, defined by UN-Habitat as cities with more than 10 million people (UN-Habitat 2016, p. 7), most of which are located in the global South. In 1990, there were 10 megacities housing 153 million people, or 7 per cent of the total urban population; by 2014, there were 28 megacities, with 453 million people, or 12 per cent of the total (UN DESA 2014); in 2016 there were 31 megacities, 24 located in the less developed regions or the global South; of these, 6 were in China and 5 in India (UN DESA, Population Division 2016).

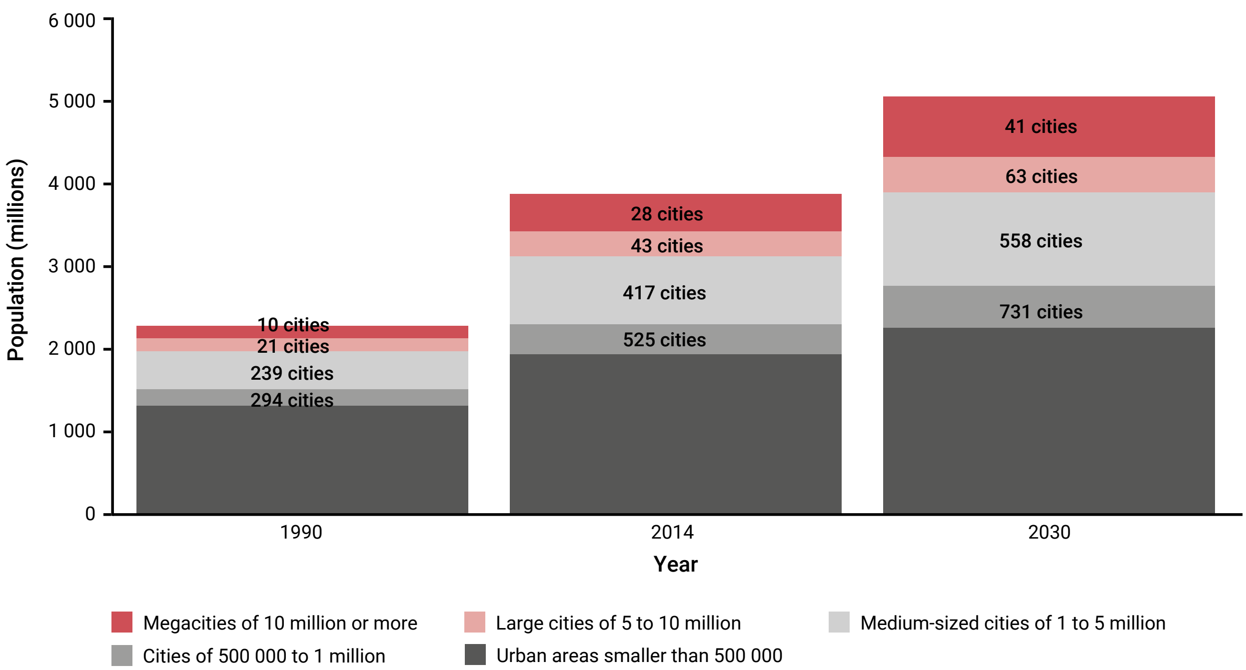
4 This support in rural areas is not an alternative to avoiding migration. Such a policy can still have detrimental effects on migrants and host areas.

However, while megacities might be economic powerhouses, they do not represent the majority of the urban population **(see Figure 2.8)**, and are not the fastest-growing urban centres **(see Figure 2.9)**. Small and medium cities now account for roughly 50 per cent of the world's urban population and are growing at the fastest rates (UN DESA 2014; United Nations Economic and Social Commission for Asia and the Pacific [UNESCAP] and UN-Habitat 2015). They will "deliver nearly 40 per cent of global growth by 2025, more than the entire developed world and emerging market megacities combined" (UN-Habitat 2015a, p. 2; Dobbs *et al*. 2011). Small and medium cities are also more vulnerable to natural hazards than big cities and megacities (Birkmann *et al.* 2016).

2.4.2 Urban agglomeration economies

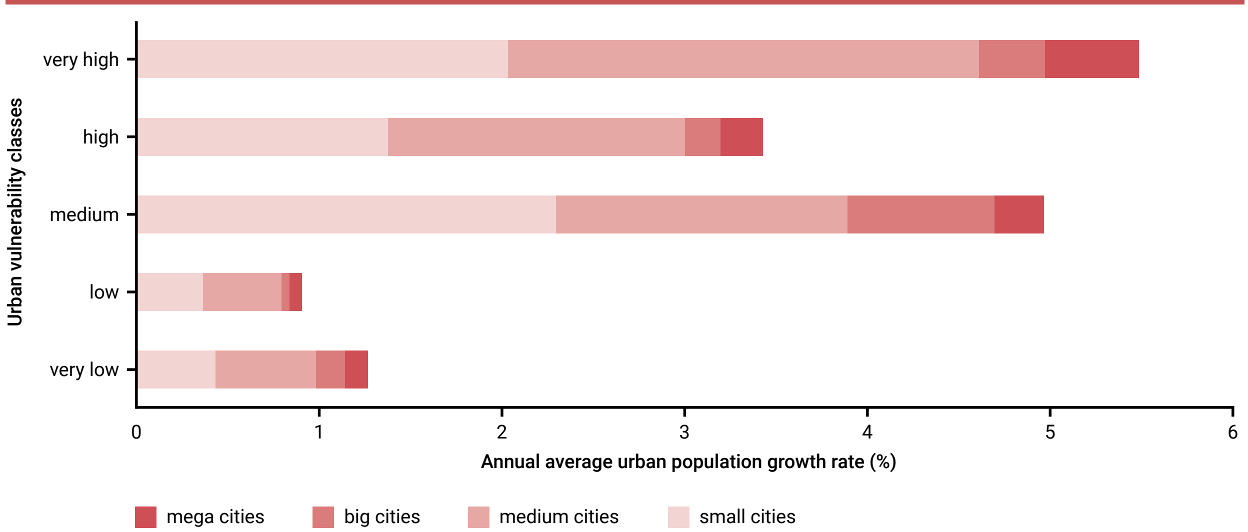
Agglomeration economies reflect the advantage of people clustering to reduce transport costs for goods, people and ideas. Higher productivity attracts inflows of people, who in turn further increase productivity. Agglomeration economies thus generate a positive feedback loop and multiply the impact of external productivity factors, and so boost urban populations and wages (Glaeser and Gottlieb 2009; Zenghelis 2017).

Figure 2.8: Global urban population growth propelled by cities



Source: United Nations (2014, p. 13)

Figure 2.9: City growth rates



Source: Birkmann *et al.* (2016)

Cities are a source of wealth creation, where wealth is measured as the sum of natural, human, and physical assets (Hamilton and Hartwick 2017). Natural capital includes land, parks, green spaces, water and biodiversity. Human capital includes the population's education, knowledge and skills. Physical (or manufactured) capital includes such things as housing, infrastructure, industry and offices. Added to these is intangible capital – ideas and inspiration captured in forms that include research and development, patents, intellectual property rights, customer lists, brand equity, social capital and institutional governance. Intangible capital is perhaps the most important but feeds off and interacts with the other forms of capital. It also provides the source for innovation and investment necessary to decouple growth from resource use and CO_2 emissions, in absolute levels as well as in rate of growth terms.

A growing body of research supports the hypothesis that cities have the capacity to spread knowledge, so the key driver of wealth is now the ability to attract skilled and creative individuals and to nurture and spread ideas. Cities therefore appear to have a comparative advantage in more idea-intensive sectors. Unlike manufacturing, which is increasingly located outside cities, ideas-oriented industries tend to cluster in urban centres. It is unsurprising that much of the generation and distribution of ideas occurs in major cities given the role of close spatial proximity. The evidence clearly suggests that the direction of innovation is strongly influenced by urban and national planning and policy, and there is substantial scope for policy to direct cities towards resource-efficient low-carbon innovation.

Urbanization carries its own penalties of success, including pollution, congestion, urban heat effect, ill health, crime, informal settlements (slums), lack of affordability and waste. Unregulated, unplanned urban sprawl might appear to be the cheapest option in the short run, as it requires minimal institutional interference, infrastructure provision and urban planning. But the medium- and long-run costs to society, the economy and the environment can be dire. Unregulated cities will be less attractive, more polluted, congested and inefficient in the use of resources. About a third of the global urban population lives in slum-like conditions without basic services and social protection (United Nations Population Fund 2010/2011 cited in Urban Habitat III #1, p.3). Poor women living in slums are particularly vulnerable and face barriers to accessing some of the advantages of urban living (United Nations Population Fund 2014 cited in Urban Habitat III #1, p.2). Moreover, two thirds of urban dwellers live in cities where income inequalities increased between 1980 and 2010 Lopez Moreno 2012 cited in Urban Habitat III #1 p.1). Urban sprawl, poor public transport and a lack of access to basic services such as water, waste collection and energy offset the economic benefits of urban concentrations and increase costs. These growth penalties hinder opportunities to prosper and also exacerbate urban poverty. Unplanned urban growth also leads to excessive GHG emissions, alienation and social exclusion, as well as a range of other social, economic and environmental costs such as congestion, ill health and crime (Floater and Rode 2014).

These trends place an enormous burden on governance structures (Frank and Martinez-Vazquez 2014; UNESCAP and UN-Habitat 2015). In developing countries, local taxes, measured as a percentage of GDP, are three times lower than in industrialized countries (Bird and Bahl 2008).

Similarly, many of the small and medium-sized cities "lack the technical capacity to lead a major urban development process" (UN-Habitat 2012, p. XIV) and suffer from devolved responsibilities without corresponding resources, hampering their planning capacity (Frank and Martinez-Vazquez 2014). The result is that the capacity of urban governments to protect both natural resources and the rights of its citizens is severely circumscribed.

2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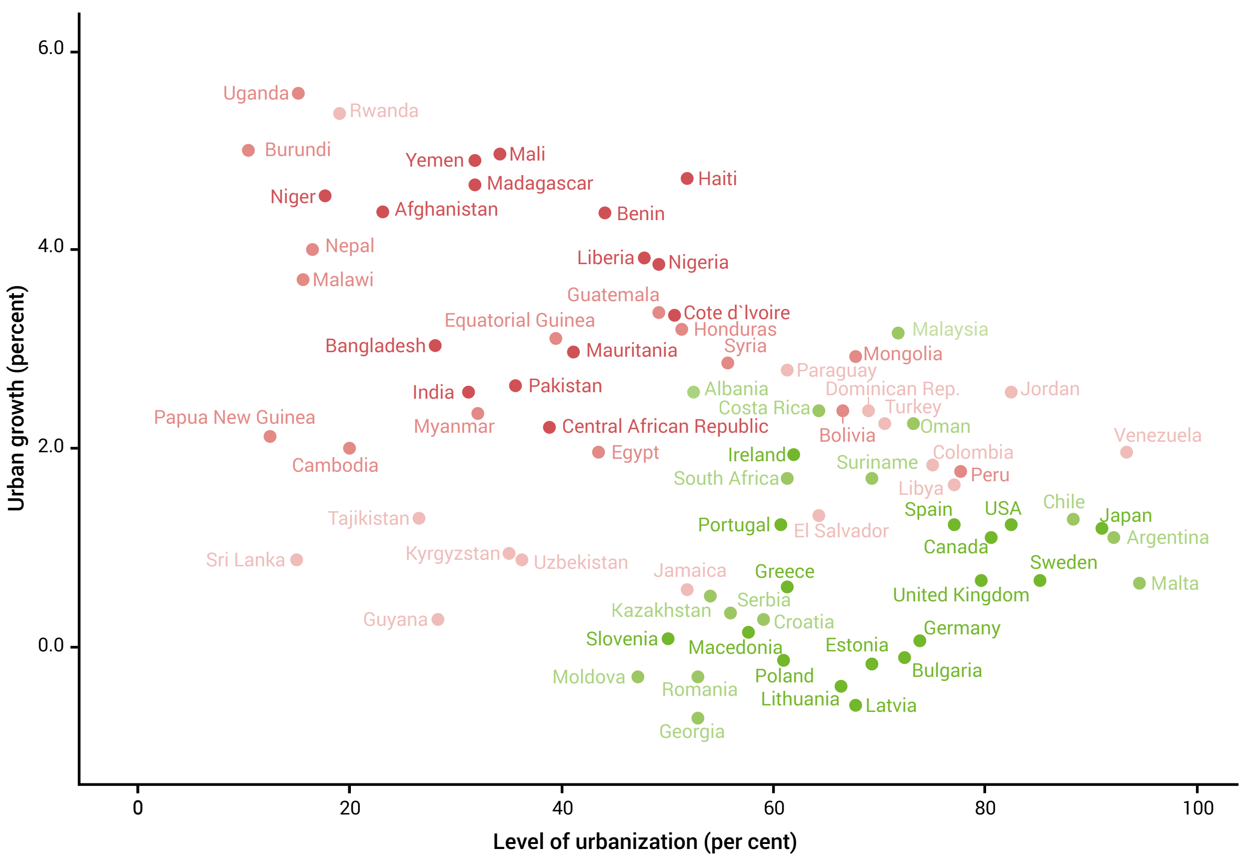
Mass urbanization is not new in Europe, North America and richer parts of Asia, but the most recent wave is focused in developing regions, including Southern Asia and sub-Saharan Africa. This influx of people into cities can place great strain on urban institutional resources and infrastructure in growing cities. **Figure 2.10** shows that in countries with lower levels of urbanization and higher growth, urban citizens are highly vulnerable – vulnerability being "calculated by adding the urban susceptibility, the lack of coping capacities and the lack of urban adaptive capacities" (Garschagen *et al*. 2014, p. 46). If the relative change in the degree of urbanization is disaggregated by income class for the 1990-2015 period, it can be seen that in Asia, low-income countries (LICs) are urbanizing at the fastest rates (15.5 per cent) in comparison with low to middle-income countries (LMCs), at 1.2 per cent, and upper middle-income countries (UMCs), at 1.5 per cent. A similar pattern is seen in Africa – where the urbanization rates are 8 per cent for LICs, 3.6 per cent for LMCs and 5.7 per cent for UMCs – and in Latin America and the Caribbean. Globally, the pace of change in urbanization overall is 2.3 per cent (1990-2015), and the disaggregation by income class reveals the pace of change in LICs is 8 per cent while in LMCs it is 1.6 per cent (Melchiorri *et al*. 2018)

These rapidly urbanizing areas present a challenge but also represent "the largest opportunities for future urban GHG emissions reduction [... because their ...] urban form and infrastructure is not locked-in" (Seto *et al*. 2014, p. 928). As is presented below and in Part B of this report, there are positive and negative examples of rapidly urbanizing areas with regard to environmental effects. Cities exemplify the reality emphasized in this report, that when it comes to the creation of complex spatial networks, the future is not 'God-given', but is system and path-dependent. If new cities are built over the next two or three decades on a resource-hungry, carbon-intensive model, based on sprawling urbanization, all hope of meeting ambitious resource and climate-risk targets will be lost. This could leave cities and countries struggling to meet their

Figure 2.10: Where rapid growth faces high vulnerability



Classes of urban vulnerability	Level of urbanization	Growth rate 2000-2015
Very low	75.80	0.71
Low	69.19	0.92
Medium	56.07	2.36
High	43.51	2.89
Very high	38.59	3.71

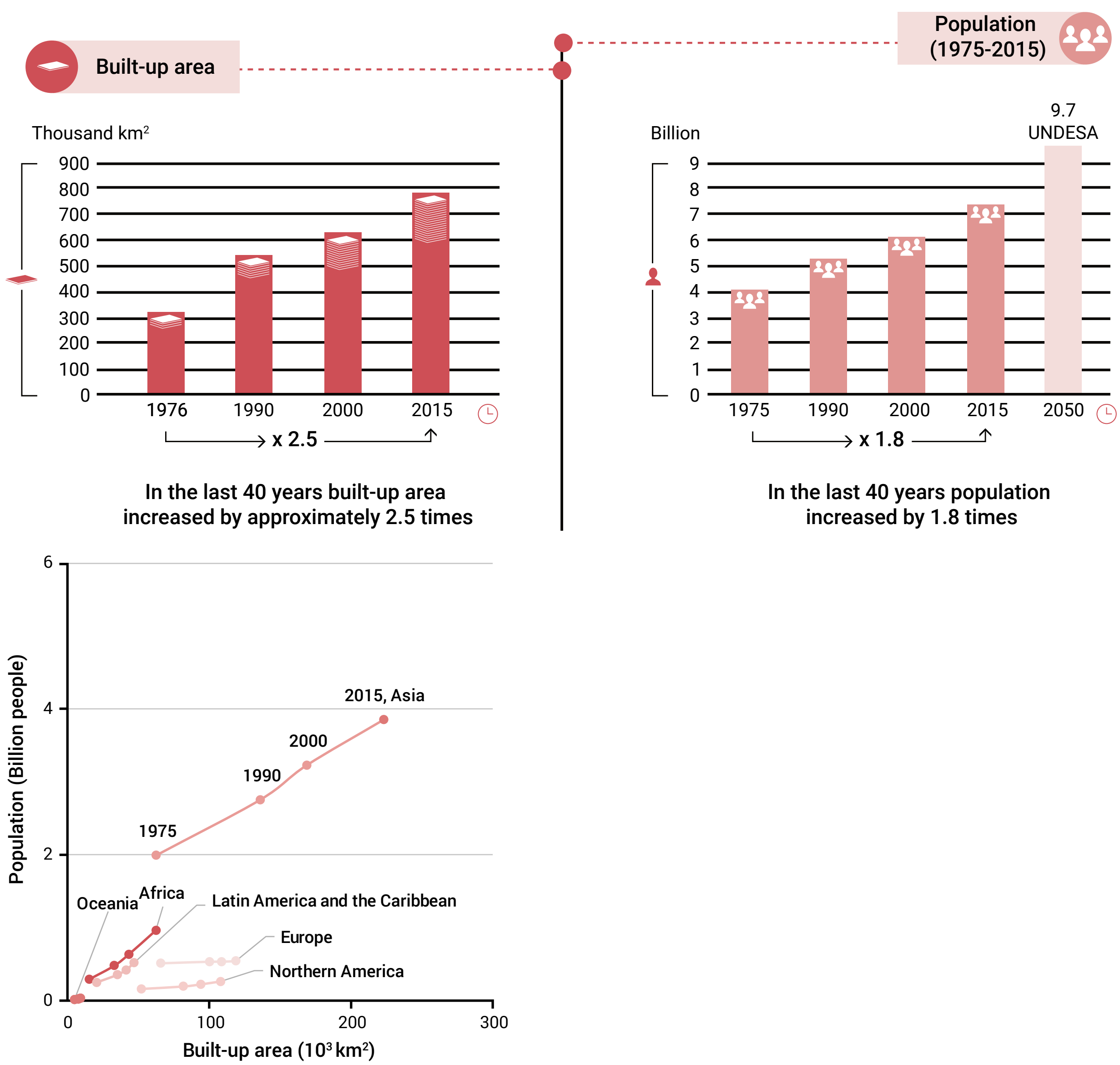
Source: Garschagen *et al*. (2014)

resource needs and unable to compete in global markets, with the stranding of physical and human assets. Cities are also vulnerable to environmental and climate impacts such as heat, water stress, and floods; while coastal cities face sea level rise, saltwater incursion and storm surges.

2.4.3 Trends in urban expansion and density

Currently there are different views regarding territorial expansion of cities and population growth. In the absence of sustainable urban management, some studies show that cities are growing in size more than in population, reporting territorial expansion at double the population growth (Angel *et al*. 2011). Pesaresi *et al*. (2016) show that between 1975 and 2015, built-up areas increased 2.5 times while total population increased by a factor of 1.8 **(Figure 2.11)**, with the highest urban growth concentrated in India, China and countries in Africa. Urban land growth in these regions has also outpaced urban population growth rates, suggesting that urbanization has resulted in sprawled developments (Seto *et al.* 2011; Wolf, Haase and Haase 2018). Even in cities that are shrinking in population, sprawl still occurs (Schmidt 2011; Wolf, Haase and Haase 2018). Conversely, recent studies from Asia have shown that urban population has grown faster than urban land (in eastern South-East Asia, a 31 per cent population increase compares with a 22 per cent land increase) and that urban areas (in East Asia) are four times more dense than in land-rich developed countries: two times more than in Europe, 1.5 times more than in the Latin American and Caribbean region, and 1.3 times more dense than in the Middle East (Schneider *et al.* 2015; World Bank Group 2015).

Figure 2.11: Built-up area vs. Population (1975-2015)



Source: Pesaresi *et al.* 2016

Increasing density alone is insufficient to make the transition to sustainable cities. Another factor that affects urban impact on the environment is urban form, namely the pattern of urban physical infrastructure, which cannot be easily modified, and determines land use, transportation and energy demand for long periods of time (Seto *et al*. 2016; Güneralp *et al*. 2017). Form patterns have implications for energy consumption, GHG emissions, biodiversity (Seto, Güneralp and Hutyra 2012; Salat, Chen and Liu 2014), water infrastructure (Farmani and Butler 2014) and land use and conversion of croplands (Bren d'Amour *et al*. 2016). Urban form, "infrastructure design and socio-spatial disparities within cities are emerging as critical determinants of human health and well-being" (Ramaswami *et al.* 2016, p. 940).

2.4.4 Urbanization as an opportunity

In a world where environmental limits are visibly closer, and with rural to urban migration expected to continue, urban population growth can represent an opportunity to increase citizens' well-being while decreasing their ecological footprint. This is made possible through lifestyle choices, improved governance, awareness and education programmes, the availability of infrastructure and services, and technological solutions. Small and medium cities have a particularly important role to play as they are usually a stepping stone between rural populations and urban centres (UN-Habitat 2015c, p. 3). In other words, urbanization can be positive, but will only amplify existing challenges if poorly managed. If cities could build technological solutions that took advantage of economies of scale not feasible in rural contexts, they could potentially hold the promise of limiting the negative environmental effects of population growth and increased consumption.

2.5 Economic development

The term economic development has been used in the literature to distinguish it from a one-dimensional measure of human welfare, which focused solely on economic growth (or, properly speaking, the growth in GDP). It includes, for example, social equity, poverty eradication, the meeting of basic human needs (access to health, education, and water and sanitation services), the provision of physical infrastructure (housing, energy, transport and communications), and the guarantee of essential political, economic, and social freedoms as elaborated by Sen (2011). Similarly, the term economic development highlights structural transformation, namely the changes in industrial structure (from an agriculture-based structure towards industry and services), social organization (from small-scale productive activities towards large-scale organizational structures), and the diversification of skills. The SDGs are derived from this broader concept of economic development.

2.5.1 The social role of economic growth

As the economy has moved from an 'empty world' to a 'full world' (Daly 1973), it has become clear that conventional growth cannot continue far into the future (United Nations Environment Programme [UNEP] 2011). Yet the social and political commitment to a vision of unending growth remains as strong as ever. The reasons are easy to see. Economic growth plays a number of vital roles in modern society, including poverty eradication, the pursuit of social justice, the building of social solidarity, the defence of civic peace and the establishment of good governance.

The most important of these is poverty eradication. Two and a half centuries after the advent of the Industrial Revolution, about 783 million people (10.7 per cent of the global population), still live on less than US$1.90 per day, and 48.7 per cent of the population lives on less than US$5.50 per day (World Bank Group 2013). Globally, about 22 per cent of children are stunted and 7.5 per cent are underweight (UNICEF 2018a) while 264 million children and adolescents are unable to enter or complete school (UNICEF 2018b), the majority of them girls. Nearly 2.1 billion lack access to safely managed water and 2.3 billion lack basic sanitation (UNICEF/WHO 2017).

This poverty is not because of a lack of economic resources. In 2017, the world's average income per capita was $16,906 per year (PPP, current international $), which is $46 per day (World Bank Group 2018) and about 24 times the poverty threshold. While redistributive policies and social security arrangements can help people to cope with poverty, the only reliable mechanism for eradicating poverty is to enable the poor to benefit from fast, steady growth.

Another argument for economic growth in developing countries is the need to narrow the huge income gap that separates them from developed countries. Indeed, this gap continued to widen well into the second half of the 20th century. Only in the 21st century was there evidence of a narrowing of the gap, as growth rates in developing countries began to outstrip those in developed countries **(Figure 2.12).**[5]

As such, even critics of the growth agenda agree that it is essential for developing countries (see, e.g. Jackson 2009, p. 4). Their main critique focuses on developed countries, where growth is, they argue, neither necessary nor desirable (see Daly 1973; Rees 1995; Victor 2008; Jackson 2009). Others (e.g. Friedman 2005) argue, however, that growth continues to play important political roles in developed countries, including supporting fairness, social mobility and social solidarity, while attracting popular support for civic and international peace (Benhabib and Rustichini 1996, p. 139; Weede 1996, p. 32; Gartzke 2007, p. 180).

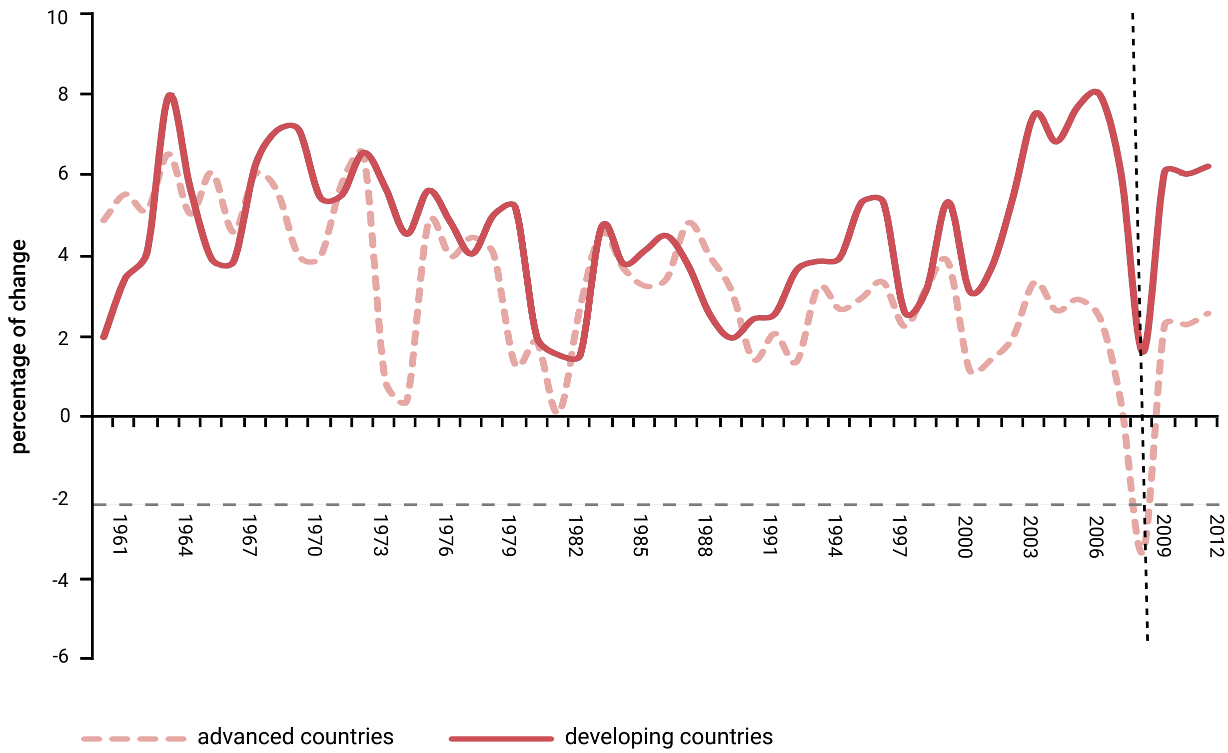
In sum, then, the recent episodes of global economic growth are associated with:

a. a narrowing of the income gap between developed and developing countries, and
b. a huge dent in the incidence of poverty in the latter countries.

The danger is that if the growth engine slows down, these trends may not continue, and this could – as outlined in the report of the United Nations Secretary-General on climate

5 This was in large part due to the higher growth rate in the large populous economies, especially China and India, but was not restricted to them. Indeed, the first decade of this century witnessed the first occasion when sub-Saharan developing countries, as a group, grew by more than 5 per cent per year for 5 years. However, the global financial crisis has resulted in the slowing of average developing country growth rates by 2-3 per cent, and a widening in the variance in growth rates, as larger countries (e.g., Brazil, China, Germany and the United States) recovered more quickly than smaller economies.

Figure 2.12: How growth rates in developing countries began outstripping those in developed countries



Source: Canuto (2010)

change and its possible security implications (A/64/350) – signal a reversion to a zero-sum world in which conflict and war would proliferate, governance systems atrophy and popular support diminish for social justice, solidarity and civic peace.

The question is not whether growth in developed countries is needed to meet their material aspirations, but whether it is an essential element in the quest of modern societies to meet their political, social, cultural and even moral and ethical goals. Ideally, economic growth and environmental sustainability are mutually reinforcing rather than in conflict.

2.5.2 From growth to development

Economic growth is only one of the factors contributing to human welfare, which also depends on social justice, poverty eradication, good governance (including anti-corruption efforts) and environmental health. The global policy process has sought to reflect this integrated approach in the form of the Millennium Development Goals (MDGs) and SDGs.

The structure of the SDGs provides an insight into the broader issues discussed in this section. The MDGs were motivated by a simple idea, namely the resolve of heads of state and government at the Millennium Summit of the United Nations General Assembly to halve poverty in 15 years (United Nations, 2000). The SDGs take it a step further and seek to eradicate poverty and hunger by 2030. In addition, the SDGs draw explicit attention to environmental and social factors, including climate change, terrestrial and marine biodiversity, sustainable consumption and production, inequality, industrialization and decent jobs, and peace and justice (United Nations Development Programme [UNDP] 2018).

In retrospect, the MDGs were a qualified success; they coincided with accelerated progress on poverty eradication, health and education, but lagged on nutrition and on access to water and sanitation (McArthur and Rasmussen 2017). The successes of the MDGs can be attributed to four factors, in descending order of significance, namely: high economic growth in developing countries, support for local programmes and community-based initiatives, large vertical programmes (especially in the health sector), and the enactment of legal rights and protections. Although it is difficult to assess the causal impact of MDGs (it is impossible to know what would have happened in their absence), some empirical research has found evidence of the MDGs accelerating progress in these areas (McArthur and Rasmussen 2017).

Although the SDGs seek to build on this success, the underlying context is very different. Their adoption was preceded by a major financial crisis, barely avoiding a full-fledged financial meltdown, a long-drawn out recession in industrialized countries, a potentially disastrous debt crisis, a dramatic rise in income inequality in the OECD countries, recurrent commodity-price volatility, significant political fallout from food price shocks, shrinking natural resources and biodiversity, growing evidence of adverse climate-change impacts, an increasing awareness that the global economy was coming up against planetary boundaries (Rockström *et al*. 2009b), and a dramatic rise in global conflicts.

The SDGs can be loosely grouped into three categories:

- *Human development*: tackling income poverty, hunger, lack of access to basic services (health, education, water and sanitation) and gender inequality (i.e. SDGs 1-6),
- *Economic development*: enabling conditions for poverty eradication, providing access to energy, providing economic growth, decent jobs, infrastructure and industry, declining inequality, housing, and peaceful societies (SDGs 7-11 and 16-17)
- *Environment*: ensuring that the agenda of poverty eradication (and by implication, of economic growth) is protected against ecological threats (SDGs 12-15).

This agenda is relevant to the Global Environment Outlook assessment. The poverty agenda remains unfinished, and the development consensus remains that its pursuit will require further economic growth in the world economy. There is a growing concern, however, that the prospects of development itself are increasingly threatened by the closing in of planetary boundaries, especially through the impacts of climate change. In the loop's other direction, there continue to be fears that the growth process entails increasing use of natural resources and sinks, thus increasing the pressure on the natural environment.

The poverty agenda remains the highest priority of the international policy community, as documented in almost every international agreement pertaining to economic development and the environment in the past quarter century. The reasons for this are not exclusively or even primarily altruistic. In the words of the founding principles of the International Labour Organization (ILO), as cited by its Director-General: "poverty anywhere is a threat to prosperity everywhere" (ILO 2011). The reasons thereby reflect an understanding that global peace cannot be built on conditions that condemn a significant segment of humanity to permanent deprivation and subservience.

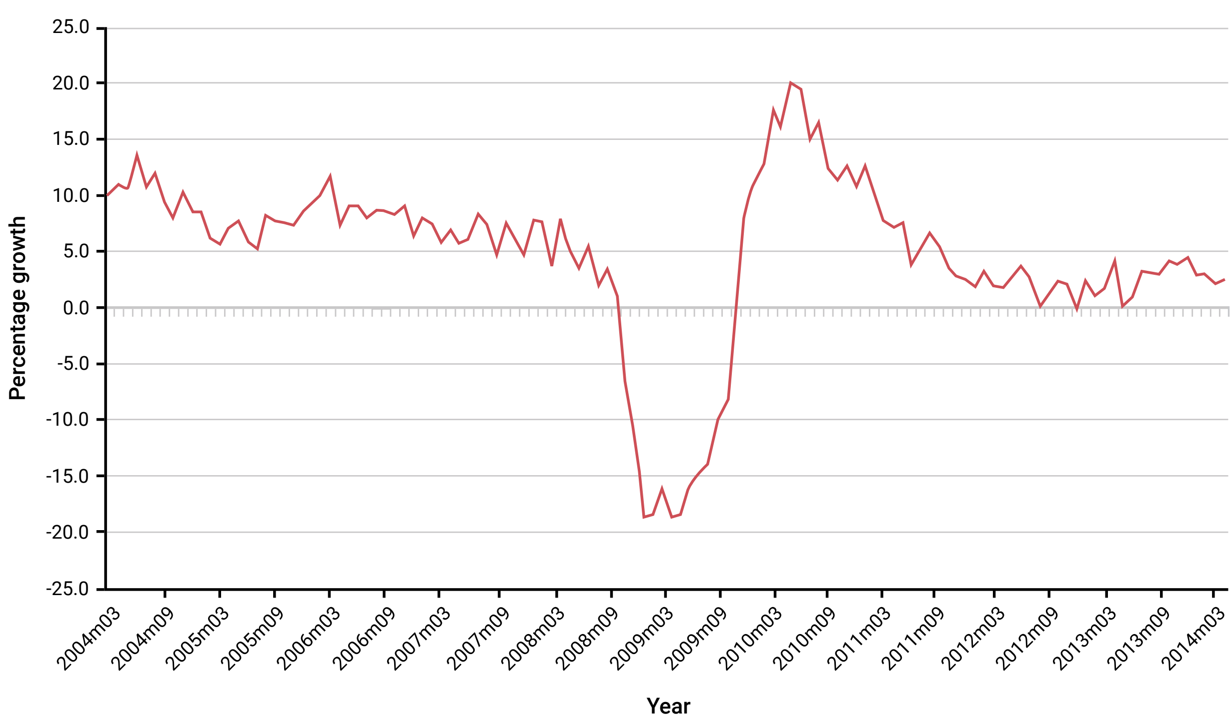
2.5.3 Recent experience

The financial crisis was followed by a slowdown in global growth. The reasons for this were to do with stagnant international trade, revival of the spectre of trade wars, heightened policy uncertainty, and a dampening of the main engine of global growth, namely emerging economies (World Bank Group 2017, p. 3). From an average of about 6 per cent growth per year between 1992 and 2008 (and a height of 10 per cent per year in 2006-2008), growth in global trade has shrunk to about 1 per cent since 2010 **(see Figure 2.13)**. More recently, this appears to have resulted in renewed threats of trade wars.

A second notable trend is the rising inequality in industrialized countries. There is a paradox in the contrasting movements in international and intra-national inequality. For much of the 20th century, income inequality between countries widened (or, at best, was static), while income inequality within countries narrowed (or, at worst, remained static). Since 1980, however, both these trends have reversed.

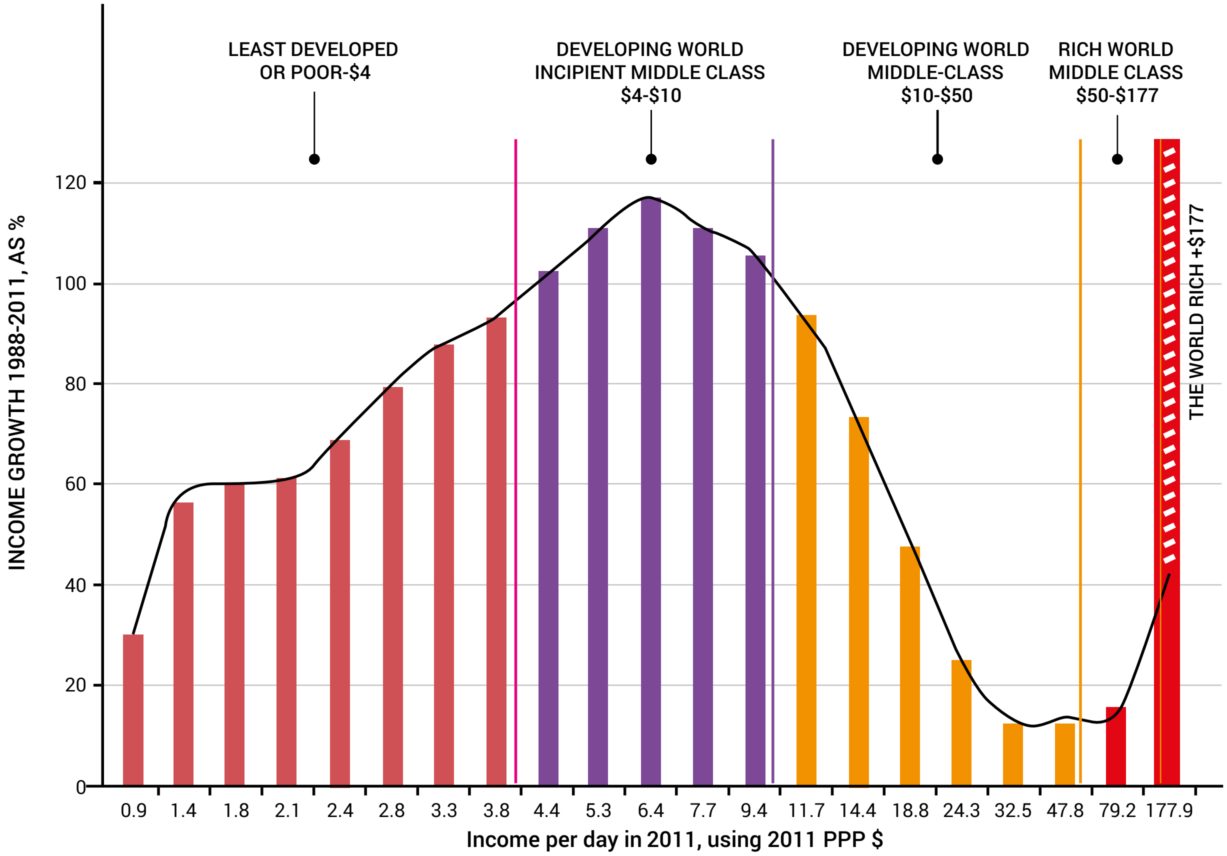
One consequence is Milanovic's global elephant curve, so called for its shape as seen in **Figure 2.14** (Lakner and Milanovic 2013, p. 31; Weldon 2016). This shows that between 1988 and 2011, while the incomes in the top 1 per cent as well as those in the 40-70 percentiles (presumed to be in developing economies) were rising, incomes in the bottom 10 per cent and in the 80-90 percentiles (presumed to be in the middle class of developed countries) were growing more slowly.

Figure 2.13: World trade growth



Source: Data from CPB Netherlands Bureau for Economic Policy Analysis (2018)

Figure 2.14: Milanovic´s elephant curve



Source: Data from Lakner (2013) and artwork from da Costa (2017)

The relationship between income inequality and the use of natural resources is not straightforward. On the one hand, the classic economic argument is that the poor have a higher propensity to consume than the rich (Carroll *et al.* 2017), and transferring income from the former to the latter should therefore reduce the impact on the natural environment. On the other hand, heightened income inequality creates upward pressure on resources, both through the impact of conspicuous consumption and out of the squeezing of the middle class. More importantly, inequality has the potential to exacerbate conflict, which in turn has an adverse impact on the environment. Inequality's effects on the environment move through the consumption, investment and community channels (Islam 2015).

There are two main justifications for the global growth agenda: the material one and the political one. The former is for the role of growth in poverty eradication while the latter is for the pursuit of growth for its possible contribution to other needed political aims, such as social justice, fairness, solidarity, civic peace and democratic governance.

Recent trends show that a significant dent has been made in the twin agendas of poverty eradication and reduction of global, between-country inequality. On the other hand, the manner and pace at which this has happened has given rise to new tensions and fractures, both within and between countries. This may indicate that there has been a renewed urgency for reviving the growth momentum, not only in developing countries, but equally in developed ones too.

2.5.4 The role of energy

A key question is the relationship between two different dimensions of economic development, namely aggregate economic growth and resource consumption, especially the consumption of energy.

There is a large body of literature on decoupling economic growth from its impact on resource consumption (see, e.g. UNEP 2011; UNEP 2017; Hennicke 2014). A key distinction is between renewable and non-renewable resources. Since the latter are finite in nature, the only way to reduce depletion is to reduce, reuse and recycle (the three Rs). However, as has been noted prominently in the literature, this redirects the focus onto energy consumption (i.e. on the energy component embedded in resource use). The 3R strategies are fairly well known; their viability depends on the cost of energy used for recycling or reuse relative to the cost of new extraction.

Some renewable resources, such as solar and wind, are drawn on without concern that these resources will run out. Other resources are renewable as long as the encompassing ecosystems are not degraded. For renewable biomass resources such as forests, the primary challenge is ensuring that their use does not exceed the rate of natural (or enhanced) regeneration. This, too, boils down to the rate with which these resources can regenerate themselves by harnessing the energy of the sun. Various techniques of increasing natural resource productivity are equivalent to enhancing their energy-harnessing potential.

In short, as noted by Hennicke (2014, p. 2), energy is the key to decoupling. Not surprisingly, environmental analysis has often used the concept of energy flows to frame these issues. Energy, construed broadly, is the motive force in both human and natural affairs. The miraculous transformation introduced by the Industrial Revolution is in essence the result of harnessing an enormous volume of readily available energy resources, namely fossil fuels (Smil 2010; Bithas and Kalimeris 2016). This is a major factor responsible for the idea of a permanently growing economy.

As we look to the future, the need for energy will continue to increase, not only to promote economic development in poor countries, but also to help reduce the unsustainable consumption of material resources. To avoid catastrophic climate change and a scarcity of resources, a major shift is needed by this increase, towards affordable and sustainable energy resources (see e.g., Yihdego, Salem and Pudza 2017; UNDP 2018, SDG 7).

2.6 Technology, innovation, and global sustainability

Technology can be a positive and a negative driver of environmental change. Technological innovation has been – and is likely to continue being – a critical driver of sustainability changes at a global level (Segars 2018). At the same time, technologies have often created unintended consequences that are far beyond the predictive ability of our best scientific analysis (e.g. the impact of effects of fossil fuel consumption on the climate system). Existing scientific analyses of technology issues often fail to capture the important negative/rebound effects (Chitnis *et al*. 2013) of the systematic impact of technologies as well as underplay the problem of technology diffusion, particularly in terms of agricultural technological innovation (Juma 2015). Motor vehicles and electricity are good examples of past scientific limitations. They represent two of the most important technological breakthroughs of the 20th century, but their negative environmental and resource impacts are likely to persist well through the 21st century.

2.6.1 Technological innovation and sustainable economic development

From an economic perspective, technological innovation has long been recognized as one of the core drivers of economic development, but in modern theories of growth it is given a pre-eminent role (see Romer 1994; Acemoglu and Daron 2009; Zenghelis 2011). Innovation in human capital, through investment in research and development and knowledge-sharing, is the key not only to productivity growth, but also to getting more out of the resources we have. This is crucial to solving many environmental problems.

Innovation offers the most important route out of many environmental problems. In an environmentally sustainable economy, economic growth and development would still occur, and humanity would continue to prosper. Economic growth and human well-being can be decoupled from material throughput and environmental impact, though the policy challenge of actually achieving this is considerable (Jacobs 1991; Hepburn and Bowen 2013).

Recognition of new opportunities, together with the falling cost of key low-carbon technologies (solar, wind, etc.), has proved game-changing in terms of driving global policy action. While the United Nations Framework Convention on Climate Change (UNFCCC) negotiations are often seen as moving slowly, 40 countries and 20 subnational regions have implemented or are planning to implement carbon pricing and other types of low-carbon technology-enabling policies (Global Commission on the Economy and Climate 2015). There are now over 1,200 climate change or climate change-relevant laws worldwide, which is a 20-fold increase over the past 20 years (Nachmany *et al*. 2017).

The Paris Agreement on climate change (United Nations Framework Convention on Climate Change [UNFCCC] 2015) itself can be seen as a consequence of accelerating momentum in countries, cities and businesses across the world to reduce GHGs. Falling technology costs of renewables and energy efficiency, growing market opportunities, changing behaviours, and a growing awareness of the co-benefits of lower emissions (such as less urban pollution and congestion, and fiscal opportunities from pricing scarce resources, carbon and pollution and from removing environmentally damaging subsidies) all helped to support the voluntary commitments signed into action after the Paris Agreement.

2.6.2 Cleaner and energy-efficient technologies

Rapid advances are occurring in the market development of cleaner and energy-efficient technologies, including renewables (solar, wind, advanced biomass, etc.), storage (batteries, pumped hydro, etc.), energy efficiency (e.g. demand-side management and dematerialization), decarbonized transport options (e.g. electric vehicles). Research and development advances are also emerging for cleaner technology options (e.g. carbon, capture and storage, second- and third-generation biofuels, decentralized electricity generation at small/micro scales, self-driving vehicles) (International Energy Agency [IEA] 2016b).

In the case of renewable energy, for instance, diffusion and scale-up become both feasible and affordable worldwide. By the year 2040, renewables will constitute two-thirds of the global investment in power generation, while solar energy will become the largest source of global low-carbon capacity, fuelled by growth in China and India. In the case of the European Union, renewables are expected to account for 80 per cent of new power-generating capacity, with wind energy becoming the leading source of regional electricity after 2030 (IEA 2017b).

Regionally, in the case of sub-Saharan Africa, where there are a number of public, private and cross-sector initiatives to address energy poverty, a rapidly developing cleaner and energy-efficient technology ecosystem is incubating early-stage off-grid solar technology companies, as well as helping to accelerate the overall market dynamics of sub-Saharan African countries (Park 2016; Yihdego, Salem, and Pudza 2017).

For instance, investments in off-grid solar companies in sub-Saharan Africa and other countries went up tenfold, to more than US$200 million between 2013 and 2016 (Bloomberg New Energy Finance 2017), although it should be stressed that this rapid growth still represents a small percentage of the investments that will be needed to make an impact on the regional energy marketplace.

Scalable solar-powered off-grid electrification solutions are important for sustainable development in many developing regions and represent a critical element in the case of the sub-Saharan Africa region (International Renewable Energy Agency [IRENA] 2013). Access to energy represents a critical economic, social and environmental issue in both industrialized and developing countries because energy access is linked to a wide range of economic and environmental benefits (IRENA 2016). Yet sub-Saharan Africa as a region consumes just 145 terawatt-hours of electricity a year – or one incandescent light bulb per person used three hours a day (Lucas 2015) – making it the most energy-poor region in the world (Park 2016).

There is substantial potential for the unit costs of resource-efficient and low-carbon technologies to continue to fall as these new technologies are developed and deployed, and as engineers learn how to connect and service them cheaply. This potential is far higher for new technologies than it is for long-established, high-carbon incumbents.[6] For example, price drops in renewable energy technologies have allowed new combinations of solar, wind, and energy storage to outcompete coal and gas on cost.[7]

Not only does the energy sector benefit from productivity improvements associated with a transition to low-carbon, there are also important economic spillovers from low-carbon innovations. Acemoglu *et al*. (2012) argue that sustainable growth can be achieved by adopting temporary policy levers such as a carbon tax that can redirect innovation towards clean inputs, while Dechezleprêtre, Martin and Mohnen (2014) conclude that economic spillovers from low-carbon innovation are consistently 40 per cent greater compared with conventional technologies, while information and communication technologies (ICTs) can, in theory, vastly increase productivity and energy efficiency, while reducing material consumption throughout the lifespan of a product (a mobile phone for instance). While ICTs may one day usher in a new era in which digital technologies play a key role in accelerating global environmental governance, it is not yet clear if the energy and materials savings are greater and outweigh the cumulative sustainability impact of the ICT product lifespan from resource extraction to waste disposal **(see Box 2.3 on** electronic waste).

Beyond the direct social and environmental impacts of ICTs, one emerging sustainability issue is the electricity use of data centres, which in the case of the United States is estimated to be around 2 percent of the country's total electricity consumption (Whitney and Kennedy 2012). With energy efficiency of computers reportedly doubling every 1.5 years (Koomey *et al*. 2011), the more important long-term sustainability question may be the use and application of ICTs in avoiding future energy use and lowering climate change impact.

Box 2.3: Electronic waste

Electronic waste (e-waste) – which can be defined as "items of electrical and electronic equipment and their parts that have been discarded by the owner as waste without the intention of re-use" – represents one of the fastest-growing waste streams in the world (Solving the E-waste Problem (StEP) Initiative 2014).

Fuelled by rapid global sales of computers and electronics, combined with shortening product life cycles, 44.7 million metric tons – the equivalent of 6.1 kg per inhabitant of e-waste were generated in 2016, while the overall e-waste stream is expected to increase to 52.2 million metric tons or 6.8 kg per inhabitant by 2021 (Baldé et al. 2017).

Some e-waste from industrialized countries is being shipped to the developing world, "where crude and inefficient techniques are often used to extract materials and components", a trend which is posing challenges to global sustainability governance (Baldé, Wang and Kuehr 2016).

Digital technologies such as smart meters are projected to link more than 1 billion households and 11 billion smart appliances in interconnected electricity systems by 2040. The use of digital technology innovations will enable individual homes to determine when and how much they draw electricity from the grid. They will also enable the design of environmentally friendly demand-side responses in the building, industry and transport sectors, resulting in US$270 billion of avoided new investments in new electricity infrastructure (IEA 2017a). Governments of cities ranging from Copenhagen to Addis Ababa are also investing in ICT-based smart technologies (e.g. open data stores, citizen engagement platforms) to help improve urban governance at lower financial and environmental cost (C40 Cities Climate Leadership Group 2015).

2.6.3 Food-agricultural technology

A number of global food-agricultural trends – population growth and increasing global affluence, among others – will require increased agricultural productivity (by as much as 60-120 per cent on 2005 levels), in direct conflict with the wider SDGs (Ort *et al*. 2015).

Moreover, there is a wide range of perspectives in terms of what the yield gap is likely to be - the difference between how much a crop could yield per hectare with enough water and nutrients, and how much is currently being harvested (White 2015) - and over what technology options are available to address it. Total agricultural production is projected to increase by 60 per cent by 2050 compared with 2005 (Alexandratos and Bruinsma 2012), due to an increase in global population and in the number of people from the developing world who can afford to eat more and better food. The emerging question confronting the international community is likely to be: will the global food supply be adequate to meet global food demand,

6 The so-called sailing ship effect (whereby the introduction of steam ships induced a leap forward in efficiency and design of sailing ships) suggests that incumbent industries can respond with competitive innovation when faced with existential competition.

7 Solar photovoltaic and onshore wind technologies are competitive with gas and coal in a number of global locations, even without a carbon price. The cost of solar photovoltaic modules fell by 60 per cent in the two years to the first half of 2017, and by a factor of five in the five years post-2008 (Bloomberg NEF 2017). Energy storage prices are falling even faster than solar photovoltaic and wind prices. A recent study found that research and development investments for energy storage projects have lowered lithium ion battery costs from US$10,000/kWh in the early 1990s to a trajectory set to reach US$100/kWh on or by 2018 (Kittner, Lill, and Kammen 2017).

and can this demand be met without adversely impacting land use, biodiversity, freshwater use and other natural resources? If not, can this demand be met, or reshaped, using alternative technologies beyond agriculture as we know it today?

Bijl *et al*. (2017) suggest that a sustainable balance between reducing global hunger and staying within, among others, the planetary boundaries of land and water use might be struck by changing dietary patterns and more effectively addressing food waste as a policy priority. In the case of agricultural water use, a Pacific Institute study (2014) concluded that the adoption of existing water technologies and management techniques could reduce agricultural water use in the state of California by 5.6 million to 6.6 million acre-feet (one acre-foot is 1,233.48 cubic metres) per year, or by between 17 and 22 per cent, while maintaining the same level of agricultural productivity.

The International Food Policy Research Institute (IFPRI) (2014) argues that certain agricultural technologies and practices (e.g. crop protection, drip irrigation, drought tolerance, heat tolerance, integrated soil fertility management, no-till farming, nutrient use efficiency, organic agriculture, precision agriculture **[see Box 2.4]**, sprinkler irrigation, water harvesting, and land conservation measures) might be scaled up to achieve the dual goal of increasing food production and reducing food insecurity in the developing world. No-till farming alone can increase maize yields by 20 per cent, while heat-tolerant varieties of wheat can lead to a 17 per cent rise in crop yields (IFPRI 2014).

With the livestock sector accounting for about half of food-system GHG emissions (Food and Agricultural Organization of the United Nations [FAO] 2017; Gerber *et al*. 2013), emerging food-agricultural technologies may have the potential to reshape demand for animal produce and increase the sustainability of the food system. Reducing overall meat consumption as well as providing alternatives to conventional livestock production systems (e.g. through the introduction of plant-based meat alternatives) would, for instance, substantially reduce the agricultural land use footprint from food production (Alexander *et al*. 2017). In another example, although there are uncertainties in terms of an increased energy-use rebound effect[8], production of cultured or *in vitro* meat requires smaller quantities of agricultural inputs and land compared with raising livestock (Mattick *et al*. 2015).

Other emerging technological advances are demonstrating the potential to decouple crop production from the vulnerability of land use and climate (Gilmont *et al*. 2018). Hydroponics employ nutrient-rich water rather than soils to grow crops, and aeroponics use nutrient-dense sprays to nourish plants suspended in the air. Both techniques permit precise application of nutrients to crops grown under controlled conditions, including in land-sparing indoor vertical farms that can be located in urban and degraded environments (Eigenbrod and Gruda 2015).

As the cost of decentralized renewable energy sources falls, the constraints to the broader deployment of these technologies, including broadening them to grow staple crops, will continue to decline as the environmental benefits increase (Kalantari *et al*. 2017). To truly accelerate innovative food and agricultural technologies on the global level, particularly in the developing world, it will also be critically important to have complementary sustainable policy initiatives, such as the FAO Global Agenda for Sustainable Livestock Initiative, to diffuse both technology-based and non-technology-based sustainable food and agricultural innovations.

Box 2.4: Precision agricultural technologies

The world's population is expected to reach 9 billion by 2050, while climate change and income growth will drive food demand in the coming decades. Baseline scenarios show food prices for maize, rice and wheat would significantly increase between 2005 and 2050, and the number of people at risk of hunger in the developing world would grow from 881 million in 2005 to more than a billion people by 2050 (IFPRI 2014).

While no single technology can be offered as a solution to these global agricultural and food challenges, precision agriculture (GPS-assisted, machine-to-machine solutions that combine information collected by sensors with automated management) represents one of 11 agricultural innovations, which, in aggregate, might help by 2050 to improve global crop yields by up to 67 per cent while reducing food prices by nearly half (IFPRI 2014).

2.6.4 Technology diffusion and global sustainability

While there is strong scientific consensus on the importance of technological innovation as a driver of global sustainability change, there is far less scientific consensus in terms of two issues: first, sustainable technology diffusion – particularly in terms of the adoption and deployment of what might be described as sustainable technologies – in the developing world, and, second, how to regulate and govern new and emerging technologies in terms of global sustainability (Juma 2015). For technological diffusion, in terms of the rates of both adoption and acceleration, a good place to start might be the market development of solar, wind and other renewable energy technologies in the developing world, particularly relating to cities and urbanization (IEA 2016a).

Although renewable energy sources accounted for 70 per cent of the net increase in the global power capacity in 2017 due to the rising economic competitiveness of solar and wind energy (REN21 2018), rising energy demand, particularly in the developing world, coupled with population growth, is likely to outpace the development of economically viable and scalable renewable-based solutions without additional technology breakthroughs in the energy sector (IRENA 2017).

To provide the necessary institutional and socioeconomic conditions for technological diffusion, there is a critical need to design the appropriate innovation scale-up conditions (Rogers 2003) and to implement new public and private measures to more effectively deal with incoherent policies, misalignments in electricity markets and cumbersome and risky investment conditions (Ang, Röttgers and Burli 2017) in both industrialized and developing countries.

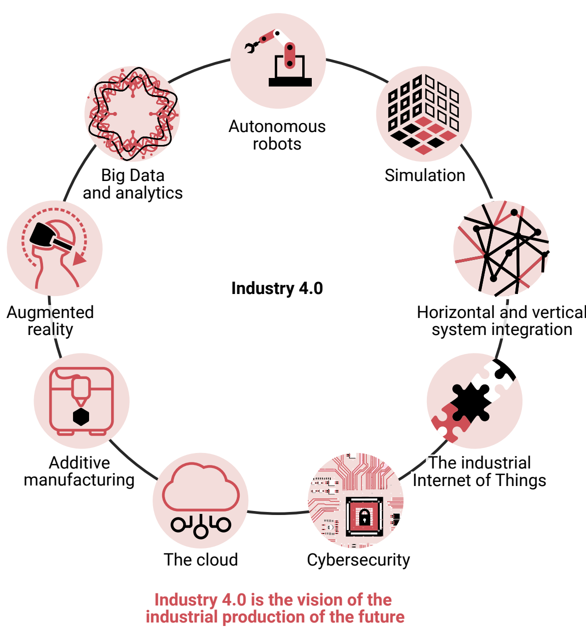
8 The energy use rebound effect refers to the observation that people may begin to consume more energy as a result of increases in energy efficiency.

In terms of technology diffusion and sustainability pathways in OECD member countries, the emerging 'industry 4.0' model is likely to have a major impact on the nexus of technology diffusion, market development and sustainability. Industry 4.0 – which can best be described as a digital industry technology platform powered by sensors, machines and information technology systems **(see Figure 2.15)** – is regarded by many scientists, technology experts and business executives as the fourth wave of technological advancement (Rüßmann *et al*. 2015).

While the industry 4.0 model, particularly as a technological platform, has the short-term potential to produce more efficient processes and higher-quality goods at reduced costs, the long-term social, environmental and economic impacts, particularly in terms of employment and workforce development, remain, at best, unclear. The emerging industry 4.0 model, along with artificial intelligence, additive manufacturing, the Internet of things, and other disruptive technologies, reflects a deep uncertainty that lies at the technology-sustainability nexus: how can the international community properly weigh the sustainability risks and benefits, particularly with regard to short- and long-term impacts on employment and economic development?

Despite the growing visibility of the social, environmental and economic impacts of global climate change and environmental dilemmas, slow progress on a wide range of international environmental (e.g. climate change) and social (e.g. refugees) policy negotiations has limited the scope for so-called good public policy options and tilted the governance framework towards riskier forms of technology like climate geoengineering as a policy alternative. Whether a particular emerging technology should be adopted or actively promoted by public organizations or private companies is not the critical issue. Rather, it is how and to what degree the international community can make sure that proper oversight, monitoring and protection against the potential adverse effects are in place as we proceed with the complex task of identifying, developing and diffusing technologies that positively impact wealthier OECD as well as lesser developed countries.

Figure 2.15: Industry 4.0: technological transformation of future industrial production



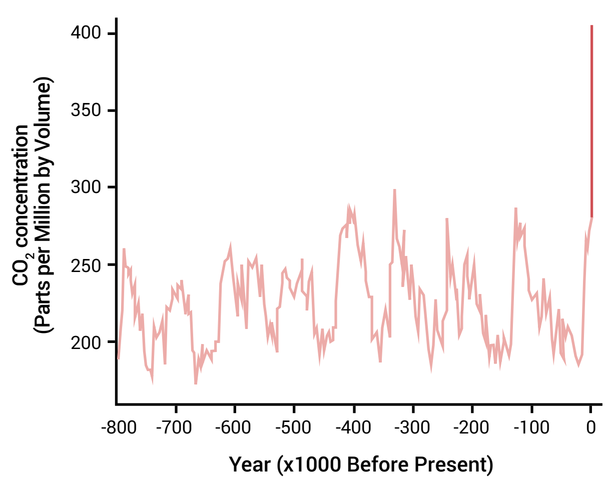
Source: Rüßmann *et al*. (2015)

2.7 Climate change

GEO-6 includes anthropogenic climate change as a driver of environmental change because it has acquired a momentum independent of future human activity; it is also analysed as a cross-cutting issue in Section 4.3.1 of this report. **Figure 2.16** demonstrates the increase in CO_2 concentration over the industrial period, charted on the same scale as the data for the transitions in CO_2 concentration between the glacial and interglacial periods over the past 20,000 years. Other GHGs such as methane and nitrous oxide have also been increasing consistently over the decades, as indicated by the National Oceanic and Atmospheric Administration's greenhouse gas index and shown by Hartmann *et al*. (2013). The impact of such changes demonstrates that climate change is now a major driver of environmental change – an inexorable force that can no longer be ignored.

According to the Fifth Assessment Report of the IPCC (2014), the world has entered an era of committed climate change. The concept of climate commitment, first introduced by Ramanathan (1988), refers to changes that are already in the pipeline, regardless of any further emissions or any future change in GHG concentrations in the atmosphere. "A large fraction of anthropogenic climate change resulting from CO_2 emissions is irreversible on a multi-century to millennial time scale, except in the case of a large net removal of CO_2 from the atmosphere over a sustained period" (IPCC 2013, p. 28).

Figure 2.16: Mean atmospheric CO_2 concentration



Source: Based on (in blue) NOAA data from http://www.ncdc.noaa.gov/paleo/metadata/noaa-icecore-6091.html and (in red) data provided by Pieter Tans, NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/ and scrippsco2.ucsd.edu/) [])

Surface temperatures will remain roughly constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO_2 emissions. According to Mauritsen and Pincus (2017), "due to the lifetime of CO_2, the thermal inertia of the oceans [Wigley 2005] and the temporary impacts of short-lived aerosols [Hare and Meinshausen 2006] and reactive greenhouse gases, the earth's climate is not equilibrated with anthropogenic forcing. As a result, even if fossil-fuel emissions were to suddenly cease, some level of committed warming is expected, due to past emissions, as studied previously using climate models [Solomon *et al*. 2009; Gillett *et al*. 2011; Frölicher *et al*. 2014]."

Therefore, the current global temperature is controlled largely by past CO_2 emitted over past decades, a consequence of the inertia in the climate and carbon cycle. The climate is committed at the current concentration of GHGs. This means that climate change has now become an independent driver of environmental change. Regardless of human action, or even human presence on the planet, impacts will continue to occur through temperature change, fluctuations of precipitation, snow melt, sea level rise, drought and other climate variables, and through changes in the hydrological cycle (Salem 2011). Climate change thus poses a challenge to growth and development.

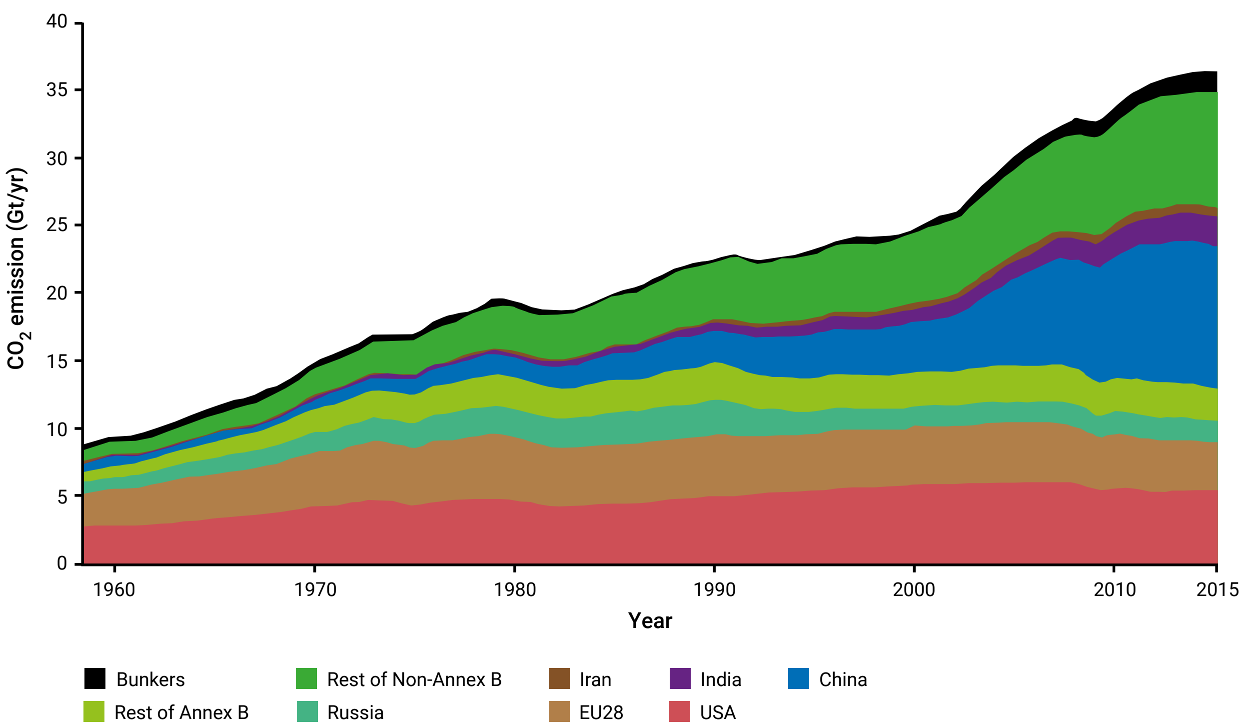
2.7.1 Greenhouse gas emissions and concentration

The emission trends in selected countries are illustrated in **Figure 2.17** and **Figure 2.18**. More than half of total cumulative emissions since the Industrial Revolution were emitted in the past four decades. Cumulative CO_2 emissions for the period 1750-1970 (220 years) are estimated at 910 gigatons[9], while those for the period 1970-2010 (just 40 years) are about 1,090 gigatons (IPCC 2014). This growth is despite the presence of a wide array of multilateral institutions as well as national policies aimed at mitigation. The 2007/2008 global economic crisis only temporarily reduced the GHG emissions growth rate, compared with the trend since 2000 (Peters *et al*. 2011).

There is an unequal distribution of GHG emissions, both in terms of individual emissions coming from varied lifestyle consumption patterns and in terms of country emissions. The richest 10 per cent of the population emits 50 per cent of total GHG emissions, while the poorest 50 per cent emit only 10 per cent (King 2015). At the same time, when the carbon budget for limiting global warming below 2°C is considered, a generational inequality arises, with future generations having a lower allowance to emit. If the current Nationally Determined Contributions (NDCs) are fully implemented, the carbon budget for limiting global warming below 2°C will be 80 per cent depleted by 2030 (UNEP 2017).

Atmospheric concentrations of GHGs have increased from around 277 parts per million (ppm) in 1750 to 403.3 ppm in 2016 (World Meteorological Organization 2016). Regional contributions to this global GHG concentration are detailed in the GEO-6 Regional Assessments (UNEP 2016). The growth in atmospheric CO_2 was 6.0 ± 0.2 gigatons in 2016 (2.85 ± 0.09 ppm), well above the 2007-2016 average of 4.7 ± 0.1 gigatons a year (Le Quéré *et al*. 2017).

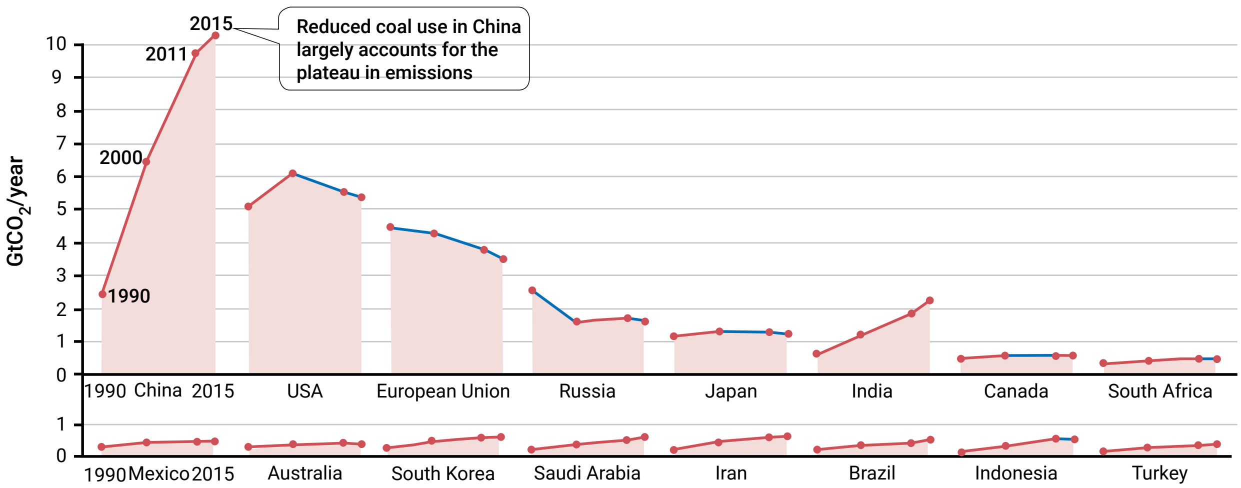
Figure 2.17: Global growth in emissions of GHGs by economic region



Source: Le Quéré *et al.* (2016)

9 Throughout this publication the term 'ton' refers to a metric ton or 1000 kilograms

Figure 2.18: Emission trends in different countries from 1990-2015. Orange lines highlight growth while blue ones show reductions



Source: Le Quéré *et al.* (2016)

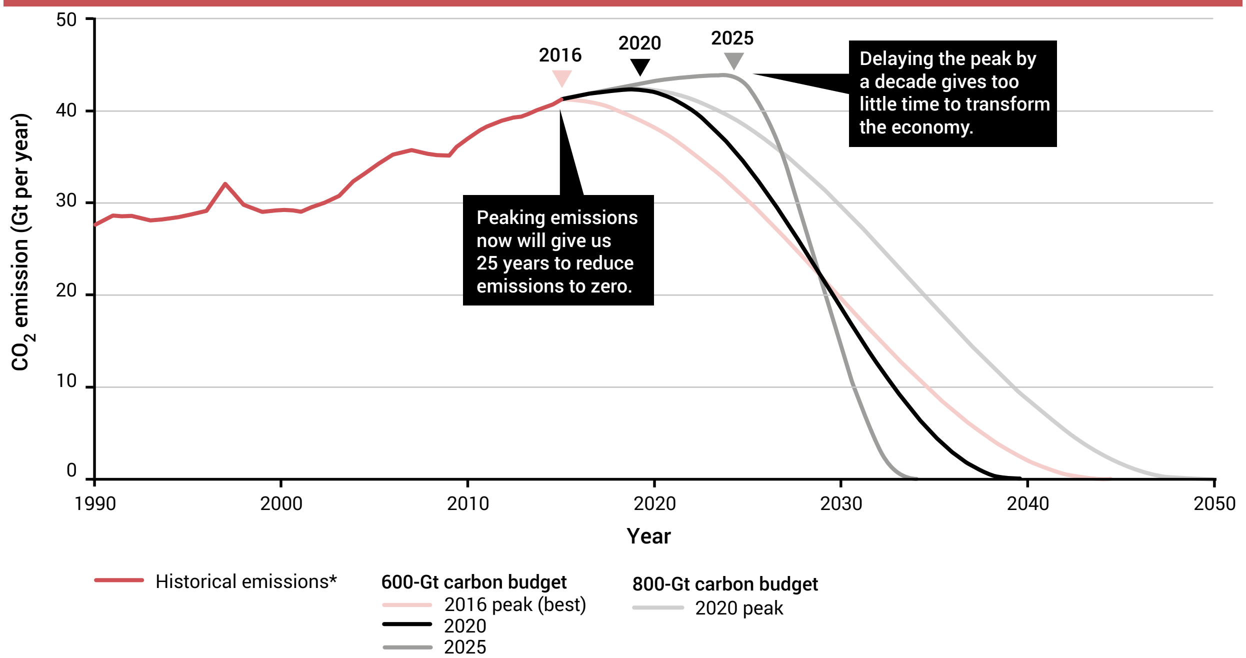
2.7.2 The emissions budget

Cumulative total emissions of CO_2 and the response of the global mean surface temperature are approximately linearly related. Any given level of warming is associated with a range of cumulative CO_2 emissions. Therefore, a given temperature target (e.g. 2°C) will translate into a long-term emissions budget. Using this information, in the synthesis report of the Fifth Assessment, the IPCC (2014) estimated how much CO_2 we could emit and yet keep the global average temperature rise over pre-industrial levels to no more than 1.5°C, 2°C or even 3°C, which could be catastrophic.

The Paris Agreement's central aim is to strengthen a global response to the threat of climate change by keeping a global temperature rise this century well below 2°C above pre-industrial levels, and to pursue efforts to limit the temperature increase even further, to 1.5°C (UNFCCC 2015). To accomplish this, countries have submitted NDCs outlining their post-2020 climate action, which will undergo a global stocktake every five years to assess the collective progress and to inform further individual actions by parties (UNFCCC 2015).

In order to achieve the Paris temperature target, the carbon budget that remains after deducting past emissions is between 150 and 1,050 gigatons CO_2. At the current annual emission rates, the lower limit of this range will be crossed in four years and the midpoint (600 gigatons CO_2) in 15 years **(Figure 2.19)**. The emissions would have to drop to zero almost immediately after the budget is exhausted (Figueres *et al.* 2017).

Figure 2.19: The carbon crunch



Source: Figueres *et al.* (2017, p. 595)

If the emission pledges in the Paris Agreement are fulfilled, the worst effects of climate change can be avoided, and studies suggest this could avoid a temperature increase of 3°C by 2100 (Le Quéré *et al*. 2016). The implications of the 2017 withdrawal of the United States, the second-largest emitter, from the Paris Agreement are mixed, because the withdrawal does not preclude individual American states' policies to support environmentally friendly innovation. It is still possible to meet the Paris temperature goals if global emissions begin to fall by 2020 (Figueres *et al*. 2017).

Under current and planned policies, the world would exhaust its energy-related carbon budget (CO_2) in under 20 years to keep the global temperature rise to well below 2°C. To meet the below 2°C goal, immediate action is crucial to reduce further cumulative emissions by 470 gigatons by 2050, compared with current and planned policy targets (IRENA, 2018)

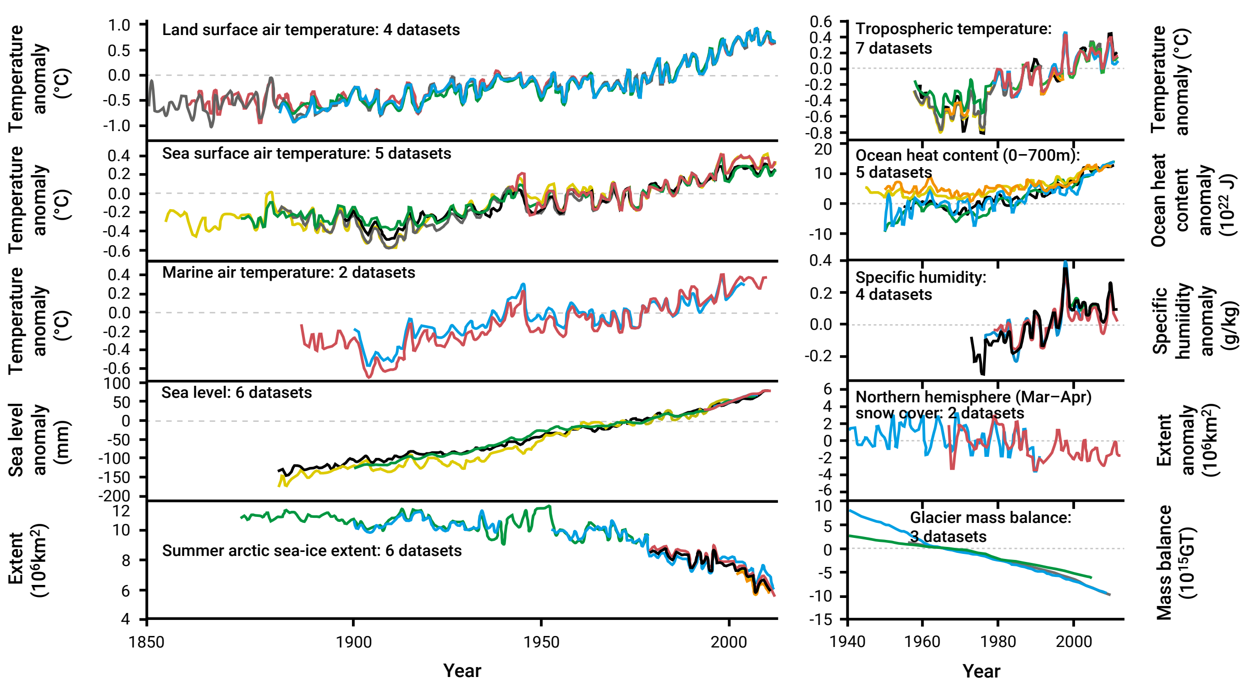
2.7.3 Impacts of Climate Change

Climate change will amplify existing risks and create new risks for natural and human systems (IPCC 2014). The risks are not only unevenly distributed but are generally greater for disadvantaged people and communities. This is so in countries at all levels of development. The risk of climate-related impacts is a result of complex interactions between climate-related hazards and the vulnerability, exposure and adaptive capacity of human and natural systems. The rise in the rates and magnitudes of warming and other changes in the climate system, accompanied by ocean acidification, increase the risk of severe, pervasive and in some cases irreversible detrimental impacts. Already, the annual global mean surface temperature has increased at an average rate of 0.07°C per decade since 1880 and at an average rate of 0.17°C per decade since 1970 (National Oceanic and Atmospheric Administration [NOAA] 2015). The trends in sea surface temperature, marine air temperature, sea level, tropospheric temperature, ocean heat content and specific humidity are similar (IPCC 2014) **(Figure 2.20)**.

Beyond temperature increase, the impacts already observed include changes in the water cycle, warming of the oceans, shrinking of the Arctic ice cover, increase in the global mean sea level, and altering of the carbon and biogeochemical cycles (see more detail in Chapters 4 and 5). Further, there have been increases in the frequency and intensity of wildfires that in turn release GHGs. Observations and climate model simulations indicate polar warming amplification resulting from various feedbacks in the climate system – the positive ice-albedo feedback being the strongest (Taylor *et al*. 2013). The reduced extent of ice cover reveals a darker surface, which leads to a decreased albedo, in turn resulting in a stronger absorption of solar radiation and a further acceleration of warming. In response to the increased warming in the Arctic, sea-ice extent is strongly decreasing, especially in summer (Vaughan *et al*. 2013). However, recent literature has concluded that temperature feedbacks play a dominant role, making surface albedo feedback the second main contributor to Arctic amplification (Pithan and Mauritsen 2014).

The global water cycle has been affected, impacting on global-scale precipitation patterns over land, and on surface and subsurface ocean salinity, contributing to global-scale changes in frequency and intensity of daily temperature extremes since the mid-20th century. The global mean sea level rose by 0.19 metres (range, 0.17-0.21 metres) over the period 1901-2010, calculated using the mean rate over these 110 years, and based on tide gauge records plus, since 1993, satellite data (IPCC 2014).

Figure 2.20: Multiple independent indicators of a changing global climate



Source: IPCC (2014)

Changes in the climate system have had large-scale impacts on various ecosystems, as documented across the thematic chapters that follow in Part A. As a driver of environmental change, climate change is exacerbating current pressures on land, water, biodiversity and ecosystems. If atmospheric CO_2 concentration increases from the current levels of 406 ppm to 450-600 ppm, leading to greater than 2°C warming over the coming century, it will lead to several irreversible impacts, including sea level rise (Smith *et al*. 2011). O'Neill *et al.* (2017) have elaborated individual risks as well as overarching key risks, including risks to biodiversity, health, agriculture and so on, as well as risks of extreme events such as extreme precipitation and heat waves and risks to specific ecosystems such as mountain and Arctic, to name but a few **(see Figure 2.21)**.

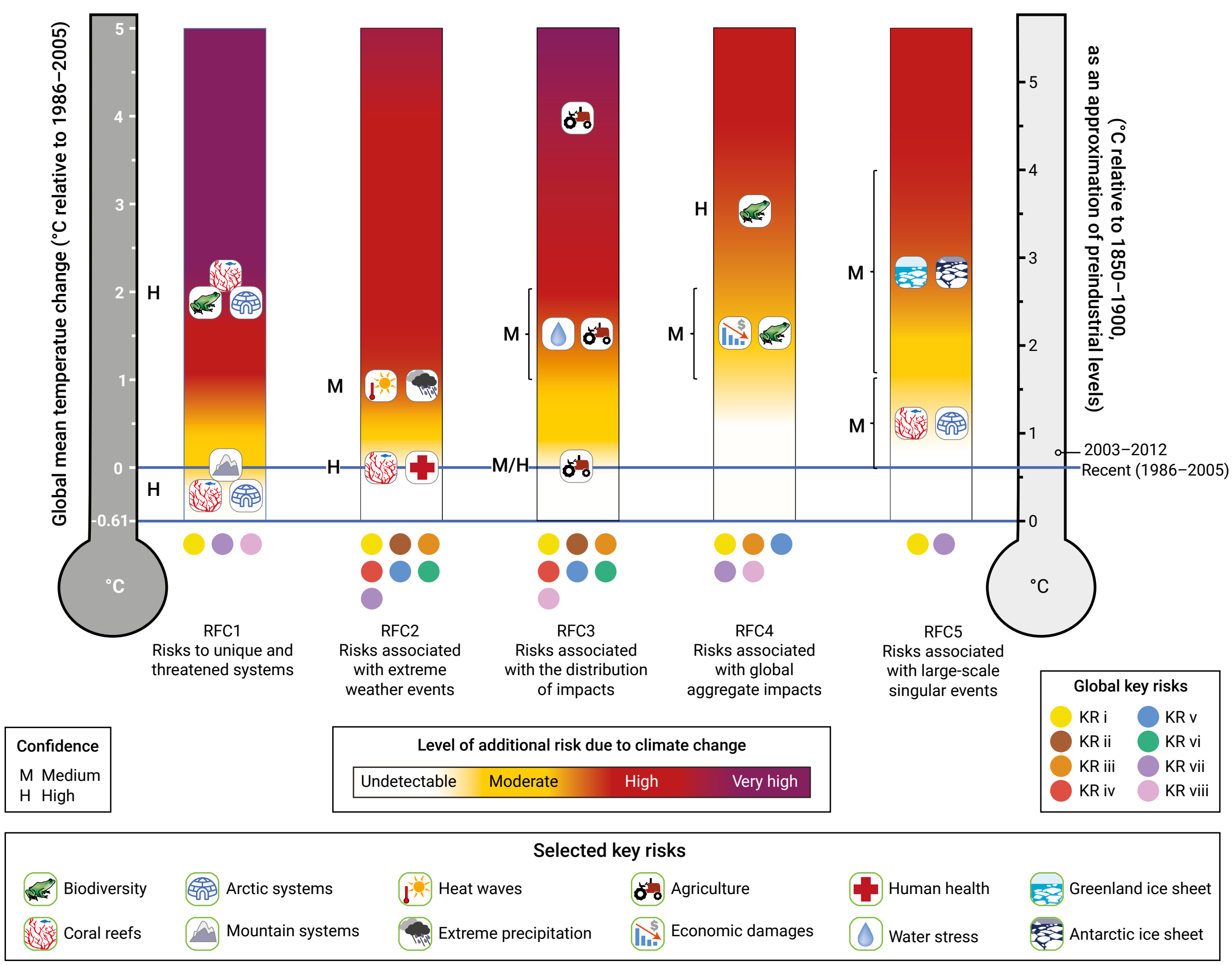
Future climate will thus depend on the combination of committed warming caused by past anthropogenic emissions, the impact of future anthropogenic emissions, natural climate variability and climate sensitivity. There are regions (particularly at northern, mid- and high latitudes) already experiencing greater warming than the global average, with mean temperature rise exceeding 1.5°C in these regions.

These impacts have implications for the quality and quantity of ecosystem services, as well as for patterns of resource use, their distribution and access across regions and within countries.

Time is running out to prevent the irreversible and dangerous impacts of climate change. Unless GHG emissions are reduced radically, the world remains on a course to exceed the agreed temperature threshold of 2°C above pre-industrial levels, which would increase the risk of pervasive effects of climate change, beyond what is already seen. These effects include extreme events (including flooding, hurricanes and cyclones) leading to loss of lives and livelihoods, pervasive droughts leading to loss of agricultural productivity and food insecurity, severe heat waves, changes in disease vectors resulting in increases in morbidity and mortality, slowdowns in economic growth, and increased potentials for violent conflict (Salem 2011; SIDA 2018). The extent, distribution and acute nature of the impacts is different between countries, and several islands have faced multiple impacts in one season – Haiti in 2004, for example – or annually in multiple years, such as Dominica experiencing hurricanes Erika in 2015 and Maria in 2017. These impacts can undermine food security mechanisms and systems, as well as social and economic progress in health and other areas.

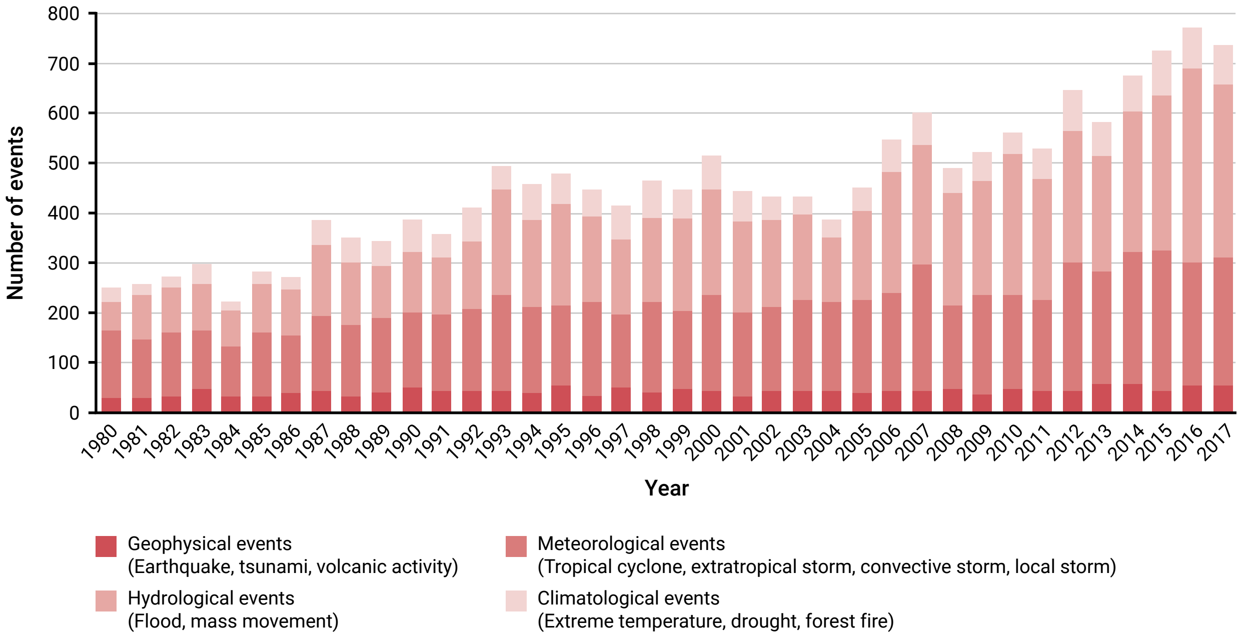
2

Figure 2.21: The enhanced burning embers diagram, providing a global perspective on climate-related risks



Source: O'Neill *et al.* (2017, p. 30)

Figure 2.22: Trends in numbers of loss-relevant natural events



Source: Munich Re (2017)

One indication of the potential impacts is the doubling of the frequency of climate-related loss events **(Figure 2.22)** since 1980 (Hoeppe 2016). These events are already estimated to have resulted in the loss of 400,000 lives and the imposition of a cost of US$1.2 trillion annually on the global economy, wiping 1.6 per cent from global GDP.

These risks are greatest – currently as well as in the future – for people who are dependent on natural-resource sectors. Such people include coastal communities, people in agricultural and forest communities, and those experiencing multiple forms of inequality, marginalization and poverty, thereby amplifying existing risks and create new ones for natural and human systems. The scale of potential damage from climate change poses a major systemic risk to our future well-being and the ecosystems on which we depend, in particular for societies in less-developed, less-resilient countries (OECD 2017).

2.7.4 Implications

The Paris Agreement recognizes that limiting warming by the end of the century could help prevent more problems. It explicitly states the need for achieving a balance of emissions and removals in the second half of the century. The 2°C target is important to achieve, to reduce the likelihood of more intense storms, longer droughts, rising sea levels and other natural disasters that are being increasingly reported (Munich Re 2016). To keep a good chance of staying below 2°C, and at manageable costs, emissions should drop by 40-70 per cent globally between 2010 and 2050, falling to zero by 2100 (IPCC 2014; Kroeze and Pulles 2015). The current trajectory of global annual and cumulative emissions of GHGs is inconsistent with the widely discussed goals of limiting global warming to 1.5-2.0°C above pre-industrial levels. Should emissions continue to rise beyond 2020, or even remain level, the temperature goals set in Paris become almost unattainable. Delayed action or weak near-term policies increase the mitigation challenges in the long-term. There are risks associated with exceeding 1.5°C global warming by the end of the century (increases in the severity of projected impacts and in the adaptation needs), making the achievement of many SDGs much more difficult. The overall costs and risks of climate change include a prediction that some regions could see growth decline by as much as 6 per cent of GDP by 2050, according to a recent report from the World Bank Group (2016) on climate change, water and the economy. If the worst of the climate change-related risks are to be avoided, the pace and scale of the required economic transformation is unprecedented (OECD 2017).

2.8 Unravelling drivers and their interactions

The same driver of environmental change can exert both positive and negative forces on the environment, as described in the previous sections. Moreover, the five drivers highlighted in this chapter are mutually interdependent, and this interdependence can itself also be positive or negative. The cumulative effect the drivers can have on the environment has been extensively discussed in the literature (Wu *et al*. 2017).

Table 2.1 presents the interactions between the drivers covered in this chapter. These are first-order interactions (excluding interactions with other variables) at a global scale and under current conditions.

The aggregate effects of these interactions on climate change are negative. This is clear from the current trajectory of GHG emissions, which not only continue to increase, but at a rate that has accelerated in the last 15 years, compared with the 1980-2000 trajectory (Section 2.7). Thus, there is little

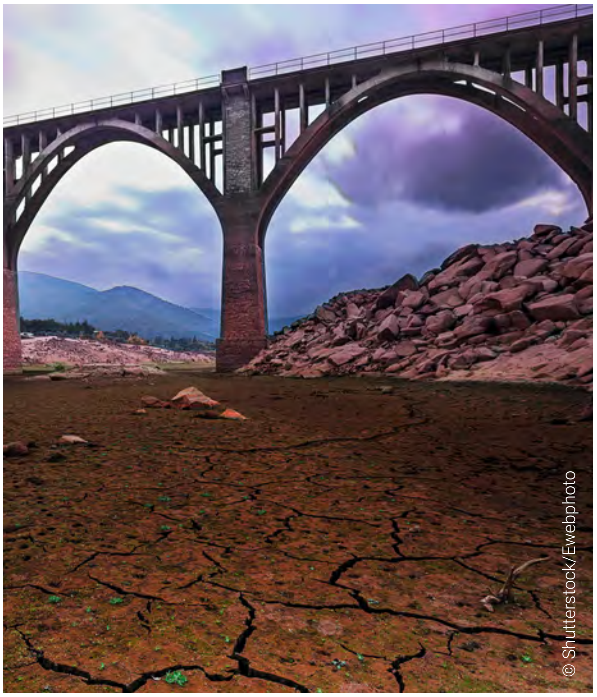
Table 2.1: Interrelationships between the drivers

	Population growth	Economic growth	Technological change	Climate change	Urbanization
Population growth	—	Negative impact due to delay in the demographic window of opportunity	Population growth fosters technological innovation, to accommodate the additional demands. Alternatively, it could lead to lower savings and investment due to high dependency rates	Population growth increases environmental pressure, and climate change	Increased pressure on urban areas, more people might move to urban areas
Economic growth	Higher GDP and development in general is associated with lower fertility rates	—	Economic growth is associated with increased investment and technological innovation	Increased economic output is associated with increased environmental pressure	Growth will push towards increased urbanization
Technological change	Technological innovation is associated with increased capacity to lower fertility rates	Innovation is associated with increased growth in GDP	—	Current trends show an increase in green technological innovation, thus lowering pressure per unit of output	Technological change can contribute to processes of urbanization or it can help to decrease the migration patterns through better access to technologies and communication
Climate change	Climate change increases mortality rates and negatively affects health	There are costs associated with climate change that limit economic growth	Climate change pressures foster adaptive technological innovation	—	Effects of climate change on rural communities puts pressure on migration towards urban areas
Urbanization	Urbanization is associated with lower fertility rates (due to access to better health care and education)	Urbanization is strongly associated with higher economic output	Urbanization will lead to intensification of technology use due to greater population density	There is no clear causal link, but there is an association between urbanization and higher emissions	—

doubt about the unsustainability of the current interaction and aggregated effects of population growth, economic development and technological innovation.

These aggregated effects are not the same for different regions. In developed countries (such as Canada, European Union countries, Japan and the United States of America), emissions have plateaued and in some cases diminished substantially. Moderate growth, stable populations, some change in consumption patterns, and technological innovations have allowed for a reduction in aggregate GHG emissions. At the same time, emerging economies that are moving from lower middle-income status to upper middle-income status have increased aggregate emissions (this is the case in most middle-income countries, including China and India).

On the other hand, both in per-capita terms and in aggregate, it is the richest and better off countries that contribute, by far, the most to emissions. This is true both for countries by income level (the developed world accounts for more than half of total emissions, with a far higher carbon footprint per capita) or for individuals by income level within countries (people in the world's richest quintiles, both from developed and developing countries, produce both higher carbon footprints per capita and greater aggregate emissions). Consumption patterns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2

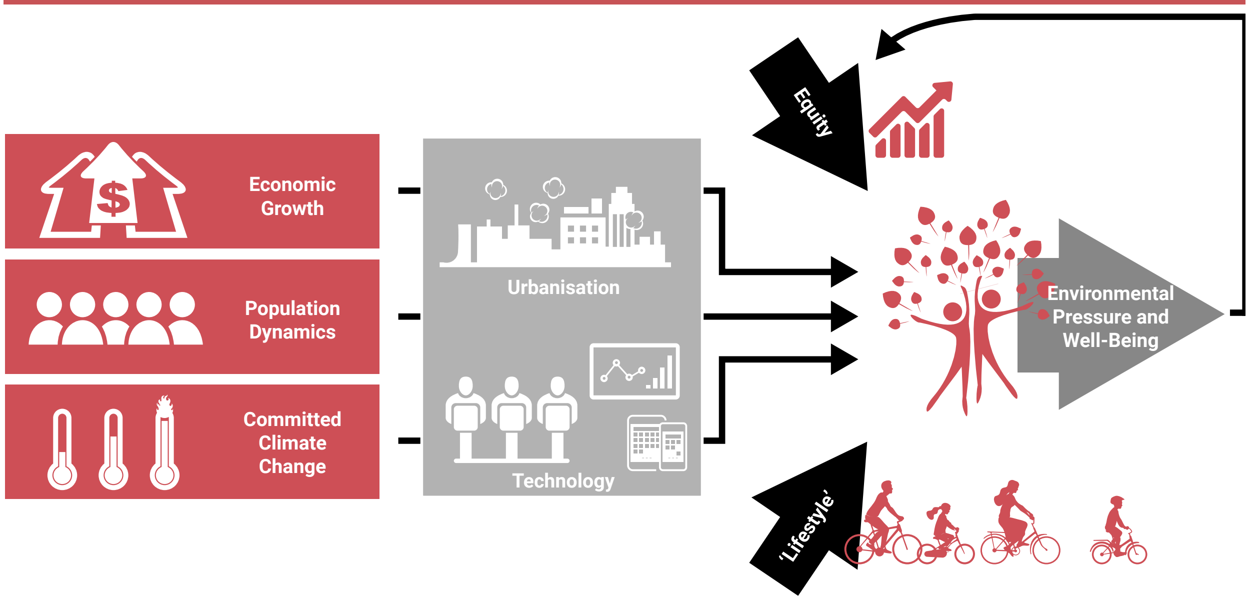
and production functions in the developed world, and the lifestyle and consumption options of the world's elites and better-off, therefore have to change drastically to adjust GHG emissions for a more sustainable path. The pathway to growth in emerging economies cannot reiterate the carbon expansion and GHG emissions witnessed in the last 20 years. Both technology and urbanization provide a window of opportunity – but no guarantee – for emerging economies to follow a developmental path that will prove more sustainable, from both consumption and production perspectives.

The diagram below **(Figure 2.23)** shows another way to look at the interactions between the drivers, by focusing on how each domain relates to the other, and how that can change. The diagram is used to evaluate the obstacles that different paths will confront. Three of the drivers considered – economic growth, population growth and climate change – stand at the left, while the right of the diagram presents the desired or preferred outcomes – lower environmental pressure, human well-being and equity. In the middle are the mediating factors of technological change and urbanization (potentially enabling mechanisms, but also potentially negative forces). Economic growth, population growth and climate change are to the left because they reflect the fundamental realities of human aspiration, demographic momentum and climate change commitment. What can change the impacts of these processes is the nature of the two other drivers in the middle – technology and urbanization.

Limiting the negative effects of the various drivers described – and indeed reframing them as the catalysts of an urgently needed transformative response – is necessary to achieve sustainable development and equity, including poverty eradication. At the same time, it is important to ensure that efforts to address one driver do not undermine actions overall to promote sustainable development.

The chapters in Parts B, C and D present a comprehensive assessment that looks at development pathways more broadly, along with their policy implications.

Figure 2.23: Relationship across the drivers



Box 2.5: IPAT identity

The IPAT identity makes a conceptual link between population, development, and technology, and different trajectories depend on the interactions between these determining factors. The IPAT identity has the following form:

I = P. A. T = P. (Y/P). (I/Y) = I, where (Eq. 1a)

- I = impact, i.e. use of natural resources or energy
- P = population
- A = affluence, an alternative term for per capita income, P/Y
- Y = national output or GDP
- T = technology, or the efficiency with which production takes place, generally interpreted as the amount of resource use (or resource impact) per dollar of output.

Eq. 1a suggests a simple multiplicative relationship between the three constituent factors, P, A and T. Indeed, population is viewed in some of the scientific and policy literature as simply a proportional factor or multiplier of the environmental impacts of the more 'substantive' factors of economic growth, technological change and regulatory restriction. Other things being fixed, a doubling of population will lead to double the consumption of natural resources and energy. We know that this does not happen, however – other things are not fixed – overall moderating population growth will improve economic growth in emerging and low-income economies thus limiting the positive effects that population moderation will have on aggregate emissions. On the other hand moderating economic growth can limit growth in lower-income economies, affecting also the rate of population moderation. So once again, what might be a gain on one side can be lost on the other. Further, growth is required to meet the other substantive SDGs. Thus a radical decoupling of emissions from both population and economic growth has to be achieved.

The Kaya Identity has often been used to analyse the various drivers of climate change.

C = P. A. e. c = P. (Y/P). (E/Y). (C/E) (Eq. 1b)

Where:

C = carbon emissions

P = population,

A = affluence = Y/P, where Y = Income (or consumption)

e = energy intensity (or energy consumption per dollar of output) = E/Y, where E is total energy consumption

c = carbon intensity (i.e. carbon emissions per unit of energy consumed) = C/E

What this suggests is that the reduction of emissions will occur only if one or more variables in Eq. 1b are reduced. Two inferences can be drawn from this relationship. First, while a marginal and gradual reduction in emissions can be achieved through marginal changes in one or more of the constituent factors (P, A, e, and c), radical reductions implied by the Paris Agreement (including, e.g., reducing emissions to zero by 2050) can be achieved only through some combination of rapid decarbonization of energy use (i.e. reducing C/E), reduction of the overall energy intensity (E/Y) of the economy, reduction of the consumption level (Y/P) of the world's rich and better off (both in the developed and the developing world), and reduction of the ultimate level of the population (P). All of these options present challenges.

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