Global megatrends assessment

Extended background analysis complementing the SOER 2015 'Assessment of global megatrends'

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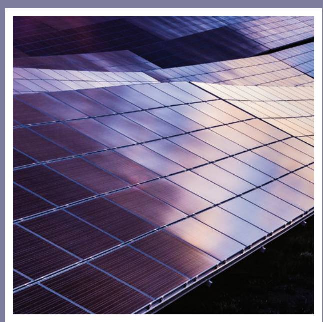

European Environment Agency

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Setting the scene

Context and use of this report

In March 2015, the European Environment Agency (EEA) published its five-yearly flagship report, *The European environment — state and outlook 2015* (SOER 2015). The report provides a comprehensive assessment of the European environment's state, trends and prospects, and places it in a global context. It informs European environmental policy implementation between 2015 and 2020, and analyses the opportunities to modify existing policies, and the knowledge used to inform those policies, in order to achieve the European Union's 2050 vision of living well within the limits of the planet.

In addition to a broad range of global, European, regional and country-level briefings available online (www.eea.europa.eu/soer), the SOER 2015 comprises two printed reports: an overarching *Synthesis* report and an *Assessment of global megatrends* (GMTs).

The purpose of this technical report is to complement the SOER 2015's *Assessment of global megatrends* by providing substantially more in-depth information and data on each megatrend. It covers aspects and topics that were given less attention — or no mention at all — in the SOER 2015 *Assessment of global megatrends* due to space limitations. The present report also provides background information on the research framework and processes that have underpinned EEA work on megatrends since 2009.

The goal of this report is to stimulate thinking, spark discussion and thought, and encourage strategic decision-makers in Europe to consider emerging threats and opportunities, and ensure that policy is 'fit for the long term'. Essentially, it aims to trigger questions about what global developments should be accounted for in order to ensure that environmental policy is relevant, adequate and resilient. While it is primarily designed to support policymaking at the European scale, is also meant to be relevant at regional and national levels of governance.

Why are global megatrends important for Europe and its environment?

Europe is bound to the rest of the world through multiple systems, enabling two-way flows of materials, financial resources, innovations and ideas. As a result, Europe's ecological and societal resilience is significantly affected by a variety of global megatrends — large-scale and high-impact social, economic, political, environmental or technological long-term change processes with decisive and critical implications. As the boundaries between developments in Europe and other parts of the world grow more blurred, Europeans are increasingly likely to be affected by developments in distant regions — some very sudden, others unfolding over decades.

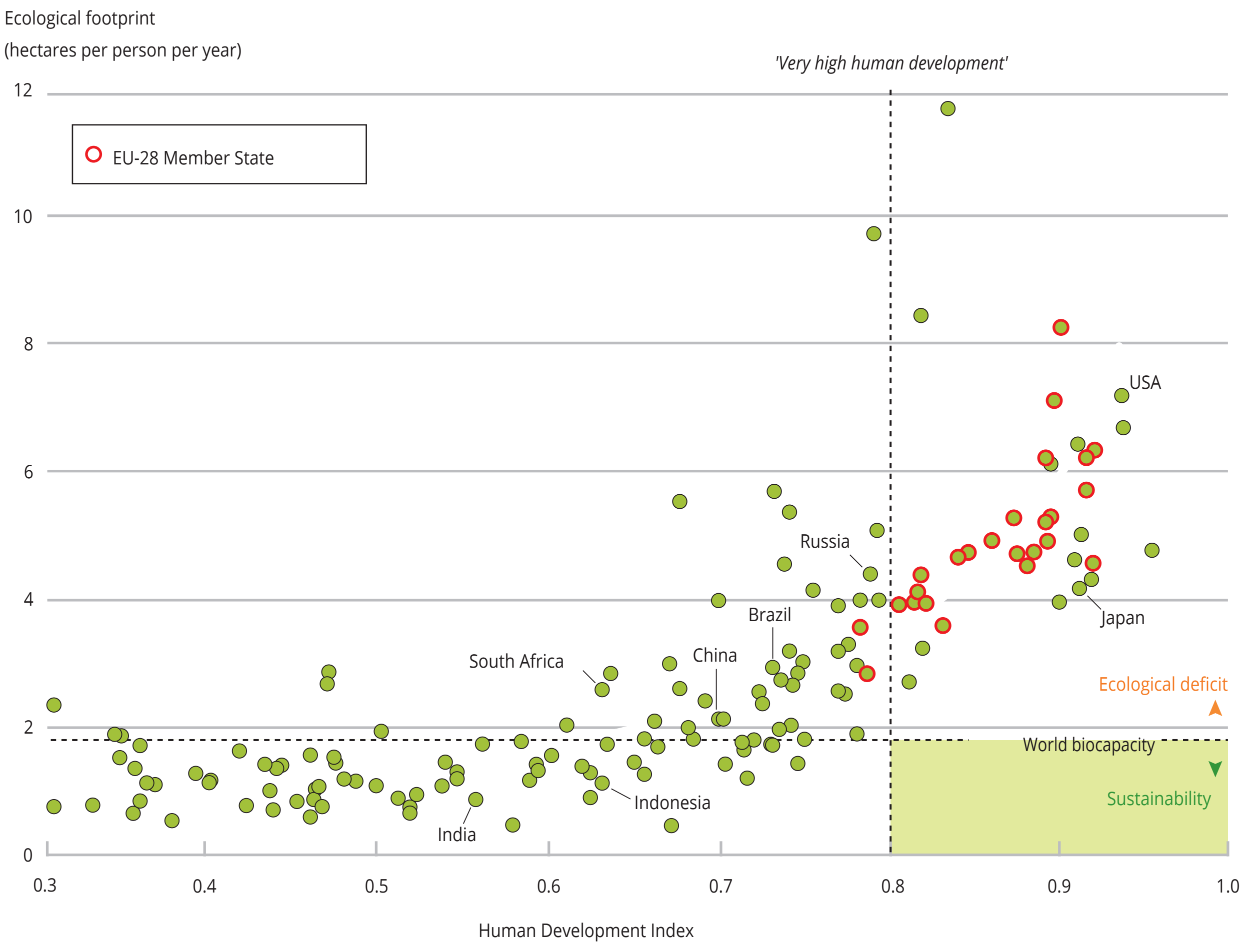
Since global megatrends are complex and subject to major uncertainties, their impact on the European environment and society in general cannot be determined unambiguously. Understanding global megatrends and their impacts is made all the more difficult by the fact that they can be perceived in contrasting ways by different societal groups and stakeholders. Continued global population growth, for example, can be seen as either a boost or a burden for economic development; urbanisation can be perceived as a source of growing pressures on ecosystems, or as an opportunity for more resource-efficient lifestyles.

Such complexities notwithstanding, it is clear that global megatrends will have significant consequences for Europe in coming decades. For example, demographic, economic or geopolitical developments elsewhere can influence the availability and price of natural resources and energy in Europe. Increasing environmental pollution in other world regions likewise contributes to direct environmental and human harm in Europe. For instance, although European emissions of ozone precursor gases have declined significantly in recent decades, measured concentrations of ground-level ozone have not fallen at most ground monitoring stations (EEA, 2014). There is evidence that this is partly due to the long-range transport of precursor gases from other parts of the world (HTAP, 2010).

At the same time, Europe contributes to environmental pressures in other parts of the world. Greenhouse gas emissions in Europe contribute to climate change impacts elsewhere and potentially far into the future. Globalised supply chains likewise mean that European consumption contributes to pressures on ecosystems and communities in other areas of the globe, for example through threats to global freshwater quality and quantity, and the degradation of habitats and landscapes (Tukker et al., 2014).

Taken together, these interdependencies clearly imply that 'business as usual' is no longer a viable development path for Europe. Current lifestyles in Europe and other developed regions put excessive pressures on the environment (Figure 0.1). As a growing global middle class increasingly adopts the resource-intensive consumption patterns of advanced economies, the total environmental burden is rapidly moving beyond globally sustainable limits (Rockström et al., 2009; Steffen et al., 2015). This represents a growing threat to future advances in living standards and increasingly raises questions about the fairness of wealthy nations imposing highly disproportionate burdens on the global ecosystem. Such trends underline the need for action to reconfigure systems of production and consumption so that they operate within ecological limits and thereby ensure the well-being of current and future generations. In Europe, as elsewhere, efforts to manage environmental pressures, economic development and human well-being need to overcome the short-termism currently dominating political and economic thinking and instead embrace long-term, integrated, global perspectives.

Figure 0.1 Correlation of Ecological Footprint (2008) and Human Development Index (2010)



Note: The Human Development Index is calculated using three components: education, life expectancy at birth and wealth. It is expressed as a value between 0 and 1, from less to most developed countries.

The Ecological Footprint measures how much land and water area a population requires to produce the resources it consumes and to absorb its waste. The world biocapacity is the global productive area available on Earth (it decreases as population grows).

Source: Global Footprint Network, 2012; UNDP, 2014.

Assessing global megatrends

Perspectives and time scales

Global megatrends can be assessed in numerous ways and with different thematic focuses. Multiple diverging perspectives can be valid — as reflected in the growing number of reports and studies on global megatrends that have been published in recent years.

The EEA has approached the assessment of global megatrends from two key angles:

- First, the assessment takes a global-to-European perspective and explores how global developments may impact Europe, particularly the European Union (EU). The analysis does not address Europe's contribution to environmental pressures in other parts of the world.

- Second, alongside a global-to-European perspective, a particular focus is put on assessing the potential implications for Europe's environment, including ecosystem resilience and services.

A global-to-European and environmental perspective is relevant for European policymaking in general and European environmental governance in particular because Europe's systemic environmental challenges and response options are increasingly shaped by global drivers. Like other advanced economies, Europe's relative size and influence on the global economy is expected to decline in coming decades. This changing global setting presents both challenges and opportunities, some of which are explored in this technical report.

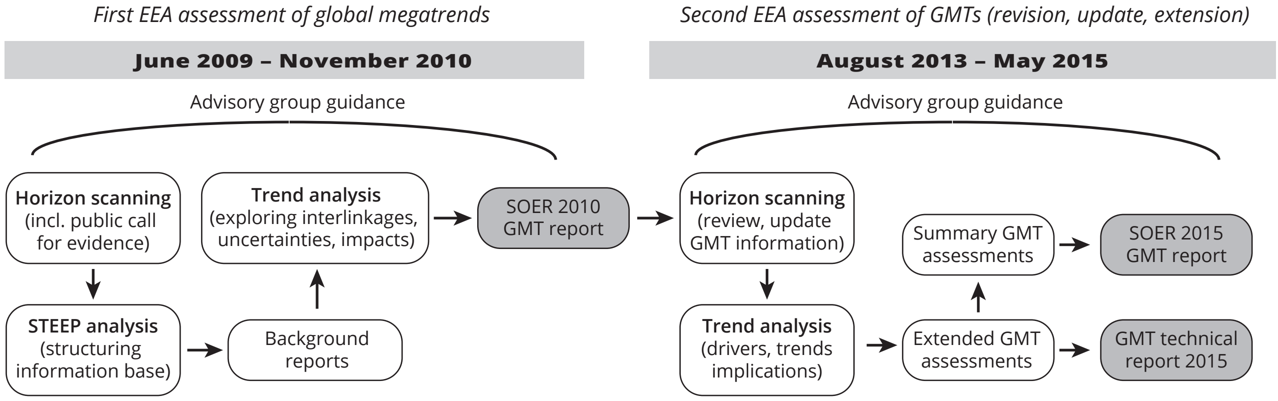
The temporal scale of the analysis strongly depends on data and information availability. For many issues and topics, the analysis draws on historical trends beginning in the 1950s and projections and scenarios up to 2030 or 2050. In some cases, however, the assessments include historical time series data extending back over centuries or forward-looking information stretching as far ahead as the end of the 21st century. Examples of such extended time scales include topics such as human population and climate change.

Methodologies used in EEA work on global megatrends

The complex interlinkages and uncertainties inherent in global megatrends necessitate an open, exploratory, participatory, integrated and interdisciplinary approach to analysis, drawing on a variety of methodologies. The EEA has used quantitative modelling results alongside a variety of qualitative foresight methods and techniques, including horizon scanning, STEEP analysis and trend analysis. Similarly, desk-based literature reviews and analysis have been complemented with inputs from expert panels and workshops. The EEA's network of partners across Europe, in particular the EEA National Reference Centres for Forward-Looking Information (NRC-FLIS), has also played a major role in providing ideas and reviewing outputs.

As illustrated in Figure 0.2, the work has comprised multiple activities and assessments since 2009, culminating in three published reports: the SOER 2010 and SOER 2015 'Assessments of global megatrends',

Figure 0.2 Process of assessing global megatrends (GMTs) at the EEA



Source: EEA.

and the present technical report. The methodologies, activities and outputs of EEA megatrends work since 2007 are described in more detail in the remainder of this section.

EEA Scientific Committee workshop 2007

EEA consideration of global megatrends commenced in 2007. In order to strengthen its work on environmental scenarios and outlooks aimed at supporting strategic EU policy, the EEA held a workshop in May 2007 with its Scientific Committee exploring 'megatrends and surprises'. The workshop highlighted the need for more in-depth assessments of global trends at the EEA, in particular the need to identify potential 'global megatrends' and their relevance for Europe.

Horizon scanning 2009

In early 2009, a group of EEA experts was established to coordinate the GMT assessment. The group set up a horizon scanning process with the aim of building a robust information base for assessing GMTs. The scanning followed a meta-study approach, focusing on assessing existing information and data from academic and non-academic sources across disciplines, and on stakeholder consultation. This included a public call for evidence on GMTs via the EEA website, which was disseminated to relevant research networks and mailing lists. The call for evidence enabled a list of relevant studies to be drafted, which helped further prioritise topics for the GMT assessment. An international, interdisciplinary and cross-institutional advisory group was also formed to support and guide the GMT assessment.

STEEP analyses

The material obtained thought the scanning process was analysed and consolidated using the STEEP framework. STEEP is a generic foresight framework developed for (environmental) scanning purposes, which structures diverse information into social, technological, economic, environmental and political trends (Fowles, 1978).

A template was used to organise the information on each of the trends. It included categories such as 'trend description', 'key drivers', 'interlinkages between trends', 'key uncertainties' and 'implications'. The information for each trend was then consolidated into eight coherent background reports, which were commented on by the advisory group.

Trend analysis towards SOER 2010

The eight background reports provided the basis for an initial selection of 20 key GMTs until 2050 according to three selection criteria: relevance for Europe (direct/indirect), novelty of analysis, and information availability. A mixed-methods approach was taken to analyse and describe the GMTs in a systematic and comprehensive way. This involved:

- a cross-impact analysis focused on exploring the interlinkages between GMTs and between drivers;
- an uncertainty analysis focused on determining a range of plausible future trends, and related impacts on the environment and human well-being;
- a trend impact analysis to identify the importance of GMTs for policymaking, potential impacts on different spatial scales (global, European, transboundary), the timeline of impacts (using two time horizons — 2030 and 2050), the potential severity of impacts, and associated uncertainties.

This procedure resulted in the number of GMTs being reduced to the 11 considered most relevant for Europe's long-term environmental context (Figure 0.3).

The outcomes of the analysis were summarised in 11 factsheets, which included information on the relevance of the GMT, key indicators, drivers, uncertainties and environmental impacts on Europe. The factsheets were elaborated with support from external consultants and in consultation with the EEA's main stakeholders, including the EEA Scientific Committee, DG Environment, the Eionet and the advisory group. Finally, the factsheets were summarised and published as a print product under the umbrella of the SOER 2010 and as web-based documents on the EEA homepage.

Horizon scanning 2013–2014

Updating of the GMTs began in August 2013 (Figure 0.2) with a horizon scanning process. In this process, external consultants and EEA experts reviewed the relevance and robustness of the GMTs based on literature reviews and desk research.

In addition, 27 selected GMT studies published by other organisations up until 2013 were compared systematically to explore the added value and the synergies of the EEA GMT assessment work. The outcomes of this comparative analysis were summarised in factsheets according to a common template (for details see the next section and Annex 1).

Trend analysis towards SOER 2015

Based on the second horizon scanning exercise, the EEA prepared background reports on each of the 11 global megatrends addressed in SOER 2010. Those background reports make up Chapters 1–11 of the present technical report.

While the background reports prepared in advance of SOER 2015 aimed to be consistent and comparable with the earlier EEA work on global megatrends, they also included some shifts of emphasis. For example, in some instances the titles of the megatrends were also adapted slightly to better differentiate them and to reflect their key characteristics. In addition, the reports were structured to provide a greater focus on the drivers, trends and implications associated with each megatrend. This restructuring of the analysis helped to clarify the interactions between the different megatrends, their drivers and impacts.

As illustrated in Figure 0.3, the global megatrends are strongly interdependent, with multiple cause-effect relationships between their underlying drivers. Two megatrends — demographic trends and economic growth — stand out as being particularly important drivers of the other megatrends, although others such as innovation, education and consumption patterns also have pervasive impacts.

For SOER 2015, the 11 background reports were consolidated into 11 GMT briefings, which that were subject to a broad consultation with EEA experts, NRC-FLIS, the Eionet, the EEA Management Board, the EEA Scientific Committee, DG Environment and DG CLIMA. In addition, for the purpose of reviewing and guiding the preparation of the GMT briefings, a new cross-disciplinary advisory group was established, which also included several representatives of the European Commission.

Finally, the GMT briefings were published under the umbrella of the SOER 2015 as web products and in a consolidated printed report (EEA, 2015), which also included a summary analysis of the impacts of the megatrends on Europe's resource needs.

As a follow-up to the SOER 2015, GMT workshops are planned for 2015 and 2016 at the national, regional and EU levels. These workshops aim to allow policymakers to explore the impacts of GMTs on policymaking at multiple geographical scales. The next revision of the GMT assessment is envisaged for 2018 as an input into the EEA's next five-yearly report, 'The European environment — state and outlook 2020' (SOER 2020).

Other assessments of global megatrends

The number of reports and studies on global megatrends have increased significantly in the last few years. Annex I to the present technical report contains summary factsheets describing 15 global megatrend studies undertaken by a range of European and international institutions. The factsheets follow a common template, including a short summary of the report contents; the study objectives and target audience; a description of the study's characteristics; and information on the assessment methodology applied.

Some studies are connected with specific planning and policy contexts, whereas others seek to engage with and spark debate among their intended audience. However, only a few studies identify clearly a specific audience or intended use. This might reflect their role as exercises to inspire thought and discussion. The majority of the studies are predominantly analytical (based on literature reviews and desk-based research by one or more experts). Almost all studies include some form of expert input, however, either through peer-review, small expert meetings, or more formalised workshops or working groups.

There are some notable exceptions. For example the ESPAS-commissioned study (developed by RAND Europe) *Europe's societal challenges — an analysis of global societal trends to 2030 and their impacts on the EU,* used a Delphi approach through online surveys (involving in its first round more than 400 experts), interviews and an expert seminar. The World Economic Forum's *Global risks report* is another example of a participative study, in which more than 1 000 experts from diverse organisation types, countries and technical areas of expertise were invited to identify and rank key risks. This in turn formed the basis for the analysis within the report.

Most of the studies are exploratory in nature, although some consider normative outlooks. Where normative scenarios or outlooks are considered they tend to be used to support the presentation of suitable policy or planning responses to exploratory trend analyses. For example, business-focused studies such as those generated by Ernst & Young or KPMG present options for actions today that could maximise opportunities and minimise risks from emerging and future developments. Generally there is limited detailed methodological information provided within the studies, although most do describe in broad terms the steps taken in their development.

The predominant approach used in developing the megatrend assessments listed in Annex I is similar

Figure 0.3 The eleven global megatrends assessed by the EEA and their key drivers

Source: EEA.

to the one employed by the EEA: conducting broad literature reviews of existing studies; compiling data from historic trend and outlook indicators from international organisations; developing preliminary analysis; and sharing and testing the analysis with experts through review or participation (e.g. workshops). However, the EEA's approach differs from the other studies reviewed in combining a global-to-European perspective with a focus on the environment and the links to EU policy.

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Global megatrend 1 — Diverging global population trends

Across the world, the basic determinants of population size and structure — fertility, mortality and migration — have been fundamentally altered by the processes of social and economic development. As a result, the global population doubled to 7 billion in the last half century and will continue growing fast in coming decades, although regional trends differ markedly. In advanced economies, populations are ageing and in some cases reducing in size. At the other extreme, populations in the least developed countries ([1]) are expanding rapidly. Migration is also affecting the distribution and structure of populations, as people move in search of higher earnings or to escape conflict or environmental degradation.

An expanding workforce relative can create a 'demographic dividend' of greatly increased economic output. But it can also create the risk of social unrest if there are insufficient employment opportunities. Furthermore, some of the returns from the demographic dividend must be invested in areas such as health and education, and in savings for retirement, if living standards are to be sustained as the population ages.

If the world remains on its current development path, population growth and investments in human capital will continue to provide a boost to global economic output, potentially increasing the burdens on natural capital stocks. But the challenges facing regions will vary. Developing countries will need to identify ways to exploit the opportunities presented by a large economically active population and few dependents. Advanced economies will need to maintain living standards as the elderly population expands and the workforces contracts.

The world population has more than doubled since the 1960s and is projected to continue growing in coming decades. Trends in population size and structure are likely to vary greatly between countries and regions, influenced by a range of factors such as economic growth, improving public health, education and migration. This chapter will review these drivers, the resulting population trends and their implications for societies in Europe and elsewhere.

1.1 Drivers

Fertility and mortality rates

Among the factors that most directly shape the size and structure of populations are fertility and mortality rates ([2]), and the related issue of life expectancy. Small changes in assumptions about fertility can produce big variations in projections of population size over time. They are therefore an important source of uncertainty regarding future population trends.

Globally, fertility rates have converged since 1950, with the average rate in most regions falling below 3.0 by 2010 (Figure 1.1). In 2004, the total fertility rate in Asia and Latin America was 2.6, which was half the level in 1970. Africa remains a significant outlier but the fertility rate there is also projected to decline to below 3.0 around 2050.

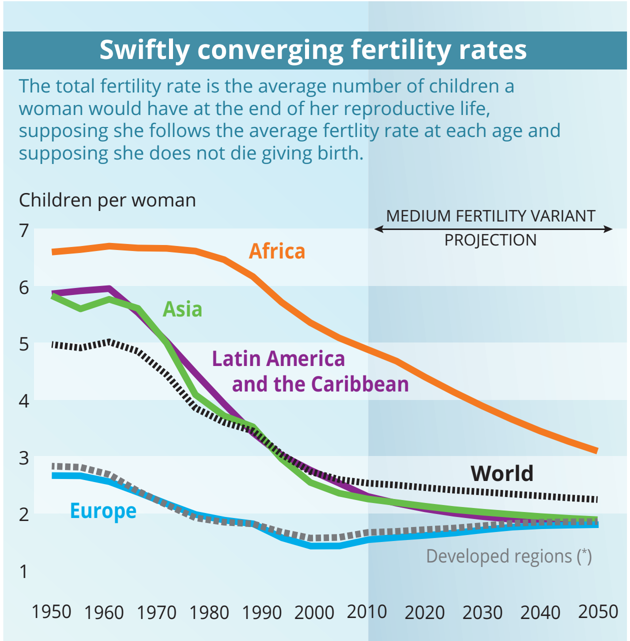
Mortality rates have recorded similar decreases in recent decades. As a result, global average life expectancy has undergone the most significant increase in history, rising from 48 years in 1950–1955 to 69 years in 2005–2010 (UN, 2013b), although significant regional variations persist (Figure 1.2). Childhood mortality (i.e. death under the age of five) fell from 203 per 1 000 live births to 60 during that period. According to United Nations projections, global life expectancy will continue rising in coming decades, reaching 75 years by 2045–2050 (UN, 2013b).

In combination, these trends in fertility and mortality rates have important implications for population

([1]) This chapter employs the United Nations categorisation of countries and regions according to their level of economic development (UN, 2013a). As of 2013, the UN defines 49 countries as 'least developed countries', and identifies seven 'developing regions' and four 'developed regions'. As such, references in this chapter to 'developing countries' and 'developed countries' thus relate to countries in those regions. 'Developed countries' are also referred to as 'advanced economies'.

([2]) The fertility rate refers to the number of children born to a woman during her lifetime. The mortality rate is the number of deaths in a population or a segment of a population (e.g. infant mortality).

Figure 1.1 **Total fertility rate by selected world regions, 1950–2050**



Note: (*) Europe, Northern America, Australia, New Zealand and Japan.

Source: UN Population Division, World Population Prospects (2012 revision).

growth and structure. The immediate effect of fewer births and increasing life expectancy is an increase in the average age of a population.

The interaction of fertility and mortality rates also influences population size. In particular, childhood mortality rates play a central role in determining the replacement fertility rate ([3]), which ranges from less than 2.1 in advanced economies to almost 3.4 in the least developed countries (Engelman and Leahy, 2006). If the fertility rate remains below the replacement rate for a sustained period then the population will decline unless net migration inflows offset the reduction.

The global total fertility rate stood at a little over 2.5 in the period 2005–2010, which was slightly higher than the global replacement rate of approximately 2.3. Both rates are projected to decline in coming decades, with global fertility falling below the replacement level in the second half of the current century (UN, 2014b).

Economic development and education

The trends in fertility and mortality rates are themselves shaped by interrelated drivers, such as economic development; advances in health care, science and governance; and related cultural and lifestyle changes.

Economic development impacts both fertility and mortality. As illustrated in Figure 1.3, fertility rates typically start to drop when a country achieves a per capita income level of USD 1 000–2 000 (2010 PPP) and declines to replacement level when the country reaches a per capita GDP of USD 4 000–10 000. After this income level, fertility continues at or below the replacement level but may increase again in some cases.

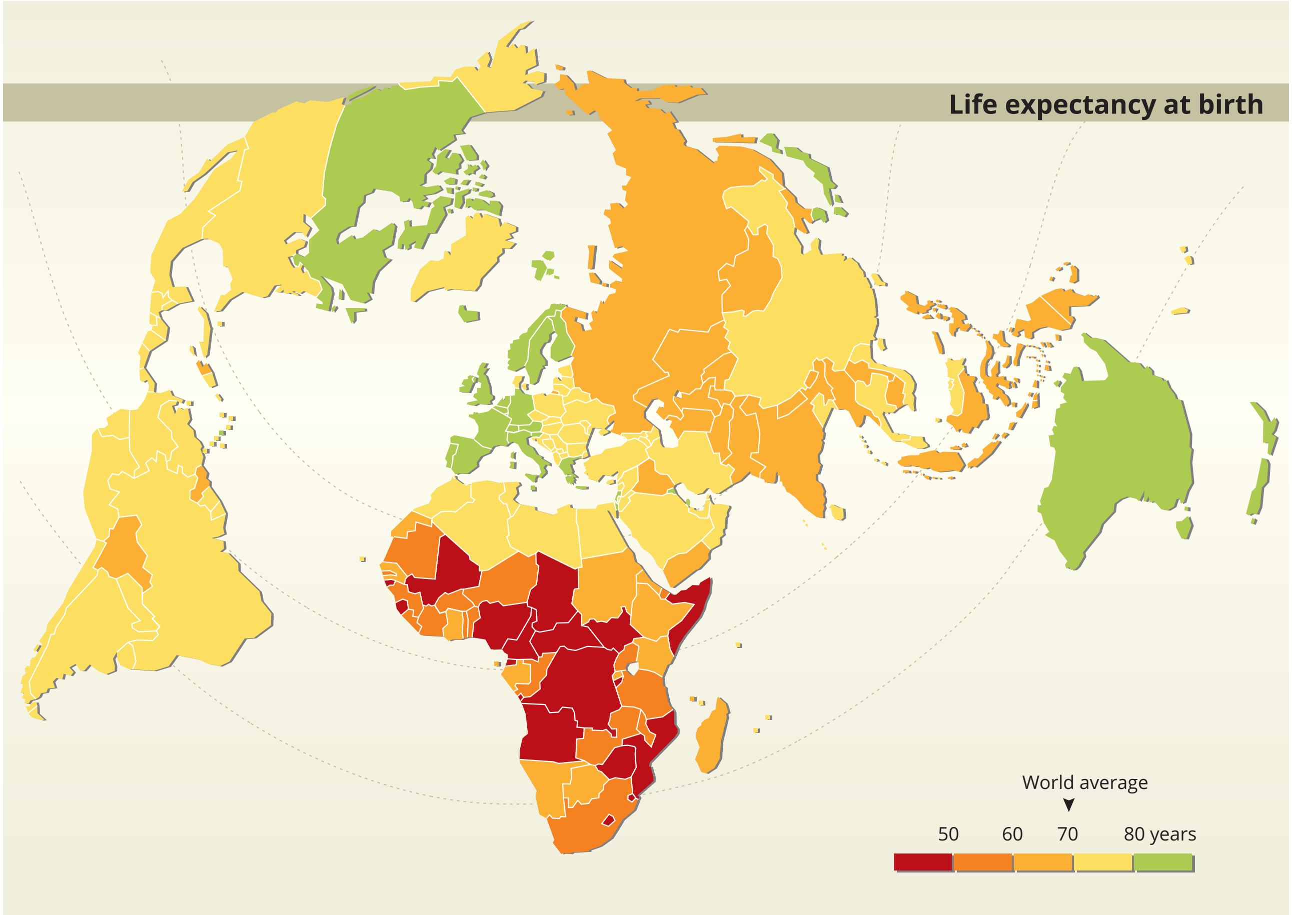
Economic growth is both a cause and a consequence of numerous other societal changes that influence fertility and mortality. For example, increased incomes and savings, as well as the emergence of well financed social security and health systems, can reduce reliance on family assistance during old age, shifting the incentives that inform choices about family size. Economic development can also influence access to reproductive planning and to contraception (UNFPA, 2014).

As national income increases, investments in human capital — in terms of both health and education — emerge as a particularly important determinant of population trends. Improved health services can greatly reduce infant and maternal mortality, as well as influencing life expectancy for the broader population (Claeson and Waldman, 2000). Higher earnings also provide access to better nutrition. And beyond certain levels of economic development, countries tend to reduce some types of pollution (Van Alstine and Neumayer, 2010).

Education is recognised as having a particularly marked impact on fertility rates (Figure 1.4). For example, a study addressing 24 sub-Saharan countries found that birth rates were four times as high among uneducated girls aged 15–19 than among those with at least secondary schooling (UNFPA, 2012). The importance of education is also reflected in population growth projections. One study addressing the implications of different education levels for population growth projects a global population of 8.9 billion in 2050 based on its 'highest education' scenario and a population of 10.0 billion in its 'lowest education' scenario (Lutz and Samir, 2011).

([3]) 'Replacement fertility rate' refers to the average number of children that the women in a population must have during their lifetime in order to sustain a constant population size. Variations in the rate between countries reflect differences in the likelihood that female children will survive to child-bearing age, as well as differences in the ratio of female to male children born.

Figure 1.2 **Global life expectancy at birth, 2011**



Note: Data for 2011 (or most recent data available).

Source: World Health Organization, 2014.

Migration

Another key determinant of the size and structure of national or local populations is migration, which is itself a manifestation of complex economic, social and environmental drivers.

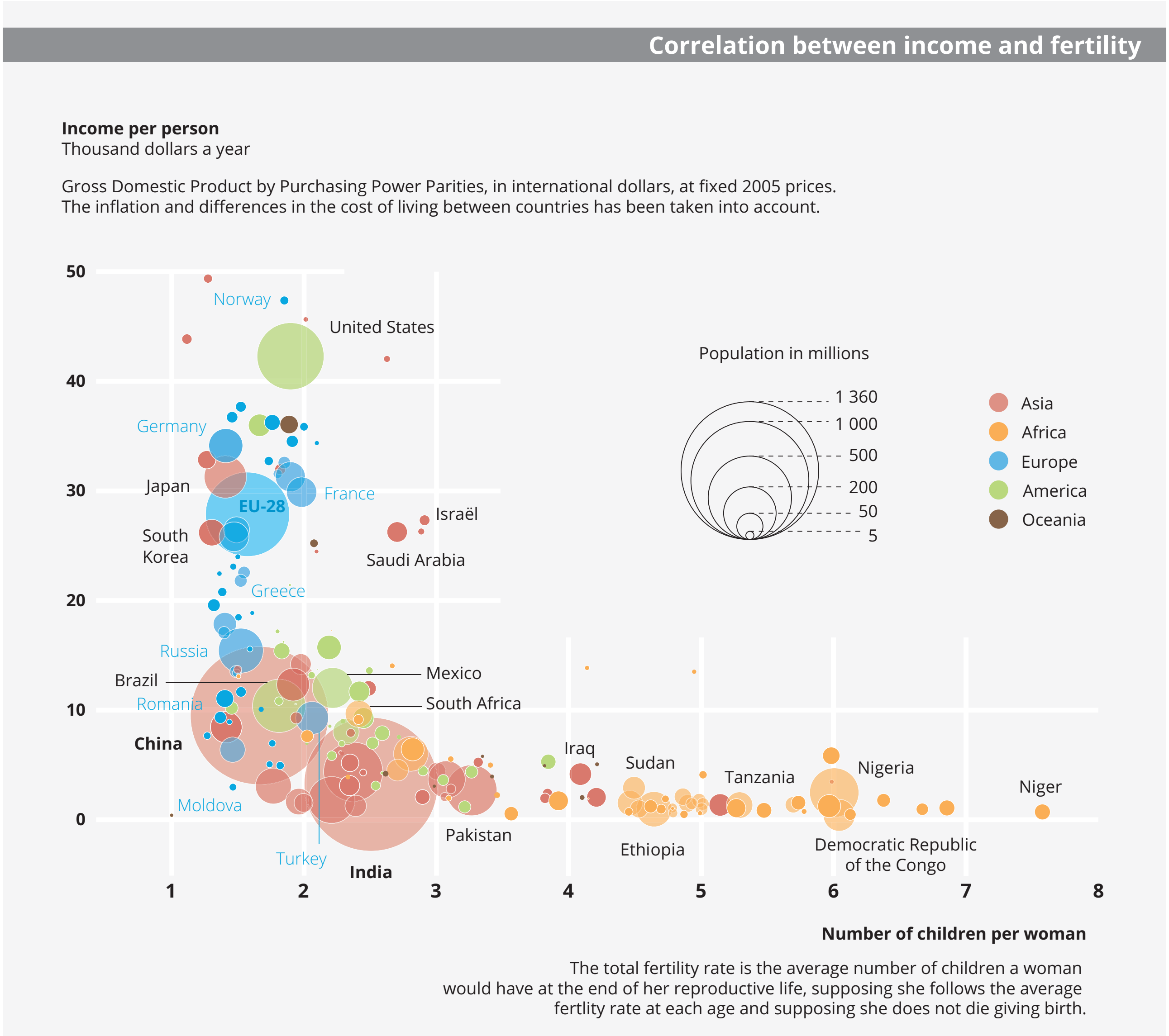
Differentials between the earnings available in different locations are a powerful incentive for migration — both within countries (see GMT 2 on urbanisation) and between countries (IOM, 2013). Such movements can have implications for the population size and age structure at the source and destination locations, exacerbating or counteracting demographic trends at the national level.

Similarly, conflict, natural disasters and environmental degradation have long been recognised as catalysts for forced migration (IOM, 2013). In recent years, climate change has emerged as additional driver, potentially exacerbating existing migration pressures by threatening livelihoods and increasing exposure to natural hazards (ICMPD, 2011; Foresight, 2011).

The links between environmental change and migration are complex, however, linking to many other social and political drivers of migration. Economic migration, for example, can often be partially or wholly rooted in environmental degradation. This makes it very difficult to generate precise estimates of environmentally induced migration (IOM, 2009; Foresight, 2011).

The precise effects of climate change and environmental degradation are rendered even more complicated by the fact that in some instances they can actually deter migration. This could occur, for example, if environmental change means that communities lack the resources to meet the costs of relocating (Foresight, 2011).

Figure 1.3 **Correlation of fertility rates and per capita GDP, 2010**



Note: European Union countries are represented both individually and collectively (EU-28). Data for 2012–2013.

Source: World Bank, UN Population Division, Gapminder.org.

1.2 Trends

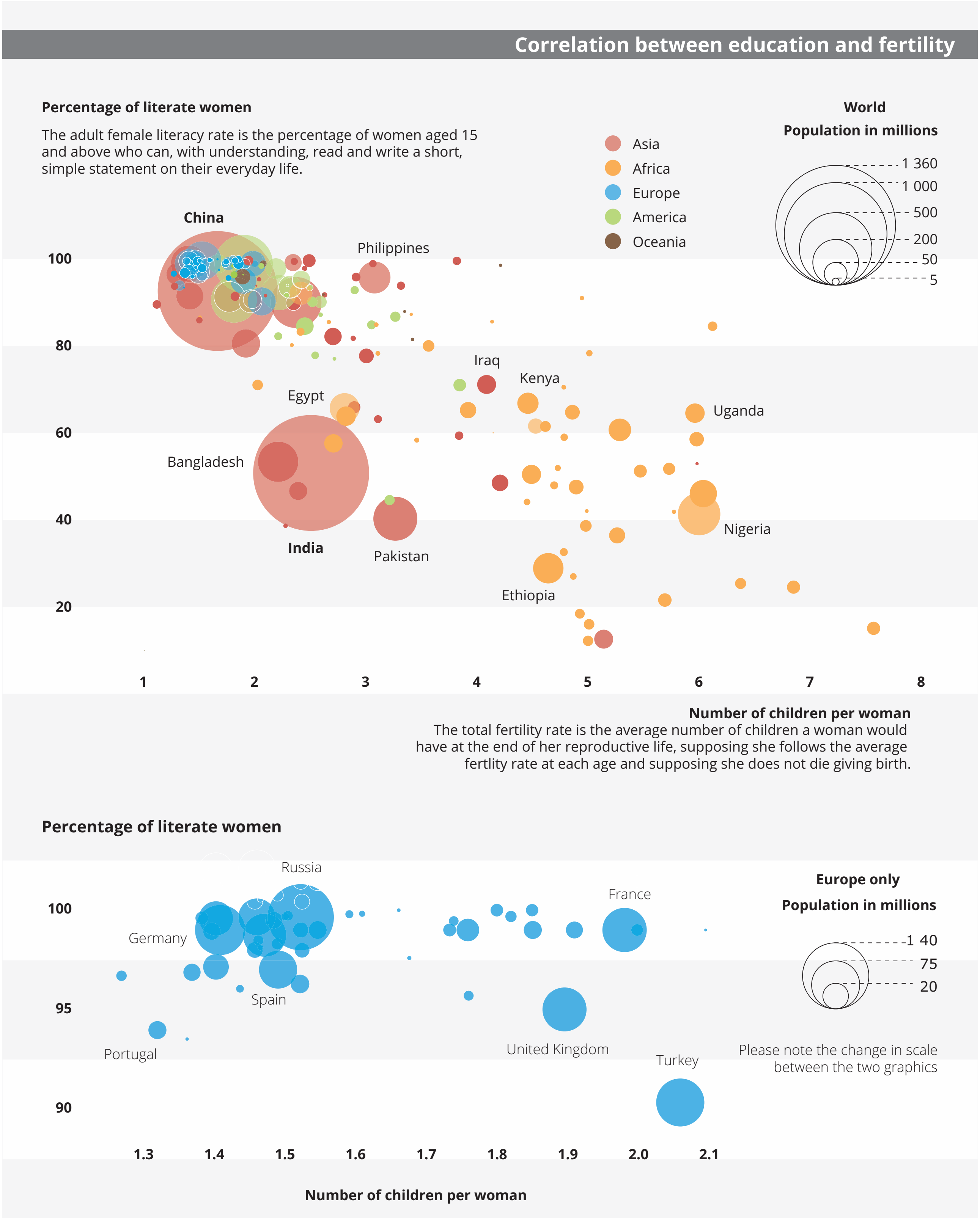
Global population growth

Driven in part by the economic and social forces described above, the world population has more than doubled since the 1960s. Today, it exceeds seven billion people and continues to grow by approximately 1.1% annually (UN, 2013b). In the decades ahead the rate of global population growth appears likely to slow, although the interaction of the different drivers creates many uncertainties — a fact reflected in large differences between projections.

As illustrated in Figure 1.5, according to UN estimates (UN, 2013b) the world population will be between 8.3 billion and 10.9 billion in 2050, with a medium variant of 9.6 billion ([4]). Thereafter the population is expected to keep rising, exceeding 10 billion at the end of the century.

([4]) The medium variant is defined by certain assumptions about future fertility trends in developed and developing countries. It is not a 'mean' growth estimate.

Figure 1.4 Correlation between fertility and adult female literacy rate, 2000–2009



Note: Data for 2012 (or most recent value).

Sources: UNESCO; Gapminder.org; CIA World Factbook; 2013.

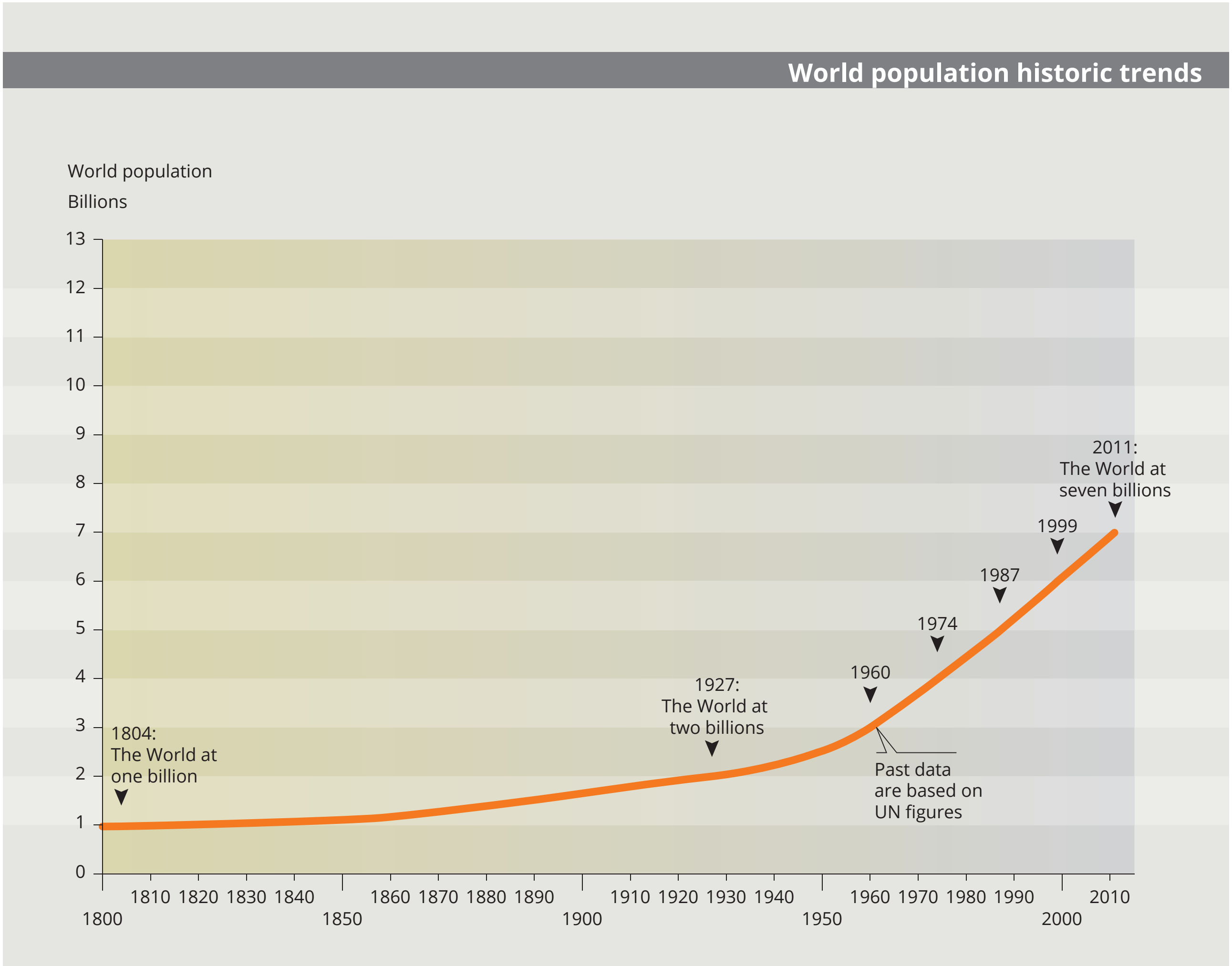
In contrast, IIASA (2007) projects a medium-variant population of 8.75 billion in 2050, with a range from 7.8 to 9.9 billion. It foresees the global population peaking at 9.45 billion around 2070 and then starting to decline.

The projected global trends mask significant variance in the population growth in different areas of the world. The UN estimates that the population of today's developed regions will grow marginally from 1.25 billion in 2013 to 1.3 billion by 2050. This increase is due to a projected annual inflow of 2.4 million immigrants in the period 2013–2050. After 2050 inward migration is projected to decrease, resulting in a slight reduction in the population in these regions. Europe's population is expected to begin its decline sooner, falling from 739 million in 2011 to 709 million in 2050 in the medium variant scenario.

With the population in more developed regions growing only very slightly, almost all of the projected increase in the global population in coming decades is concentrated in countries currently categorised as less developed. The UN foresees the population of these countries rising from 5.9 billion in 2013 to 8.2 billion in 2050. As illustrated in Figure 1.6, this implies that today's developed regions will account for just 12% of the world population in 2050, down from 16% in 2010 and 27% in 1950 (UN, 2013b).

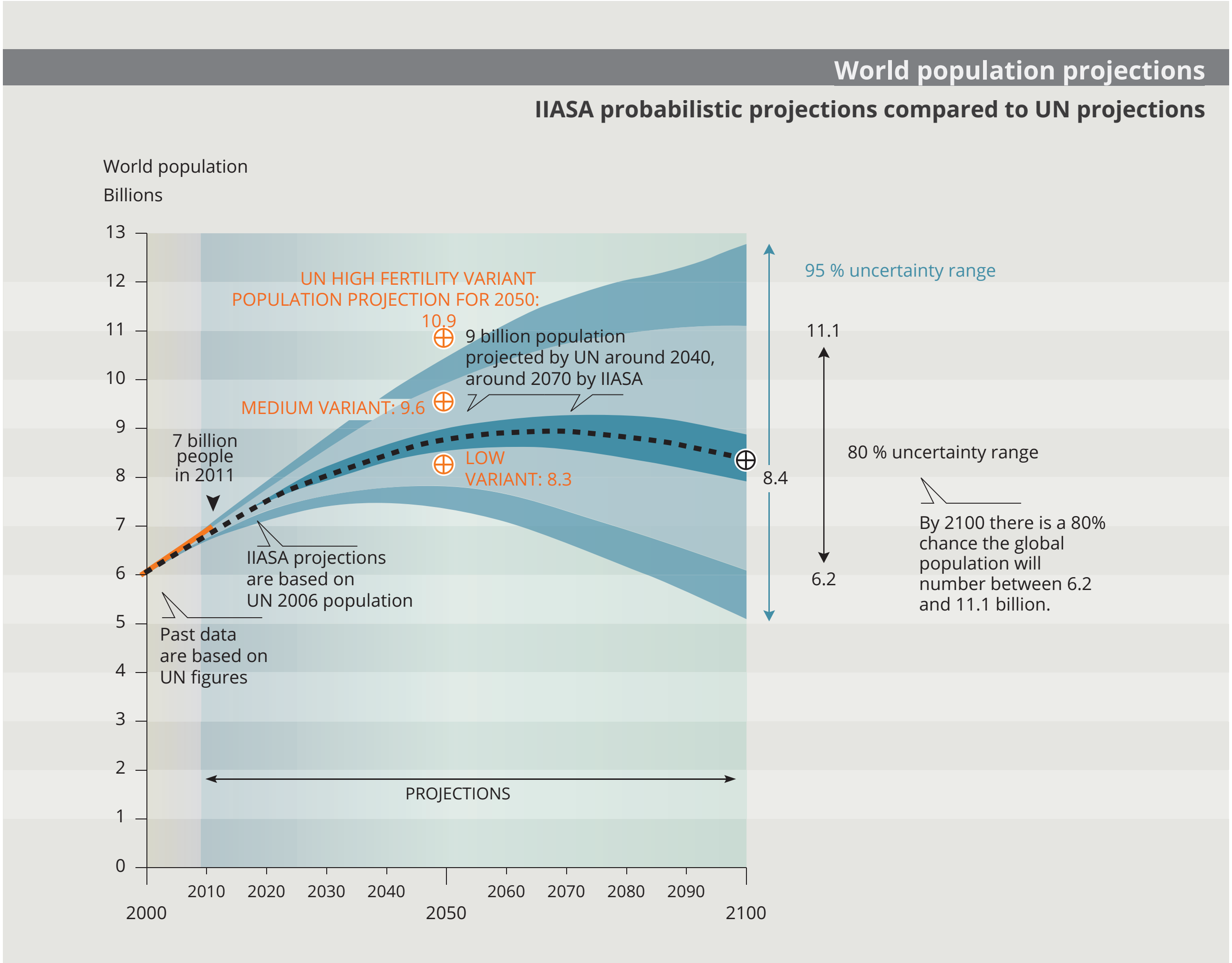
Among the less developed regions, Asia and Africa are projected to dominate population growth in coming decades, with particularly robust increases expected in the 49 'least developed countries' (LDCs). The UN estimates that the population of the LDCs will double from 898 in 2013 to 1.8 billion in 2050, which would represent almost a fifth of the global population (UN, 2013b).

Figure 1.5 IIASA and UN world population projections



Sources: UN Department of Economic and Social Affairs, The World at Six Billion, 1999.

Figure 1.5 IIASA and UN world population projections (cont.)



Note: The UN Population Division studies fertility-evolution scenarios to produce high, medium and low variant figures, whereas the IIASA bases its calculations on assumptions for fertility, mortality and migration (the latter only affecting regional projections).

Sources: Lutz W., Sanderson W. and Scherbov S., 2007 Probabilistic World Population Projections, International Institute for Applied Systems Analysis (IIASA); UN Population Division, World Population Prospects (2012 Revision).

In today's developing regions, population trends are expected to shift towards the stagnation and decline that have already commenced in developed regions. Despite continuing population growth in much of the developing world, in the future, some developing nations will begin to experience population ageing, stagnation and decline in coming years. For example, the populations of Russia, Ukraine and several Caribbean countries will decline in the period 2010–2030. Indeed, Russia's population is projected to decline by 10 million over that period, and a further 10 million by 2050 (UN, 2013b).

One effect of these uneven growth trends will be a significant adjustment in the geographical distribution of the world population (Figure 1.6). The contribution of Asia, Europe and South America to the global total is expected to decline during the remainder of the century.

In contrast, Africa's contribution is expected to expand significantly, from less than 15% of the world total in 2010 to more than 35% in 2100.

Changes in population age structure

Changes in population age structure are an inevitable consequence of the adjustments in fertility and mortality rates associated with socio-economic development. As socio-economic conditions improve, structural changes in the population tend to occur in three phases (NTA, 2011a; Figure 1.7):

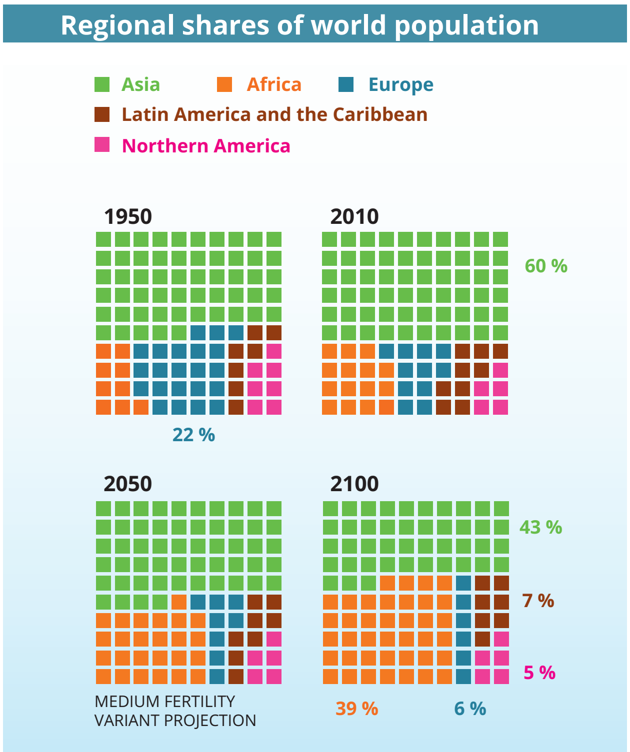
- In the least developed economies, high fertility rates are balanced by high infant and child morality rates. As infant and child mortality rates decline, the proportion of children in the total population increases.

- Fertility rates decline and the many young people born during the era of high fertility enter adulthood. As a result, the working-age population expands relative to the populations of young and old dependents.

- The large workforce enters retirement and the smaller generations that follow imply a reduced working age population. At the same time, increased life expectancy means a further increase in the population of elderly dependents relative to workers.

While this sequence of structural changes appears to occur globally, populations vary greatly in how far they have progressed through the transition. As illustrated in Figure 1.8, in 2010 just 4% of Africa's population was aged 65 or more, while 51% were under 20 years old. In Europe, the figures were 16% and 21% respectively. Looking ahead, it is projected that children will still account for more than 40% of the population in Africa in 2050.

Figure 1.6 Distribution of the world population by major area, medium variant, 1950, 2010, 2050 and 2100



Source: UN Population Division, World Population Prospects (2012 revision).

Notwithstanding the variance in global population change, population ageing is an increasingly important trend in both developed and developing nations. The median age declined in most world regions in the first two decades after 1950 as child populations expanded but has since increased markedly (Figure 1.9). Again, the trends vary between regions. In Africa, the increase did not commence until the 1990s. In Europe, the process of demographic transition is more advanced, resulting in a steady rise in the median age since 1950.

Globally, the population aged 60 or over is expected to rise from 841 million people in 2013 to two billion in 2050. In developing regions, the population aged 60 or over is expected to grow at an annual rate of over 3% in the next three decades, rising from just 9% of the population today to 20% in 2050 (UN, 2013b). In developed regions, the percentage aged 60 or over is projected to increase from 22% to 32% in the same period (UN, 2013b).

Alongside these changes in the size and structure of populations, coming decades are expected to see substantial shifts in the distribution of populations. Half of the world's population today inhabits cities and this Figure is likely to reach 67% by 2050 (UN, 2012). This would imply an increase in the global urban population from 2.6 billion in 2010 to 5.2 billion, meaning that cities would account for all of the population growth up to 2050.

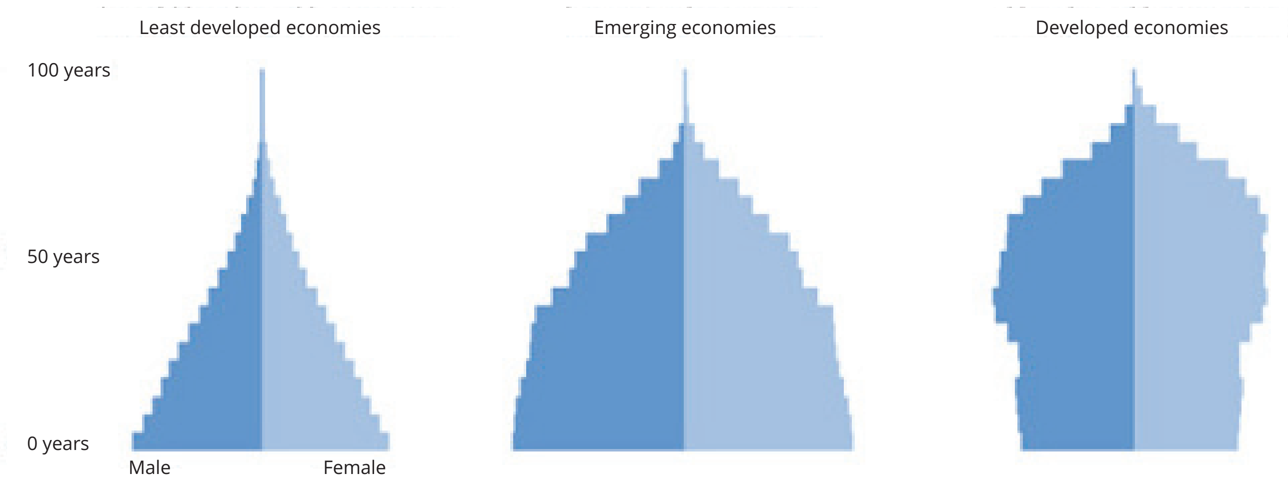
Shifting migration trends

Since the 1960s, migration patterns have been marked by an increase in the share of migrants from developing countries, with developed countries receiving the majority of international migrants. Between 1960–1970 and 2000–2010, the average annual net number of migrants to Europe grew from 95 000 to nearly 1.9 million (UN, 2013b), steadily increasing in significance as a component of the European population (Figure 1.10). Indeed, 20 of the 30 countries that experienced population growth in 2000–2010 primarily due to net migration (rather than natural increase) are European (UN, 2011a).

By 2010, nearly 70% of international migrants were from developing regions, with half of these migrating to developed regions (OECD, 2012). Overall, 59% of global international migrants in 2013 were living in developed regions and accounted for 11% of the population there (Table 1.1).

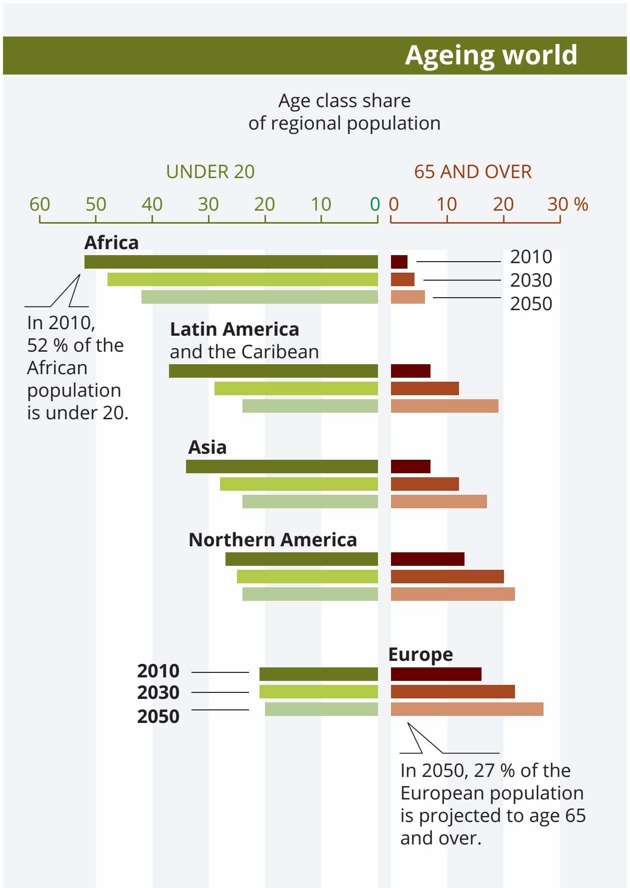
At present, the trend of migration from developing to developed regions appears to be continuing. The UN (2011b) estimates that 32 of 45 developed countries

Figure 1.7 **Population pyramids for the least developed economies, developing economies and developed economies**



Source: NTA, 2011a.

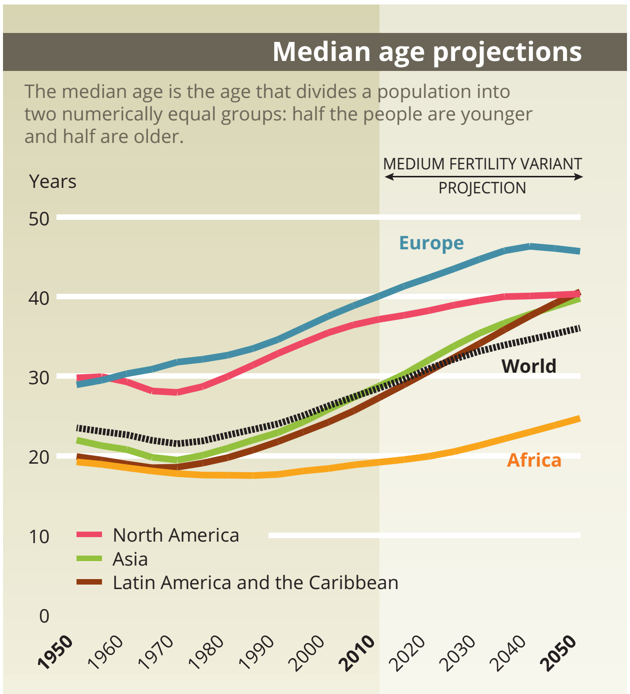
Figure 1.8 **Percentage of total population under age 20 versus age 65 and above in major regions of the world, 2010 and projected for 2030 and 2050**



Source: UN Population Division, World Population Prospects (2012 revision).

were net receivers of migrants over the period 2000–2010. And although migration into the OECD countries and Russia saw a modest slowdown in 2008–2010, largely due to the global economic crisis, it began to increase again in most of these countries in 2011 (OECD, 2012).

Figure 1.9 **Median age projections, 1950–2050**



Source: UN Population Division, World Population Prospects (2012 revision).

Table 1.1 Estimated number of international migrants and their percentage distribution by major area, 2013

Geographic region	Number of migrants (million)	As a% of total migrants in the world	As% of regional population
World	231.5	100	3.2
Developed regions	135.6	58.6	10.8
Developing regions	95.9	41.4	1.6
Africa	18.6	8.1	1.7
Asia	70.8	30.6	1.6
Europe	72.4	31.3	9.8
Latin America and the Caribbean	8.5	3.7	1.4
Northern America	53.1	22.9	14.8
Oceania	7.9	3.4	20.7

Source: UN, 2014a.

Looking further ahead, however, the direction of migration flows is likely to evolve as the economic incentives shift. Already, several countries in developing regions (e.g. Kuwait, South Africa and Thailand) have been attracting significant numbers of migrants, including refugees from neighbouring countries (UN, 2011b). China and India, for example, could attract more labour migrants as their working-age population slows whereas wages rise. Equally, labour migration into the United States is projected to decrease as certain areas of South America are expected to attract labour migrants that would traditionally have gone to the United States (NIC, 2008).

Climate change will exacerbate existing pressures on migration, and could lead to changes in migration patterns (ICMD, 2011). However, the complexity and uncertainty of the associated drivers is reflected in widely diverging projections for climate change-induced migration. ESPON (2013), for example, conclude that climate change-induced migration may be slight compared to migration for other reasons. In assessing the current state of knowledge on the subject, the International Organization for Migration found that 200 million people are expected to migrate by 2050 but projections vary from 25 million to one billion (IOM, 2009).

UN analysis (taking into account the migration policy stance of developed countries) predicts that international migration flows to developed regions will decline smoothly in the coming decades. The average number of annual migrants is projected to ease from 3.4 million people in the period 2000–2010 to about 2.3 million per year in 2040–2050 (UN, 2011b).

1.3 Implications

The changing size and structure of populations across the world has wide-ranging implications, driving other global trends such as economic growth and increasing environmental burdens. At each phase of the demographic transition, the shifting population structure and related migration flows bring opportunities and difficulties.

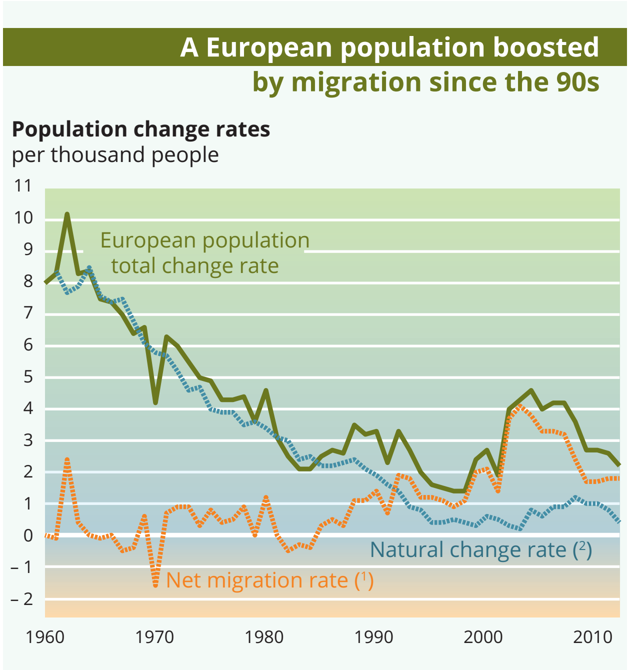
Economic and environmental impacts of expanding workforces

Population trends directly influence economic production by shaping the size and age structure of the workforce. In many countries, strong growth in the working age population, alongside improvements in human capital (e.g. health and education) and investments in infrastructure and technology, have contributed to rapid economic growth in recent years (WEF, 2012).

The expansion in workforces and skills is likely to vary globally, however. Samir et al. (2010) project that Africa's population will grow significantly up to 2050 (Figure 1.11), with a substantial youth cohort persisting throughout, in parallel with a growing older population. Asia will experience marked population growth and significant ageing. In contrast, Europe's population is projected to contract and age. In all regions the share of the population with secondary and tertiary education is projected to increase but the expansion is very substantial in Africa and Asia. Age structure of human capital (education levels) influences future societal economic growth and democracy processes, longevity and disabilities of population, as well resilience of individuals along many dimensions of well-being (Figure 1.11).

This rebalancing of productive potential is already apparent in economic output data. While the advanced economies dominated growth during the 20th century, emerging economies are rapidly gaining prominence. The BRIICS countries accounted for 21% of global output (in PPP terms) in 2000 but by 2010 that had already

Figure 1.10 European population change by component, 1960–2009 (per 1 000 population)



Note: EU-28: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia Slovenia, Spain, Sweden and the United Kingdom.

(1) Including statistical adjustment.

(2) Number of births minus number of deaths per thousand people.

Source: Eurostat, 2014.

risen to 32% (OECD, 2013). The OECD projects that their economic production will exceed the GDP of OECD members by around 2030, and will account for 56% of global GDP by 2050 (OECD, 2013; GMT 6).

As illustrated in Figure 1.12, rapid economic growth in developing regions is projected to translate into marked reductions in the proportion of populations living in extreme poverty.

Population growth and related economic development can boost humanity's competition for non-renewable resources (GMT 7). They can also increase the burden on the environment through increased consumption of biotic resources (GMT 8) and via the production of harmful emissions and waste (GMT 10). Environmental damage may be particularly significant in regions such as sub-Saharan Africa and parts of south-east Asia, where high population growth rates coincide with a high and direct dependency on natural capital for economic development (OECD, 2012).

Employment opportunities and threats to social cohesion

While the surge in workforce numbers offers the potential of rapid economic expansion, it also generates challenges. One important issue is the need to create sufficient employment opportunities for the young and fast-growing workforce. Failing to create such opportunities is a waste of valuable human resources and potentially a source of conflict.

While the world as a whole reached a peak in its share of young people (aged 15–24) around 1985 (Figure 1.13), in the least developed countries this peak occurred in 2005 and is projected to remain high in the coming decades. By 2025, three quarters of the countries with youth bulges (particularly large cohorts in the 15–24 age bracket) will be located in sub-Saharan Africa, with the rest located in the Middle East and a few across Asia and the Pacific Islands (Ortiz and Cummins, 2012). The largest youth bulges are found in some of the world's most fragile countries, which are likely to be particularly vulnerable to civil unrest and ill-equipped to respond.

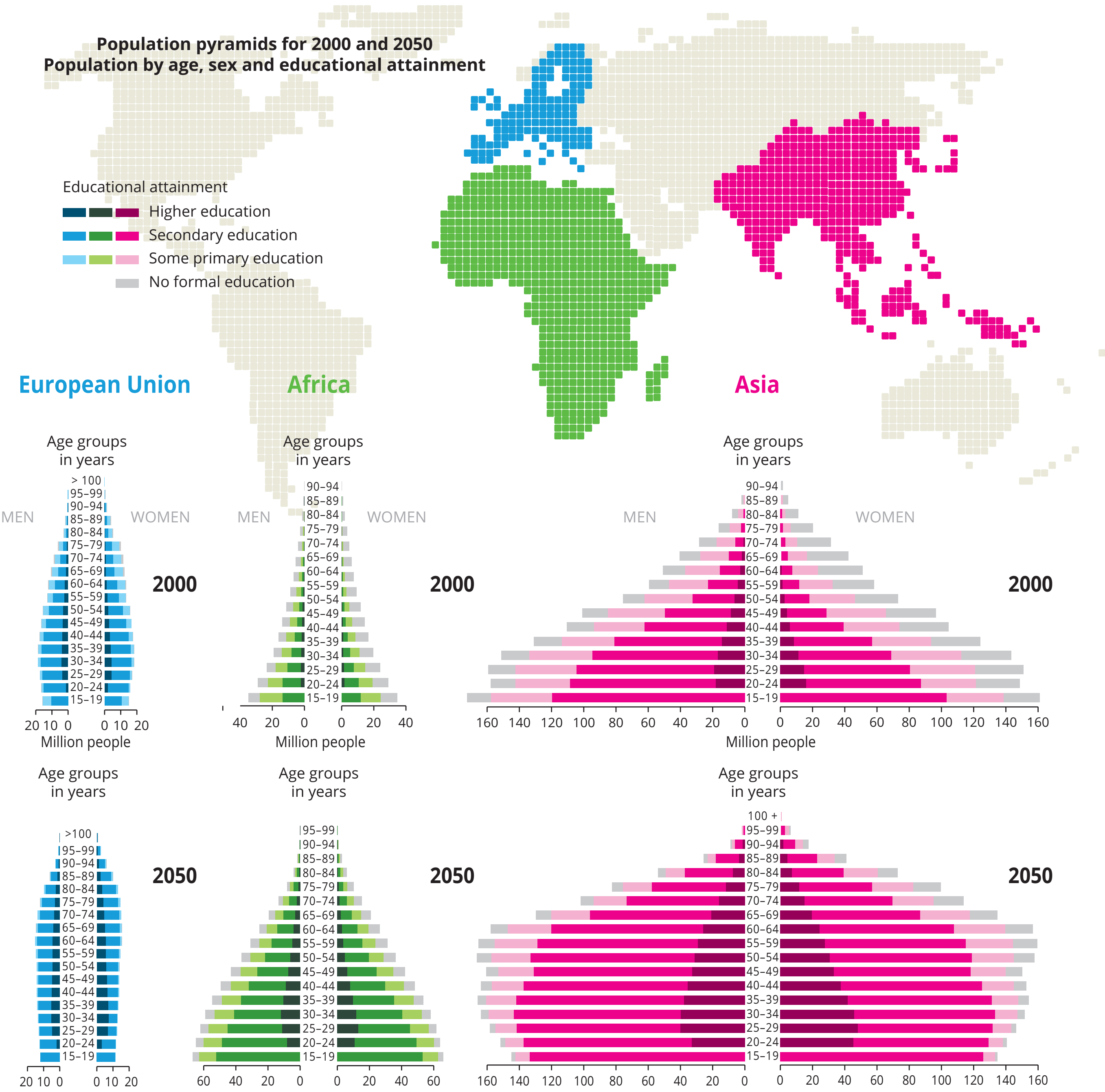
The challenges facing those countries currently experience youth bulges have been exacerbated in recent years by the global economic crisis, which has disproportionately impacted young people. Since employment itself provides an important means of developing skills and experience, the jobs crisis has serious implications for the future employability and earnings potential of a substantial group of young workers (Ortiz et al., 2012).

Increasing burdens of ageing populations

In other countries further advanced in the process of demographic transition, threats to social cohesion are more likely to arise from population ageing and decline. While these trends may alleviate some of the growth in demands on ecosystems, they can threaten the social security and public health systems established in the context of growing working-age populations. As old-age dependency ratios increase, the social contract may come under strain. Public finances could worsen as a smaller economically active population is relied upon to provide for the pensions, health care and other needs of the elderly.

Preserving living standards as populations age and avoiding a breakdown in social cohesion will require that countries use the period when they benefit from a disproportionately large workforce to prepare for subsequent population ageing and decline. This could involve two sets of measures: first, investing some

Figure 1.11 Population pyramids for Europe (left), Africa (centre) and Asia (right) in 2000 and 2050



Note: Please note that children under 15 are not represented on the age pyramids.

2050 education attainment calculated according to the Global Education Trend (GET) scenario.

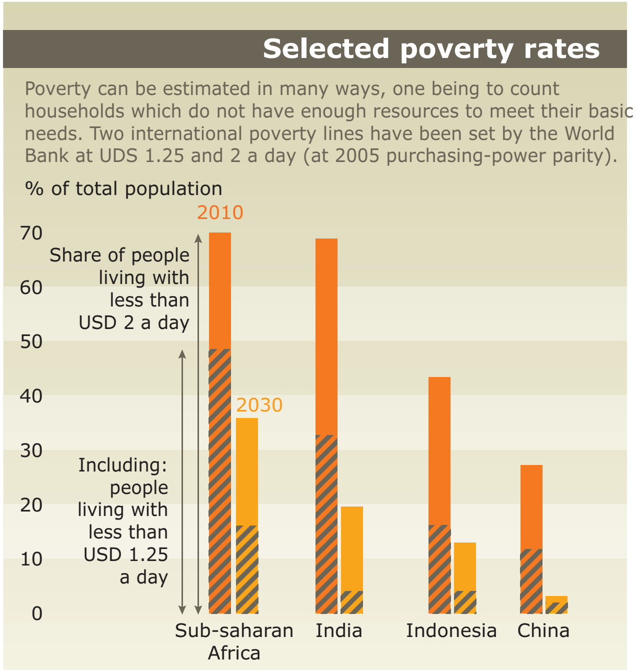
The GET scenario is not derived from a simple assumption. It is based on the country's educational expansion historical trend.

Source: Samir et al., 2010.

of the economic returns into education, skills, health and infrastructure that can enable a relatively smaller workforce to maintain or enhance economic output (Figure 1.11); second, building up savings to finance pensions, thereby reducing the need reliance of the elderly on transfers from current workers.

China has made very significant progress in improving educational enrolment. By 2030 it is expected to have more educated people of working age than Europe and Northern America together (Lutz and Goujon, 2001). Whether the large populations of young people concentrated in the world's poorest countries will benefit from such investments is unclear.

Figure 1.12 **Reductions in population living in extreme poverty**



Source: World Bank PovcalNet, 2013; Uri Dadush and Bennett Stancil, The World Order in 2050, Carnegie Endowment for International Peace, Policy outlook, April 2010.

Migration and workforces in developed regions

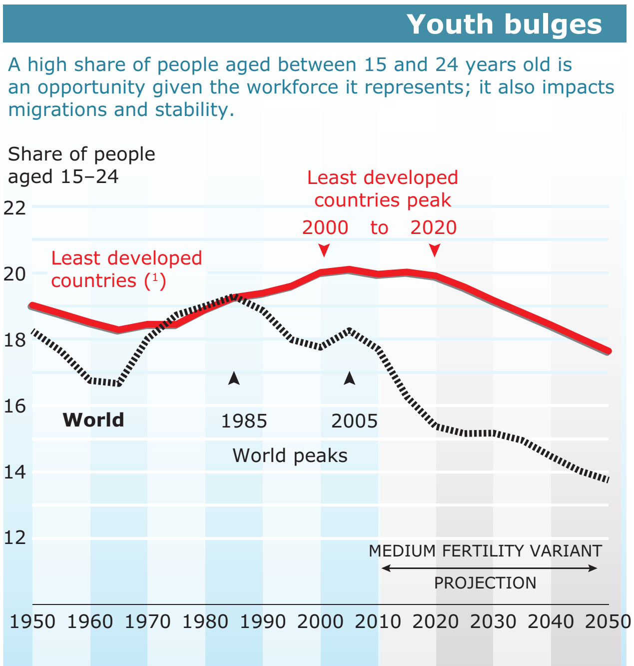
In past decades, migration from developing regions has often delivered economic benefits to the advanced economies. In addition to mitigating population ageing (in part by affecting fertility rates), immigration can increase the working-age population and offering valuable skills to the labour market. It is estimated, for example, that 30% of migrants in the OECD have tertiary education (OECD and UNDESA, 2013). Migration flows have also brought changes in the ethnic and cultural complexion in the recipient countries.

For developing regions, past migration flows have brought significant costs but also some benefits. The loss of highly skilled persons is one major concern, potentially undermining the productive capacity and development prospects of poor nations. According to OECD and UNDESA (2013), one in nine tertiary educated persons born in Africa resides in OECD countries. The situation is especially worrying in small countries and island states. For example, in 2010 almost 90% of highly skilled persons born in Guyana lived in OECD countries. In contrast, large countries in developing regions, such as Brazil, China, India and the Russian Federation, had low emigration rates of the highly skilled (below 3.5%).

At the same time, however, migrant workers provide a major source of revenues for the populations that they leave behind. The World Bank estimates that remittance flows to developing countries reached USD 414 billion in 2013 — nearly three times the size of official development assistance. By 2016, they are projected to increase to USD 540 billion. Transfers on this scale represent a crucial source of income to support livelihoods and finance development.

The projected changes in migration flows in coming decades are likely to bring some redistribution of the benefits and costs of migration. In developed regions, reduced immigration to some countries may imply that populations age more rapidly, increasing the ratio of dependents to workers. In relatively prosperous parts of the developing world, increasing inflows of migrants may produce the opposite effects.

Figure 1.13 **Share of youth in world population and in least developed countries, 1950–2050**



Note: ([1]) Afghanistan, Angola, Bangladesh, Benin, Bhutan, Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Comoros, D.R. Congo, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Haiti, Kiribati, Lao, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Myanmar, Nepal, Niger, Rwanda, Samoa, São Tomé and Príncipe, Senegal, Sierra Leone, Solomon Islands, Somalia, South Sudan, Sudan, Timor-Leste, Togo, Tuvalu, Uganda, Tanzania, Vanuatu, Yemen and Zambia.

Source: UN Population Division, World Population Prospects: (2012 revision).

Challenges for Europe

Global environmental policy today seeks to address and mitigate the environmental effects of anticipated population growth, particularly in the most vulnerable areas (typically developing regions).

Costs related to ageing, health and education (pensions, expanded education spending, labour shortages) will increase fiscal pressures, and a drying up of migration could make things worse. Both, population age structure and the specific features of economic life-cycle in each society (including consumption and production patterns) have important economic and policy implications. The legacy of the crisis — with often large increases in public debt — unfavourable demographics, and rising spending pressures in areas like health and education all contribute to substantial fiscal pressures. In several cases, structural reforms can mitigate fiscal pressures without harming growth and equity, thus providing a way to avoid difficult trade-offs (OECD, 2014).

In Europe as a whole, population decline later in the current century may help ease environmental pressures, although it will need to be coupled with sound environmental policy in order to achieve substantial reductions in resource use and pollution. Moreover, demographic trends create some difficult challenges for European policymakers. The expanded workforce during recent decades has underpinned substantial improvements in living standards and the development of the welfare state. Sustaining these systems will present significant challenges in the light of population dynamics.

It is important to stress, however, that projected demographic trends vary markedly across Europe. According to Eurostat (Eurostat, 2011a), the EU-27 population will remain fairly static in the period 2010–2060, increasing by 5% between 2010 and 2040 and then declining slightly. Some Member States are projected to grow substantially, however, for example Ireland (46%), Luxembourg (45%), Cyprus (41%), the United Kingdom (27%) and Belgium (24%). Others are expected to contract significantly, such as Bulgaria (27%), Latvia (26%), Lithuania (20%), Romania and Germany (19%).

These trends would have important implications for the distribution of Europe's population, and for the related distribution of economic output, resource use and environmental pressures. For example, according to the Eurostat projections, Germany's population would decline from 82 million to 66 million, whereas the United Kingdom would become the EU-27's largest population, growing from 62 million to 79 million.

The contrasting population dynamics would also result in variance in the burden of ageing populations. Although the proportion of the population aged over 65 is expected to increase in all European countries up to 2060, the projected rates range from 22% in Ireland and 25% in the United Kingdom, Belgium and Denmark to 36% in Latvia, 35% in Romania and Poland and 33% in Bulgaria, Germany and Slovakia (2011c).

Understanding and anticipating Europe's demographic trends will allow the EU to reach out to its population, to promote awareness, and to invest in its human capital, in order to help manage risks and drive a more sustainable economy. EU Member States may be able to pre-empt certain associated challenges, for example via smart urban design or effective support structures for older populations. Such measures could help tackle some of Europe's environmental and sustainability issues more quickly and effectively.

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Global megatrend 2 — Living in an urban world

Urbanisation is an integral aspect of development. As countries transition from primarily agricultural economies, the shift to cities offers substantial productivity gains. Jobs and earnings in urban settings create strong incentives for internal migration, often reinforced by government policies and environmental degradation. Only later in economic development do urban-rural disparities begin to dissipate, easing the pressure for further urbanisation.

Together, these drivers have brought extraordinary changes to the geographical distribution of humanity during the last century. Whereas just 10–15% of the global population lived in urban areas in the early 20th century, that figure had risen to 50% by 2010 (WBGU, 2011) and is projected to reach 67% by 2050 (UN, 2012). Almost all of that growth is expected to occur in today's developing regions, with urban populations there increasing from 2.6 billion in 2010 to 5.1 billion in 2050.

At the individual level, urbanisation can boost opportunities and living standards. At the macroeconomic level, cities drive innovation and productivity. But while the associated growth of the middle class is welcome, it also carries risks in terms of rapidly growing burden of resource use and pollution. Dense urban settlements can provide for comparatively resource-efficient ways of living but exploiting this potential and creating a healthy, secure living environment requires effective urban planning. Indeed, the consequences of ill-managed urbanisation are apparent in the vast slums that today accommodate a quarter of the world's urban inhabitants — more than 850 million people.

2.1 Drivers

Urbanisation ([1]) — growth in the proportion of a population inhabiting towns and cities — is the result of multiple, interrelated drivers. As detailed in this section, these drivers tend to evolve as urbanisation progresses, enhancing or mitigating rural-urban disparities in living standards and opportunities.

Increased opportunities in cities as countries industrialise

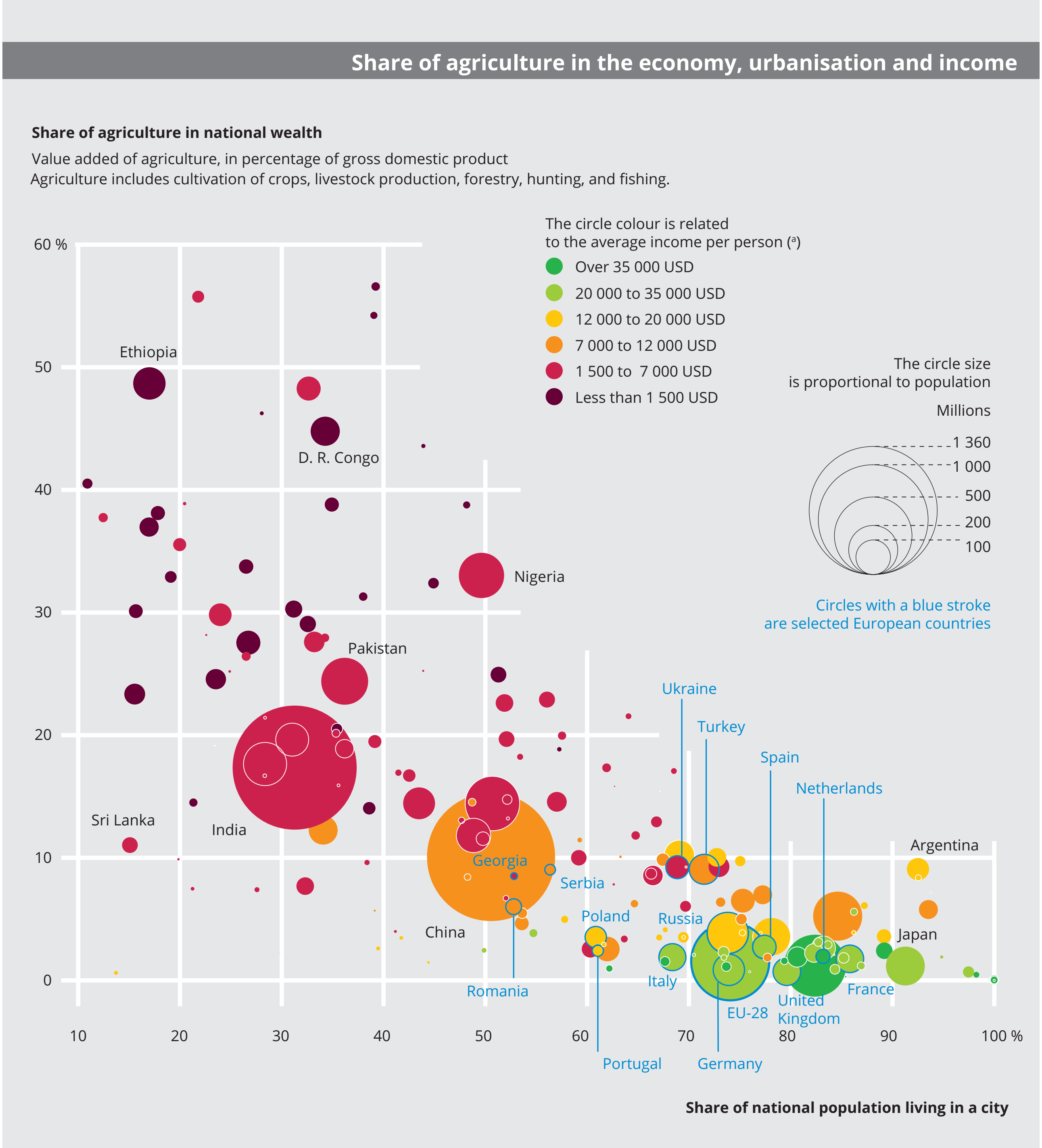
Across the world (although at different times) the shift to cities has initially been catalysed by changes in the agricultural sector (Figure 2.1). Innovations such as crop rotation, fertiliser and pesticide use, selective breeding and mechanisation have greatly enhanced food production, enabling far fewer farm workers to meet the food requirements of growing populations. The resulting pool of surplus labour allows countries to evolve towards industrialised and, later, service-based economies. Urbanisation is an essential element in this transition (Kuznets, 1960; World Bank, 2009).

Industrialisation brings urbanisation because of the benefits that businesses, workers and consumers derive from proximity. Cities make it easier for companies to benefit from two related forms of cost savings: internal scale economies, and external scale economies (or 'economies of agglomeration'). The former occur where expanding production in a single company enables cost savings (e.g. by boosting bargaining power for inputs, reducing average fixed costs, and facilitating division of labour). Cities can support internal economies of scale by providing ready access to a large pool of suppliers and skilled workers (World Bank, 2009).

Economies of agglomeration arise through the collocation of multiple companies. This can bring the firms a range of benefits, including attracting customers and skilled workers; fostering the diffusion of innovation; enabling sharing of ideas and information within the labour market; spreading fixed infrastructure costs over more taxpayers; and providing dense local markets for inputs and outputs of production, minimising transport costs. Agglomeration can also support specialisation, enhancing opportunities for innovation and cost saving (Quigley, 2008).

([1]) 'Urbanisation' is growth in the proportion of people living in urban areas. 'Urban growth' relates to the increase of populations living in urban areas, and therefore comprises both relocation of rural populations to cities and also natural population growth in cities.

Figure 2.1 **Economic development entails a shift from farming to cities**



Notes: (a) Gross Domestic Product by Purchasing Power Parities, in international dollars, at fixed 2005 prices.

The inflation and differences in the cost of living between countries has been taken into account.

Please note that European Union countries are represented both individually and collectively (EU-28).

The figure illustrates the correlation of economic development (represented in terms of GDP per capita in PPP terms) with agriculture and urbanisation. Agriculture can account for 50% or more of economic output in the countries with the lowest living standards and the populations are primarily rural. In the countries with the highest living standards, urban dwellers often account for more than three-quarters of the population and agriculture plays a minimal role in economic output.

Source: World Bank; UN Population Division; Gapminder; 2013. Agriculture data for 2012 (or most recent value available), urbanisation data for 2011, population data for 2013, income data for 2012 (or most recent value available).

The effect of these two forms of scale economies is to boost earnings in cities. Research suggests, for example, that when a city's population doubles, economic productivity increases by 130% due to the increased opportunities for interaction afforded by greater urban population density (MIT, 2013).

Turok and McGranahan (2013) stress, however, that 'there is no simple linear relationship between urbanisation and economic growth, or between city size and productivity'. This is partly because the concentration of people and business activity in urban settings can generate substantial costs, offsetting the advantages of agglomeration. These costs include congestion, overcrowding, pressures on infrastructure and ecosystems, and higher costs of living, labour and property in cities. City planning and sufficient investment in infrastructure are therefore key in determining the returns to agglomeration.

Relative decline in rural opportunities and living standards

As countries transition from primarily agricultural systems towards industrialised economies, rural areas tend to see weaker growth in productivity and earnings than cities. This partly reflects the fact that the accumulation of capital in cities allows significant productivity increases, while labour surpluses persist in rural areas (World Bank, 2009). But in many developing countries government interventions into the agricultural sector also contribute to rural poverty. Examples of such policies include an urban bias in public investments, state administration of agricultural product prices and exchange rates, and rules favouring export crops over food crops (Khan, 2001).

These forces can contribute to sharp income differentials between rural and urban populations. In China, for example, average household incomes are now nearly three times higher in urban than in rural areas (Turok et al., 2013). Such disparities are at the core of the incentives driving the shift from rural areas to cities. They extend beyond employment opportunities and income levels to a range of other aspects of development, including access to education, health services and amenities (World Bank, 2009). Today, urban areas account for 80% of the world's economic output (UN, 2012) and this wealth, coupled with the density of urban settlements, provides city dwellers with access to diverse social and cultural opportunities.

As economic development progresses, rural-urban disparities tend to diminish. This is partly because the flow of workers to cities reduces surplus agricultural labour and alleviates competition among rural workers, increasing productivity and per capita earnings. In addition, increasing government capacity and fiscal redistribution also tend to play a role (World Bank, 2009).

India's wage structure, for example, used to be characterised by a significant difference in wages but this gap in wages is now narrowing (Hnatkovska and Lahiri, 2013). The World Bank (2009) finds that disparities in access to clean water and sanitation services tend to diminish at high levels of urbanisation and per capita GDP (Table 2.1).

Environmental change and government policy

Environmental degradation (often linked to economic systems of production and consumption) plays an increasingly important role in internal migration. Climate change can have particularly severe impacts on rural inhabitants as they tend to depend heavily on activities and resources that are especially sensitive to climatic variables (Hunter, 2007). As temperatures or precipitation patterns change, some areas that currently offer favourable conditions for such climate-sensitive

Table 2.1 Rural-urban disparity in access to clean water and sanitation

Urban population share	Disparity in access to clean water (percentage points)	Disparity in access to sanitation (percentage points)	Examples of countries in this sample
75%	8	8	United States, Norway, Switzerland, Spain, Germany, Canada, Mexico, Chile, Brazil, Argentina, Gabon, Venezuela, Djibouti, Lebanon, Jordan, United Kingdom
50–70%	15	20	Estonia, Panama, Turkey, Hungary, Ecuador, Colombia, Malaysia, Syria, Azerbaijian, South Africa, Congo, Algeria, Tunisia, Bolivia
25% or lower	24	26	India, Yemen, Madagascar, Chad, Tajikistan, Bangladesh, Tanzania, Kenya, Nepal, Cambodia, Malawi, Uganda, Sri Lanka, Bhutan

Source: World Bank, 2009.

Box 2.1 Uncertainties in future drivers of urbanisation

Looking ahead, resource consumption trends could reinforce the tendency towards improving rural earnings. Economic growth has historically been based on cheap and abundant resources but prices of energy, food and metals have all increased sharply in recent years (GMT 7). At present it is often profitable to convert agricultural land into urban land but increasing demand for cash crops could increase the value of rural land and labour (IIED, 2012). Government measures (e.g. removal of price controls in agricultural product markets and investment in infrastructure) can also boost earnings and incentivise productivity increases (Kherallah et al., 2002).

Technological leapfrogging — resulting from foreign investment, development assistance or domestic innovation — also has the potential to influence the incentives driving urbanisation. Development of new energy, transportation and communication technologies could boost economic opportunities and living standards in rural areas, affecting migratory pressure towards urban areas. Increased demand for bioenergy crops, for example, could enhance rural incomes (in part by increasing food crop prices). However, it could also increase pressures on natural capital, creating uncertain impacts on well-being (de Nie et al., 2009).

Similarly, development of decentralised energy production systems could augment rural access to basic services such as lighting and water pumping, and increase opportunities for income-generating activities, further decreasing migratory pressures. On the other hand, experience suggests that technological innovation does not always alter incentives as expected. Despite the development of ever more sophisticated communication technologies (from the telephone to the internet and videoconferencing), firms and workers are still willing to bear the costs of agglomeration because of the enormous benefits if offers, including human capital spillovers and cultural complexity (Glaeser, 2009).

activities could see productivity decline (Chavas et al., 2009; see also GMTs 8 and 9).

Government interventions can also contribute to environmental change, in some cases making areas uninhabitable. A prime example is the policy of hydroelectric dam construction in China. During the 1950s and 1960s, China moved some 7.8 million people to make way for dam construction. More recently, the Three Gorges Dam has been a major driver of migration to cities. In 2007, it was reported that at least 4 million people will be relocated from the Three Gorges Reservoir area in coming years (Gleick, 2008).

Recognising the human and economic costs that can arise, many governments have introduced policies to manage urbanisation. In 2005, 73% of low-income countries had put policies in place to lower migration to cities. In most cases, however, these attempts have not been successful (UN, 2011a).

2.2 Trends

Contrasting urbanisation trends across the globe

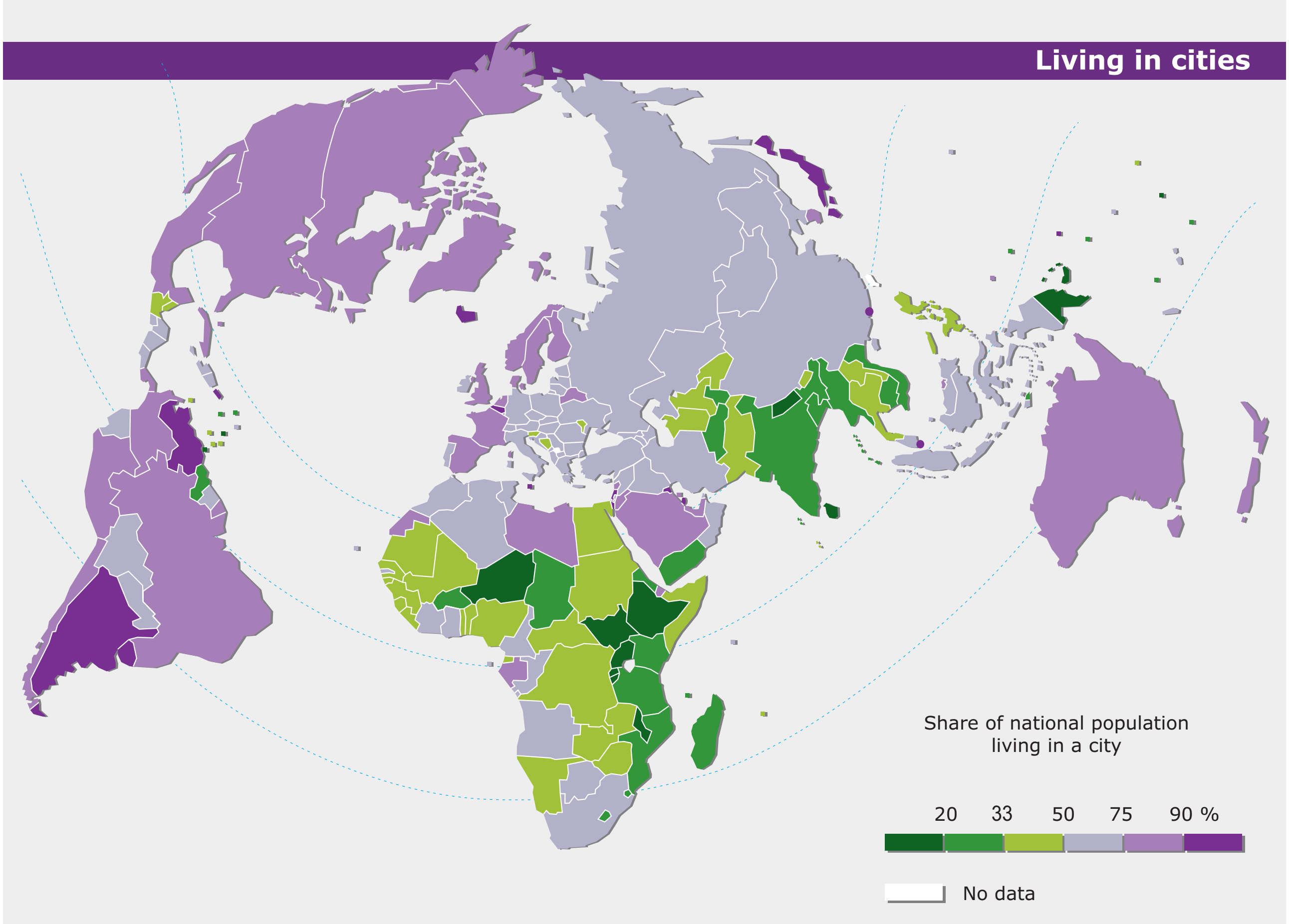
Humanity's shift from the countryside to cities has been remarkably rapid. Whereas just 10–15% of the global population lived in urban areas in the early 20th century, that figure had risen to 50% by 2010 (WBGU, 2011). In absolute terms, that represented a 20-fold increase, from around 165 million city dwellers to 3.5 billion. Today the growth of cities continues apace, with urban populations expanding by 1 million persons each week (WBGU, 2011).

The global population today exceeds seven billion and is expected reach 9.6 billion by 2050 according to United Nations medium-variant projections (see GMT 1). Urban populations are expected to grow even faster in both relative and absolute terms, reaching 6.2 billion in 2050 (about two-thirds of the world population).

Beneath these global trends lie substantial regional differences in the extent and pace of urbanisation. Developed regions tend to be highly urbanised, with modest growth in urban populations projected in the coming decades. The least developed countries tend to have relatively small but rapidly increasing urban populations — a result of both internal migration and rapid natural rates of population growth (see GMT 1).

In 2010, northern America had the highest proportion of its population living in cities (82%), followed by Latin America and the Caribbean (79%), Europe (70%) and Oceania (71%). Asia and Africa currently have the lowest urbanisation levels with 48% and 40% respectively. In 2010 city dwellers accounted for 78% of the population in developed regions, 46% in developing regions and 26% in the least developed regions (UN, 2012). Figure 2.2 presents the national urbanisation levels in 2010.

Figure 2.2 National urbanisation levels in 2010



Source: UN Population Division, World Urbanization Prospects (2011 revision).

Two waves of urbanisation

Global urbanisation trends can be crudely divided into two 'waves'. The first began in Europe and North America in the early 18th century. Between 1750 and 1950, these regions experienced the first demographic transition, with urban populations increasing from 15 million (10% of the total population) to 423 million (52%) (UNFPA, 2007).

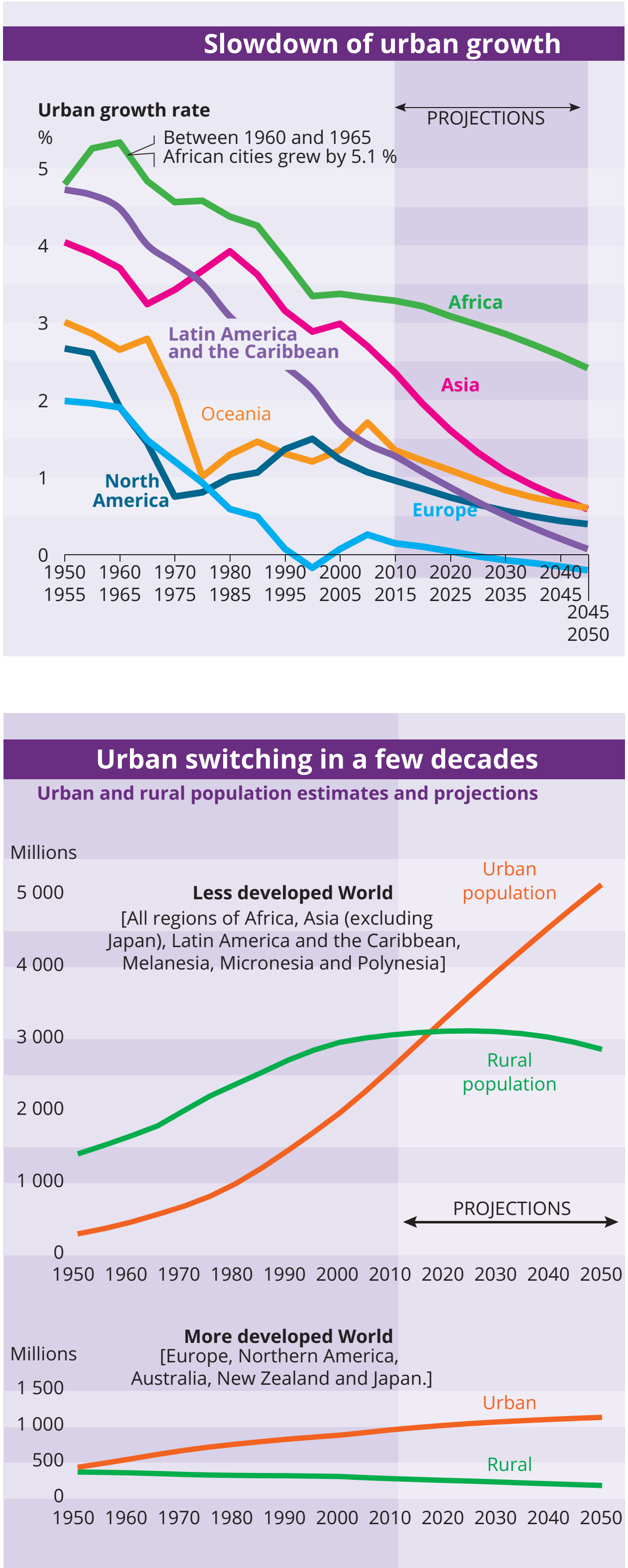
Urban populations in today's developed regions continued to grow in the second half of the 20th century but at relatively low rates (Figure 2.3). Europe's urbanisation dropped to near zero in the 1990s before reverting to very modest growth in the last decade.

By 2010, 957 million people lived in urban settlements in developed regions and the percentage of city dwellers is expected to continue rising from 78% to 86%, adding a further 170 million people to the urban population in developed regions (UN, 2012). Nevertheless, these numbers are dwarfed by trends elsewhere .

Commencing midway through the 20th century, the second wave of socio-economic transition has primarily affected today's developing regions. While the rates of change in these regions have been comparable to the earlier transition in Europe and northern America and are today declining, the size of populations in developing regions has brought urbanisation on an unprecedented scale. Many of the cities that will be created by the second wave do not even exist yet and many of the ones that do are ill equipped to handle these expansions. This can challenge the capacity of governments to plan and meet the needs of the rapidly growing number of urban dwellers.

Urban populations in developing regions rose from 309 million in 1950 to 2.6 billion in 2010 and are projected to reach 3.9 billion in 2030. It is estimated that in the 80 years between 1950 and 2030, the proportion of the population dwelling in cities in developing regions will increase from 18% to 56% (JPI Urban Europe, 2011). By 2050, the urban population in developing regions

Figure 2.3 **Unprecedented levels of urbanisation despite declining urban growth rates**



Note: Please note the five-year steps.

Source: UN Population Division, World Urbanization Prospects (2011 revision).

is projected to reach 5.1 billion — equal to 64% of the total population (UN, 2012; Figures 2.3 and 2.4).

Driven by high natural population growth rates, Africa had the highest urban population growth rate in the period 2005–2010, with an average annual growth of 3.4% (Figure 2.3). Asia recorded the highest rate of urbanisation (i.e. the fastest increase in the percentage of the population living in cities).

According to UN estimates, Africa and Asia alone will account for 86% of urban growth globally in the period 2010–2050 (UN, 2012). Even as far ahead as 2045–2050, the increase in city dwellers is projected to remain high in these countries, with an additional 25 million people per year in Africa and 35 million in Asia (Figure 2.4).

More megacities but small settlements still dominate

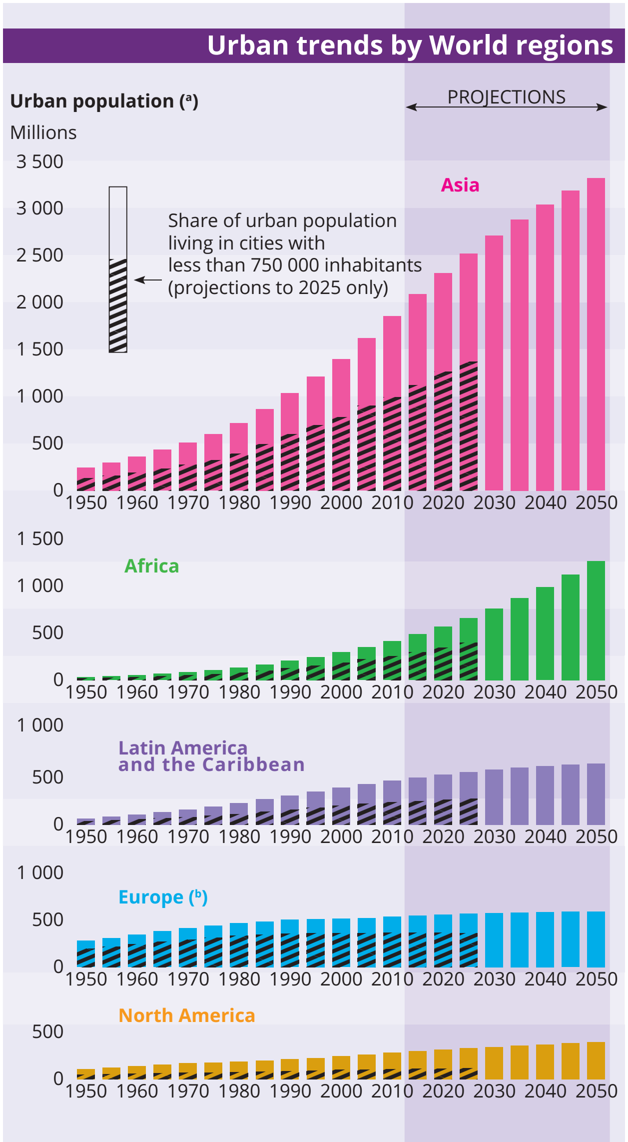
The increase in the total number of city dwellers has been accompanied by changes in city size. In 1900 there were 12 cities with more than 1 million inhabitants but by 2000 this number had reached 378. During the same period, the average size of the world's hundred largest cities increased from 700 000 to 6.3 million (Satterthwaite et al., 2010).

The emergence of megacities (i.e. cities with more than 10 million inhabitants) is equally striking. Whereas there were just two megacities in 1950, by 2014 there are 28, most of which are in developing regions. Nevertheless, the trend towards larger cities is certainly mixed. Only about 5% (359 million) of the world population inhabited megacities in 2011, whereas 52% (1 849 million) of the world's city dwellers reside in small urban settlements of less than 500 000 inhabitants (Figure 2.6).

Although the population in megacities is projected to double by 2025, the growth of megacities is not uniform. Satterthwaite et al. (2010) note, for example, that commencing in the 1970s some high-income countries have experienced 'demetropolitanisation' as people move from large to smaller cities and suburbs. Cities do not necessarily develop from small to megacity. Urbanisation has resulted in far more small and medium size cities than megacities (Figure 2.5.). For example, between 1990 and 2000, 694 new cities developed and only 52 developed into big cities of one to five million inhabitants.

Significant regional differences have also developed in the size of agglomerations. Most African and European urban populations inhabit small cities of less than 500 000 inhabitants. In contrast, city dwellers in Asia, Latin America and the Caribbean and North America

Figure 2.4 **Africa and Asia will account for the greatest increases in urban populations**



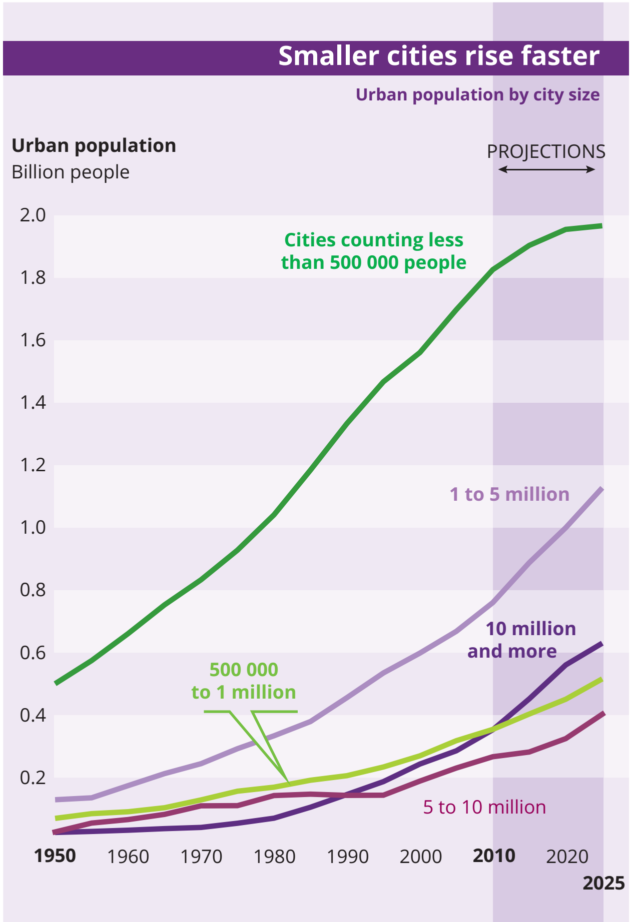
Notes: Urban areas of Oceania — are projected to reach 40 millions of urban population people by 2050 (currently 26 million). They are not included in the above graph for legibility reasons.

(ᵃ) The definiton of 'urban area' varies from one country to the next.

(ᵇ) EU-28 + Albania, Andorra, Belarus, Bosnia and Herzegovina, Channel Islands, Faroe Islands, Gibraltar, Holy See, Iceland, Isle of Man, Liechtenstein, Monaco, Montenegro, Norway, the former Yugoslav Republic of Macedonia, Moldova, Russia, San Marino, Serbia, Switzerland and Ukraine.

Source: UN Population Division, World Urbanization Prospects (2011 revision).

Figure 2.5 **Smaller cities have risen faster**



Source: UN Population Division, World Urbanization Prospects (2011 revision).

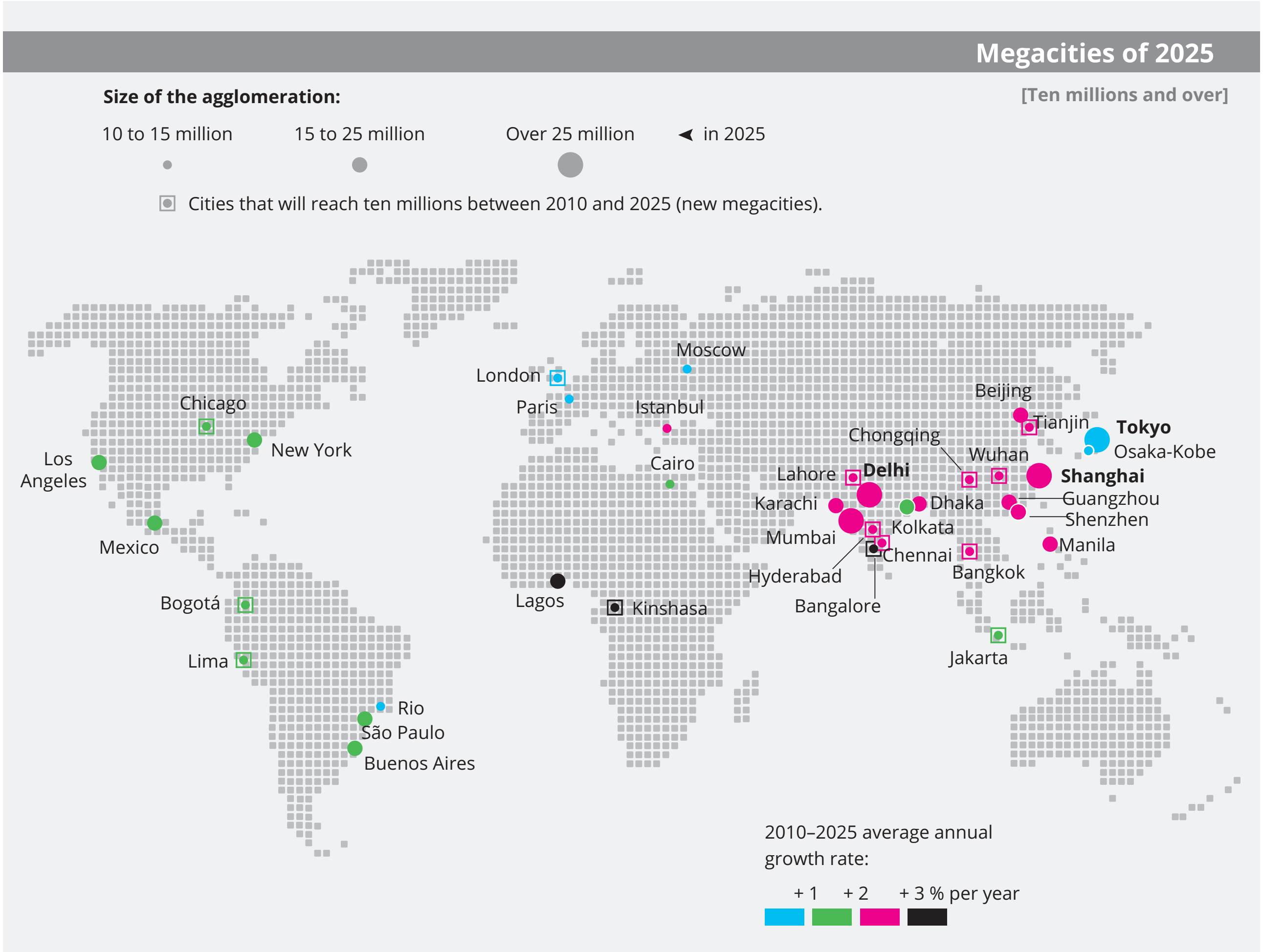
tend to live in significantly larger urban settlements (UN, 2012). As illustrated in Figure 2.6, the world's largest megacities are expected to be concentrated in south Asia and east Asia.

Slum growth on an unprecedented scale

Slums are not new. They have been a counterpart of rapid urbanisation since at least the 17th century (de Soto, 2010) and the term 'slum' dates back to at least the 1820s (UN-Habitat, 2007). Rapid, unmanaged migration, often driven by poverty, combined with weak property rights regimes provide the ingredients for the formation of crowded informal settlements, lacking basic amenities such as clean water and sanitation [2]. And the most rapid urbanisation is currently taking place in developing regions with the

[2] UN-Habitat (2013a) defines urban slum dwellers as 'individuals residing in housing with one or more of the following conditions: inadequate drinking water; inadequate sanitation; poor structural quality/durability of housing; over-crowding; and insecurity of tenure'.

Figure 2.6 **Total population in millions by city size class (1970, 1990, 2011 and 2025)**



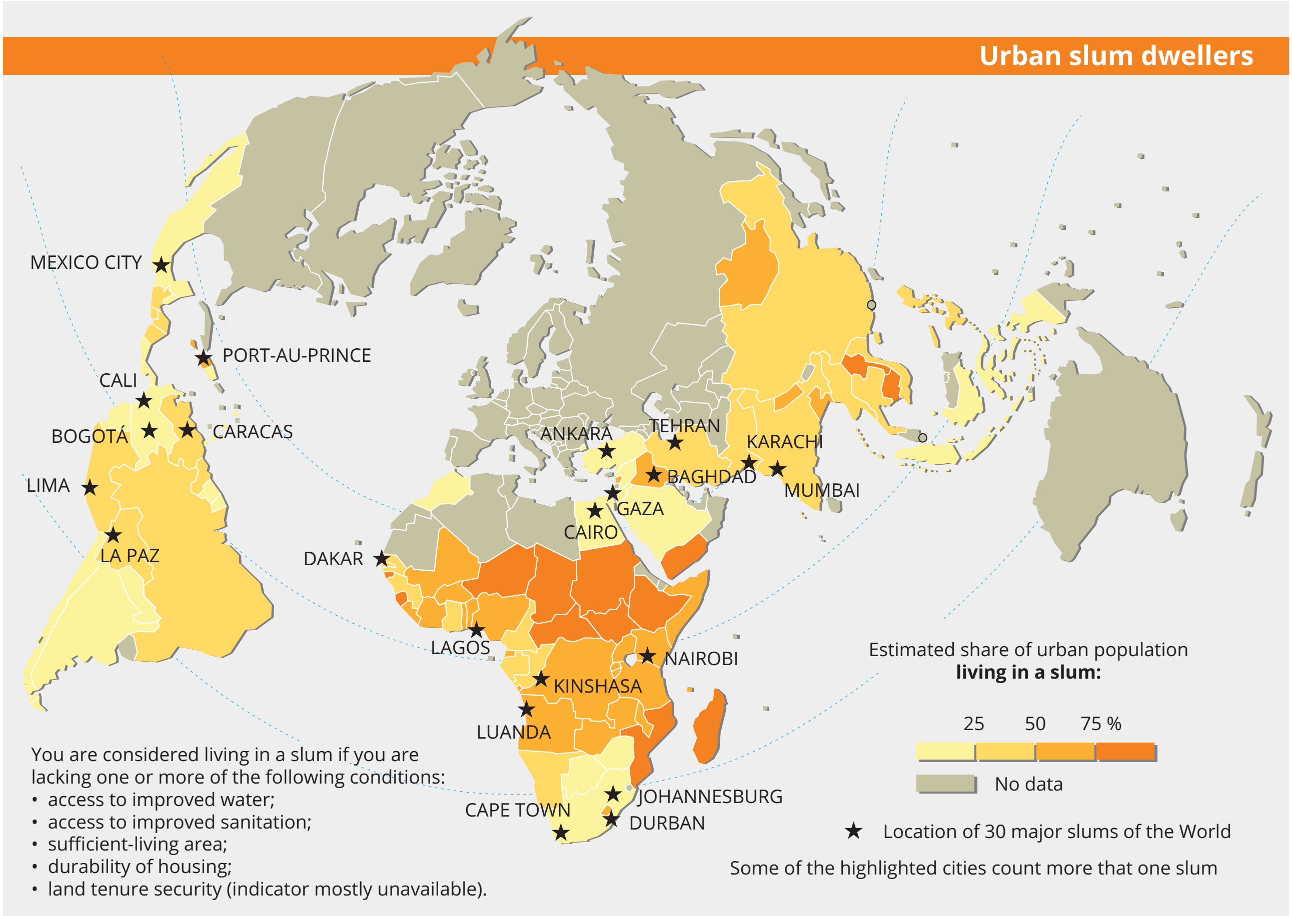
Source: UN Population Division, World Urbanization Prospects (2011 revision).

least capacity to manage effective urban planning and meet the needs of fast growing city populations.

While the formation of slums is not new, the scale and prevalence of today's slums is unprecedented. The population living in slums in developing regions totalled 863 million in 2012, up from 760 million in 2000, and 650 million in 1990 (UN-Habitat, 2013b). Slums thus account for approximately a quarter of the world's urban population and 33% of the city dwellers in developing countries. In some regions and countries the proportions are much higher (Figure 2.7). In 2012, the percentage of urban populations inhabiting slums reached 62% in sub-Saharan Africa and exceeded 90% in some African countries (UN-Habitat, 2013b).

Despite the growth in absolute numbers, however, the proportion of the urban population living in slums has declined sharply in recent years. For developing region as a whole, the percentage dropped from 46% to 33% in the period 1990–2012. And although sub-Saharan Africa's slum population accounted for 62% of urban dwellers in 2012, that was a decline relative to 70% in 1990. In some areas the decline was even more striking: from 44% to 28% in east Asia; from 57% to 35% in southern Asia; and from 50% to 31% in south-east Asia (UN-Habitat, 2013b).

Figure 2.7 **Percentage of national urban populations living in slums**



Source: UN Habitat, *Global Report on Human Settlements 2013*. Data: 2005 to 2009 (for the data on the location of the 30 largest slums in the world) and Mike Davis, Planet of Slums, 2007.

2.3 Implications

Urbanisation offers a complex mixture of opportunities and risks to individual living standards and societal well-being. At the macroeconomic level, cities can drive economic growth, boosting productivity and incomes. While the associated increase in resource use and consumption can increase pressure on the environment, dense urban settlements can also provide for comparatively resource-efficient lifestyles. Rural-urban migration can also generate significant costs, however, particularly when it occurs in an unplanned and unregulated way. The growth of slums, characterised by insecurity and poverty, is a major concern in developing regions. Equally, the concentration of people and businesses into urban areas can also significantly undermine living standards, for example via exposure to pollution.

Economic development and quality of life

The huge growth in urban populations is closely bound to the fundamental rebalancing of economic power globally (GMT 6) and associated social changes. Cities are on the forefront of economic wealth creation, as most innovation and paid employment tends to be located in urban areas. As illustrated in Figure 2.1 and 2.9, the extent of a country's urbanisation is closely correlated to its economic output. Cities are thus playing a central role in the emergence of the global consumer society, driven in particular by developments in the BRIICS countries, most notably China and India (Reusswig et al., 2003).

According to Kharas (2010), the number of middle class consumers could increase from 1.8 billion in 2010 to 4.9 billion in 2030, with Asia accounting for 85% of that growth (see GMT 6) ([3]). China's middle class already

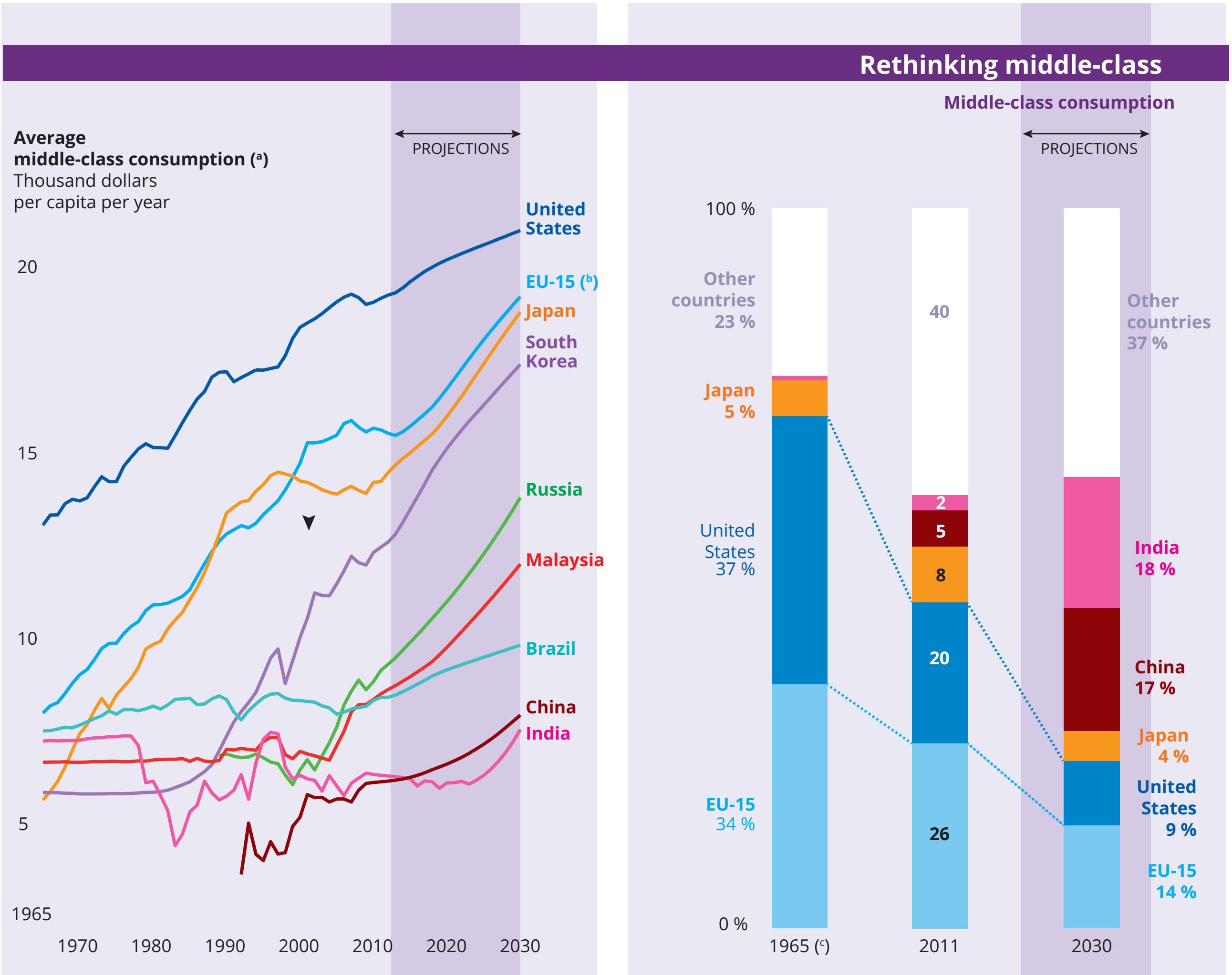
([3]) Kharas defines the middle class as individuals with total daily household consumption expenditure of between USD 10 and USD 100 in 2005 PPP dollars.

numbers more than 150 million, making it second only to the US. And whereas India's middle class currently represents 5–10% of its population, this is projected to reach 90% within just 30 years (Kharas, 2010). As a result, the global distribution of middle class consumption has shifted significantly since 1965, with the US and the EU-15 accounting for a declining share. In the period 2011–2030, this evolution is projected to continue, with India and China in particular coming to the fore (Figure 2.8).

These trends have major implications for the living standards of large portions of the global population, potentially alleviating the insecurity associated with poverty and providing access to an increasing range of goods and services. Middle class citizens have the resources to invest in human and physical capital, and tend to participate more actively in political processes, with implications for economic and social development (Kharas, 2010).

As Figure 2.9 illustrates, highly urbanised countries tend to score well in on UNDP's human development index (a composite indicator conveying life expectancy, education standards and income levels). Yet the figure also highlights the heavy environmental burden associated with high levels of urbanisation. The per capita ecological footprint of richer, more

Figure 2.8 The changing distribution of middle class consumption



Note: (a) Middle-class population is defined here as people living in households earning or spending between 10 and 100 dollars per person per day (2005 dollars, in purchasing power parity).

(b) EU-15 Member States are: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden and the United Kingdom. EU-15-only data have been chosen for consistency reasons.

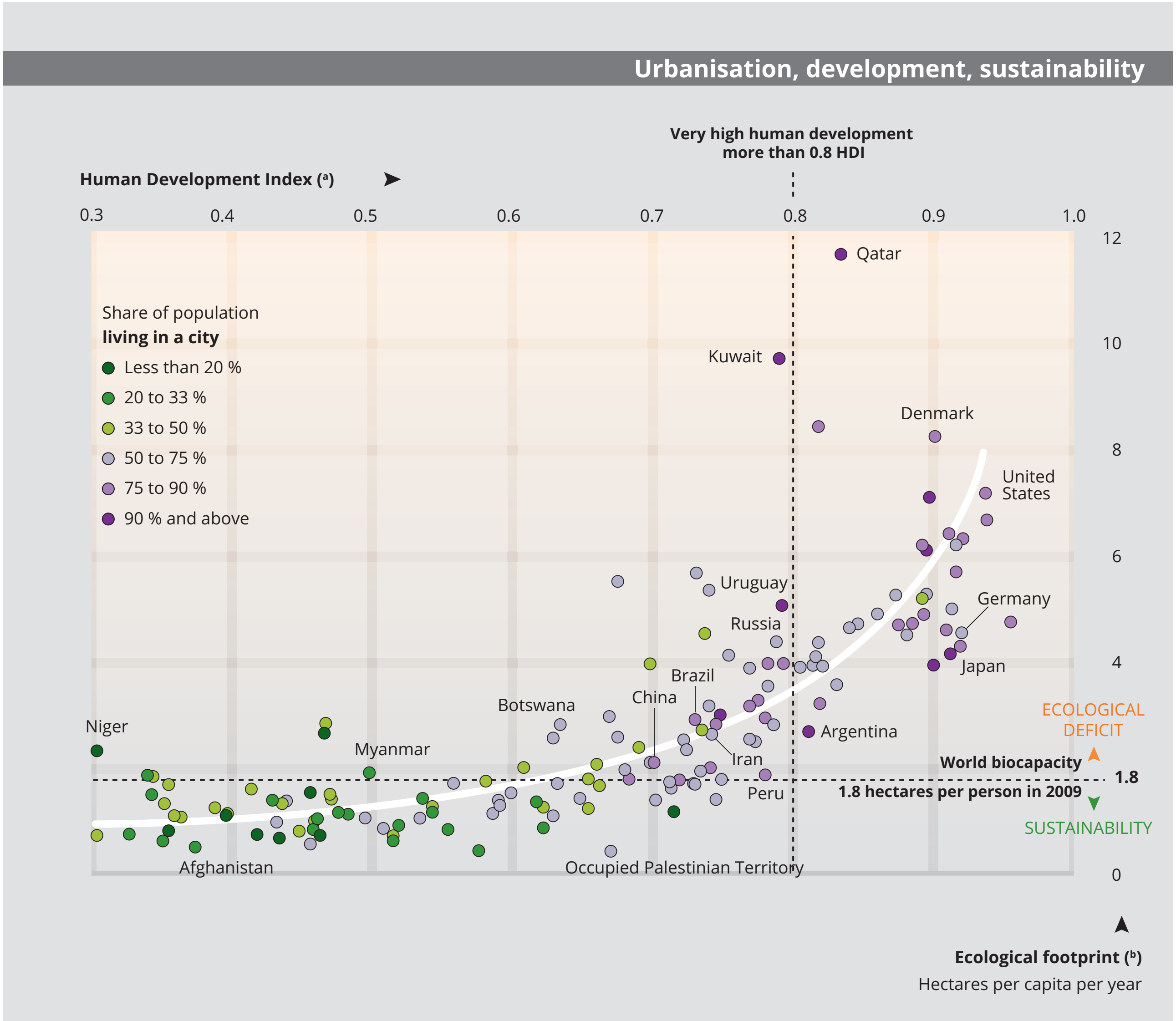
(c) No Chinese data for 1965.

Source: Kaufmann et al., 2012.

urbanised countries tends to greatly exceed global average biocapacity, indicating an unsustainable level of resource use.

Against the broad narrative of rising living standards associated with urbanisation, the rapid growth of slums described above represents a serious concern. Slum inhabitants often endure squalid living conditions and high crime rates (UN-Habitat, 2013b). As detailed in GMT 3, urban poverty and a lack of access to basic services is also associated with increased risks of infectious disease. For example, it is estimated that 20% of the urban population in the least developed countries lacked access to safe drinking water in 2008, and 51% lacked adequate sanitation (UN, 2011b). Some diseases, such as dengue, have become permanently established in urban areas and cause regular epidemics. There are also several examples of urban growth triggering the decline of infectious diseases (i.e. in Marrakech urbanisation generally decreased sand-fly populations and levels of transmission of malaria in Sub Sahara

Figure 2.9 Urbanisation, human development and ecological footprints by country



Note: ([a]) The Human Development Index is calculated using three components: education, life expectancy at birth and wealth. It is expressed as a value between 0 and 1, from less to most developed countries. Data for 2012.

([b]) The Ecological footprint measures how much land and water area a population requires to produce the resources it consumes and to absorb its waste. The World biocapacity is the global productive area available on Earth (it decreases as population grows). Data for 2008.

Source: UN Development programme, 2013; UN population division, World Urbanization Prospects (2011 revision); Global Footprint Network, 2012.

are generally lower in urban areas than in rural areas). However, highly interconnected urban hubs are considered to be in general a catalyst to the spread of diseases. Increased mobility (tourism, big sport gathering etc.) has provided new opportunities for emerging diseases, particularly in cities, which constitute entry points for most travellers. Urban epidemics can reach unprecedented scales and quickly become uncontrollable. The 2009 influenza A H1N1 pandemic shows how fast infections can spread worldwide (see GMT 3 for details) (Alirol et al., 2011).

Greater environmental burdens or increased resource efficiency?

Economic development often implies increased resource use, waste and pollutant emissions, and environmental degradation, although there is some evidence of decoupling of economic growth from environmental pressures at higher income levels (see GMT 7). The huge growth in global economic output during recent decades has greatly increased competition for non-renewable resources and the burden on natural systems (GMTs 7 and 8), with wide-ranging environmental, social and economic implications.

As a key engine of innovation and economic activity, cities are central to these growing pressures. It is estimated, for example, that cities across the world account for 60–80% of energy consumption and approximately half of anthropogenic CO_2 emissions (UNEP, 2011a; Satterthwaite, 2008).

On the other hand, compact urban settlements can provide a means to enhance living standards while alleviating the burden on the environment. Geographical concentration of businesses can make it cheaper to minimise environmental hazards and enforce environmental legislation. Proximity facilitates walking, cycling or public transport in place of private motor vehicles. And higher land prices and limited space incentivise owning smaller dwellings, often within shared structures, thereby reducing energy and resource demands (Dodman, 2009; Glaeser).

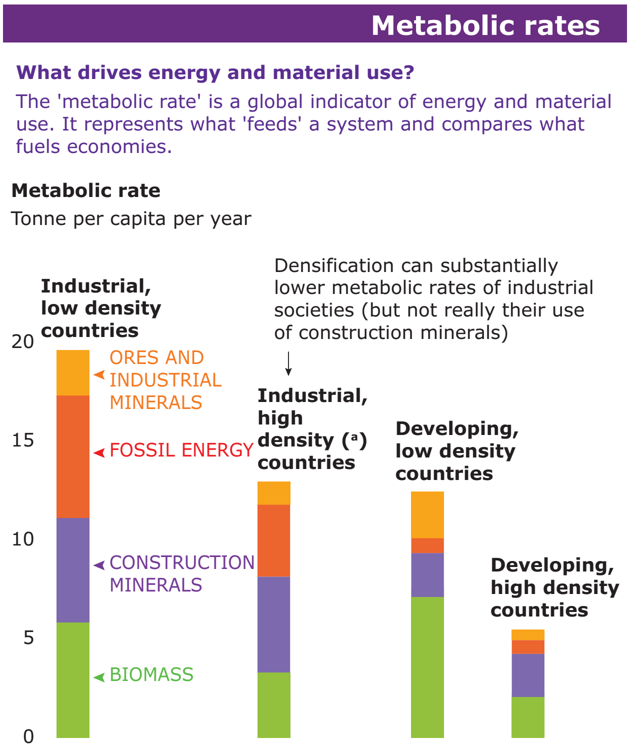
As UNEP (2011a) notes, 'compact, relatively densely populated cities, with mixed use urban form, are more resource-efficiency than any other settlement pattern with similar levels of economic output'. Major cities tend to generate higher per capita economic output at far lower per capita greenhouse gas emissions than the country in which they are situated (UNEP, 2011a; Dodman, 2009). Developing region cities with very large manufacturing sectors, such as Shanghai and Beijing, are the notable exceptions to this general characteristic.

Cities also provide for greater efficiency with respect to consumption of other resources. Krausmann et al. (2008) find that per capita consumption of resources (in particular biomass, metals and industrial minerals) is markedly lower in densely populated areas than in relatively sparsely populated areas. This holds true in both industrialised countries and in non-industrialised regions (Figure 2.10).

The resource efficiency of cities depends greatly on urban planning, in particular with respect to the compactness of settlements. As illustrated in Figure 2.11, per capita transport-related energy consumption in cities varies greatly and is strongly correlated with urban density. There is also clear a regional clustering in terms of energy consumption and density.

Urban sprawl hinders cities from fulfilling their environmental and resource efficiency potential. Based on a study of 120 cities worldwide, Angel et al. (2010) have identified substantial global variance in urban

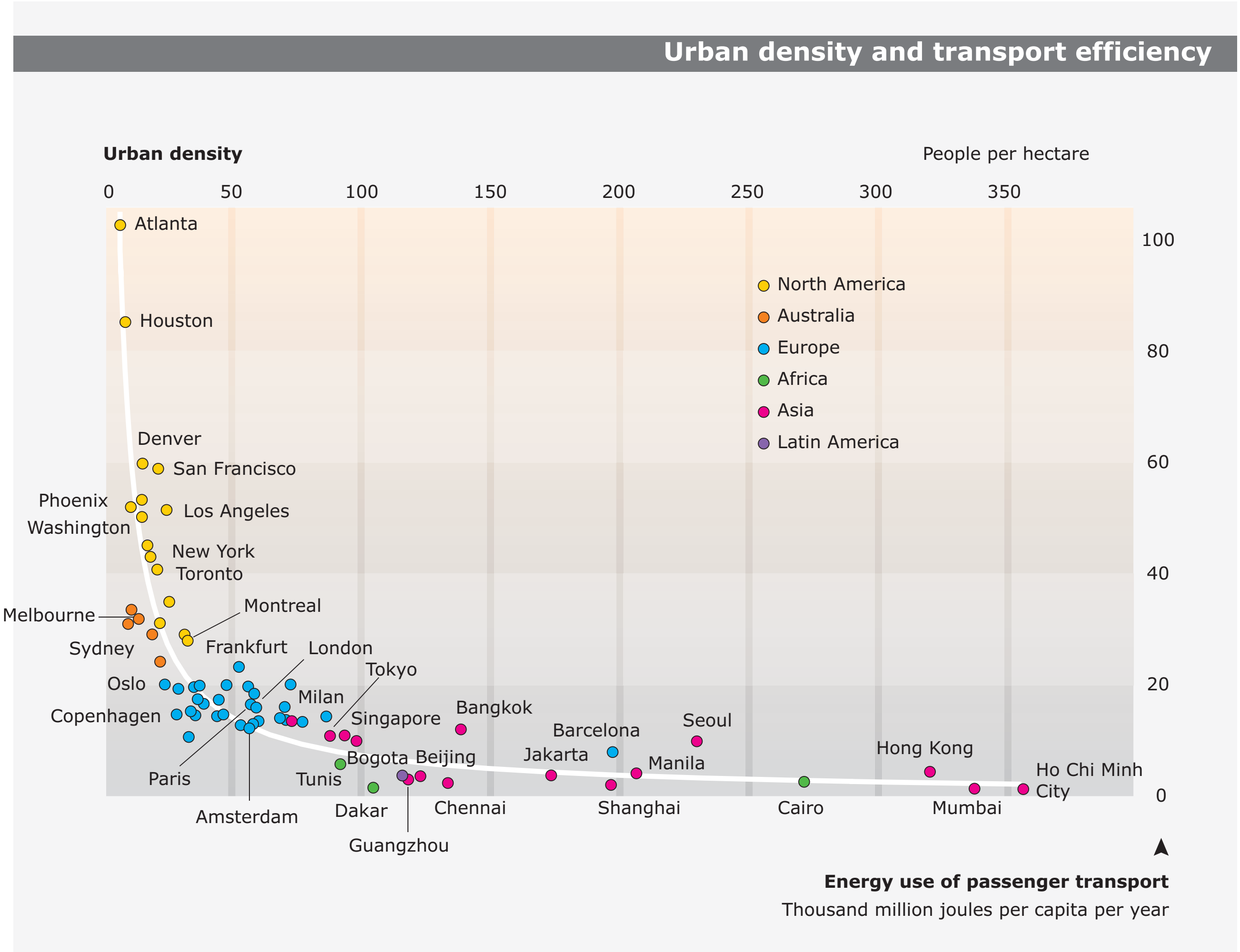
Figure 2.10 **Per capita resource use by development status and population density**



Note: ([a]) High-density means a population density of 50 people per kilometre or higher.

Source: Krausmann et al., 2008, cited in 'Decoupling natural resource use and environmental impacts from economic growth', UNEP, 2011.

Figure 2.11 Urban density and transport-related energy consumption



Note: Data for 1995.

Source: Jeffrey Kenworthy, Felix Laube, The Millennium Cities Database for Sustainable Transport, International Association for Public Transport (Brussels), Institute for Sustainability and Technology Policy (Perth), 2001.

density. In 2000, average density was estimated at 135 in cities in developing countries, compared to just 28 persons per hectare in cities in land-rich developed countries (e.g. the US, Canada and Australia). The average was 70 in cities in other developed countries.

The same study found some evidence that urban density tends to decline as urbanisation and economic development advance. Between 1990 and 2000, the average density of built-up areas in this sample declined by approximately 2% annually. A sample of 20 US cities revealed a five-fold decline in density in the period 1910–2000. And a global sample of 30 cities recorded a threefold decline in density in the period 1800–2000. The authors conclude that current rates of density decline in developing regions imply that a doubling of urban populations in the next 30 years is likely to produce a tripling of the extent built-up areas.

Innovative urban governance

Urban governance emerges as a key issue for managing urban growth and for the implementation of policy actions and strategies in pursuing competitiveness objectives. Cities have to cope with negative effects of urbanisation and international division of labour (urban sprawl and spatial disparities, congestion and pollution, social issues and distressed areas) but they also have to produce proactive actions to improve and sustain their competitiveness position and foster agglomeration economies.

OECD published analyses (OECD, 2010) build on new paradigm of regional development policy. Globalisation confronts urban and rural regions with new opportunities and threats. The new paradigm's objective is to reduce persistent inefficiency(under utilisation of resources resulting in income below potential) and persistent social exclusion (primarily, an excessive number of people below a given standard in terms of income and other features of well-being) in specific places.

The main obstacles fighting with those challenges include: the institutional fragmentation, the lack of critical mass in medium sized cities, the lack of capacity of local governments, lack of inter-municipal co-ordination within a single urban region both for strategy development and service delivery to optimising the development and impact of spatial strategies and intervention of all levels of government and involvement of civil society (see Box 2.2).

A review and analyses of metropolitan governance arrangements in OECD countries show that there is no one single model for metropolitan regions and that long term strategies are generally not well addressed in existing formal metropolitan governance arrangements. Different models of good governance alrady exist across the globe to cope with urban poverty and distressed neighbourhoods, climate change and environmental damage, mange competitiveness, land policy and strategic urban planning (OECD, 2010) (Box 2.2).

A successful urban development strategy should build upon each urban region's endogenous attributes, i.e. not only the mortar and bricks of infrastructure, but also the knowledge and skills of workers, and the social capital needed to trigger and sustain innovation.

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Box 2.2 Involving civil society in metropolitan governance

The success of any metropolitan governance reform will largely depend on the *public support* that the new established structure is able to gain. The democratic character of metropolitan governance is not limited to the involvement of citizens through voting and representation or accountability of decision-making process but also includes *participation of non-governmental groups in the decision-making process.*

In Germany, the Stuttgart Regional Association works closely with a series of economic and social groups on various initiatives(sport associations, feminists groups, the private sector through mutual participation of their respective bodies). In Hungary, the Act on Regional Development and Planning imposed the legal obligation to involve voluntary associations and businesses in the consultation process preceding the planning process. Seoul's executive leadership has sought to encourage more citizen input into metropolitan city management (they enabled for civil society and non-profit organisations to request audits of agencies, encourage their direct participation in controlling corruption and even offering financial inducements towards this aim; they made excellent use of Korea's very high rate of internet dissemination to craft an online system for handling civic affairs; they encouraged direct citizen representation in the decision-making process through various committees — 30% of the committee members are required to be women with clear guidelines of work. In France, the 1999 act on regional planning that established the establishment of mandatory councils which represent the economic and social actors at the metropolitan level to assist in the elaboration of their strategic projects and actions. However, they largely differ in membership and in place since the law does not provide for any rules in that matter (Lefevre, 2006; OECD, 2010).

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GMT 3 — Changing disease burdens and risks of pandemics

Global megatrend 3 — Changing disease burdens and risks of pandemics

The world is currently experiencing a major shift in health problems related to economic development and changing lifestyles. Since 2000, the global burden of disease from communicable diseases (such as HIV, tuberculosis, and measles) has been outweighed by non-communicable diseases (such as cardiovascular diseases, cancers, chronic respiratory diseases, diabetes). Non-communicable diseases are also the most important cause of death in the world and are typically associated with developed-world lifestyles. But although communicable diseases are globally in decline, they still pose a significant health burden, especially in the developing world. A third factor in changing health conditions is the persistent threat of pandemics.

Many developing countries will find this shift challenging, as they will have to deal with a multiple burden of persistent communicable diseases and the risk of pandemics, combined with the increasing burden of non-communicable diseases.

In addition, significant health disparities still exist between and within countries, in particular between urban and rural areas. Consequently, some vulnerable population groups (e.g. children, poor people) are still at greater risk of poor health, although life expectancy and general health have been continually improving around the world.

A broad range of economic and social trends will influence the future of global public health. While some global environment-related drivers (e.g. access to drinking water) are getting better, others — such as urban air pollution and lack of access to basic sanitation — continue to pose a serious risk to human health. In addition, the incremental effects of climate change are contributing to the global burden of disease (as for example the risk of spreading vector-borne diseases). Another driver is related to accelerating technological innovations which are bringing many health benefits but also unknown health risks. Additionally, the pharmaceutical industry is slowing-down its development of new drugs for the treatment of 'non-profitable' diseases (mostly communicable diseases in developing countries) and diseases resistant to traditional antibiotics.

Actions on the global and national levels can greatly reduce the risks posed by these trends. Increased investment in health and infrastructure, improved education, and better governance are key factors in realising sustained improvements in human health.

The Millennium Ecosystem Assessment underlined that human health depends on healthy ecosystems, and so there are synergies between efforts to address health issues and those to protect the environment, both in Europe and worldwide.

In its constitution, the World Health Organization (WHO) defines health as 'a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity'. It also affirms that the 'enjoyment of the highest attainable standard of health' is a fundamental human right (WHO, 1946 and 2005).

Diverse social, economic, environmental and other factors influence human health, including living and working conditions, and cultural influences. Mediated by social and community networks, these factors interact with innate factors, such as an individual's age, sex and genetic makeup. Changing demography, behaviour and living and working conditions thus directly influence global health, as do changes in environmental burdens (Figure 3.1).

The world population is currently undergoing a major shift in health problems, related to economic development and changing lifestyles. The burden of disease from non-communicable diseases (NCDs) such as diabetes and strokes has since 2000 outweighed the burden from communicable diseases. NCDs, which are typically associated with developed-world lifestyles, are also the most important cause of death in the world (Figure 3.2).

Despite their continuing decline, communicable diseases still pose a significant burden, in particular in developing countries where they remain the leading cause of mortality and morbidity. The risk of new pandemics also remains a global threat. In addition, major inequalities in health outcomes persist between the countries of the world as well as within them, related to factors such as income, education and health care quality.

Figure 3.1 **Human health risks and health risk factors in relation to development and economic growth**

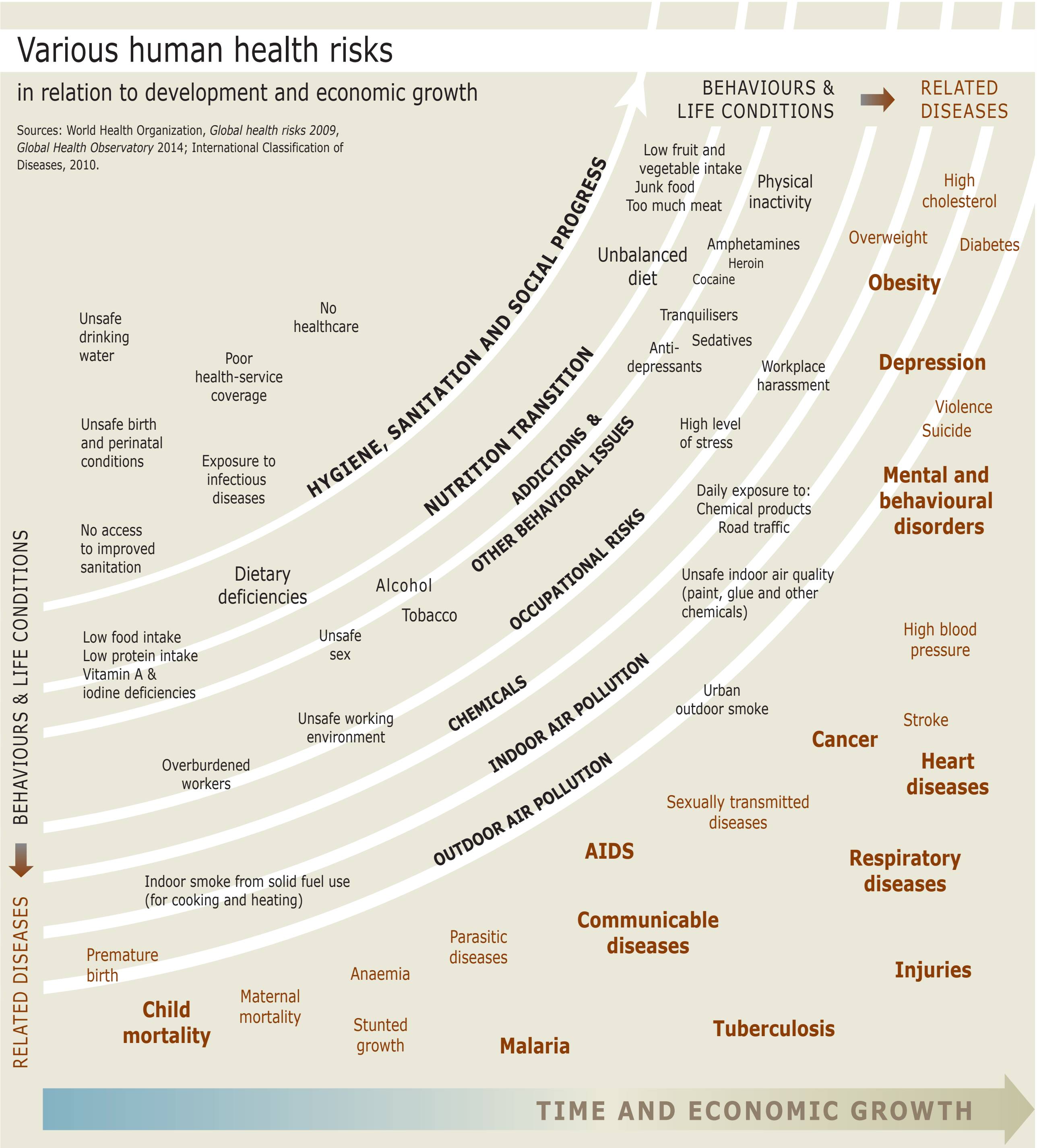
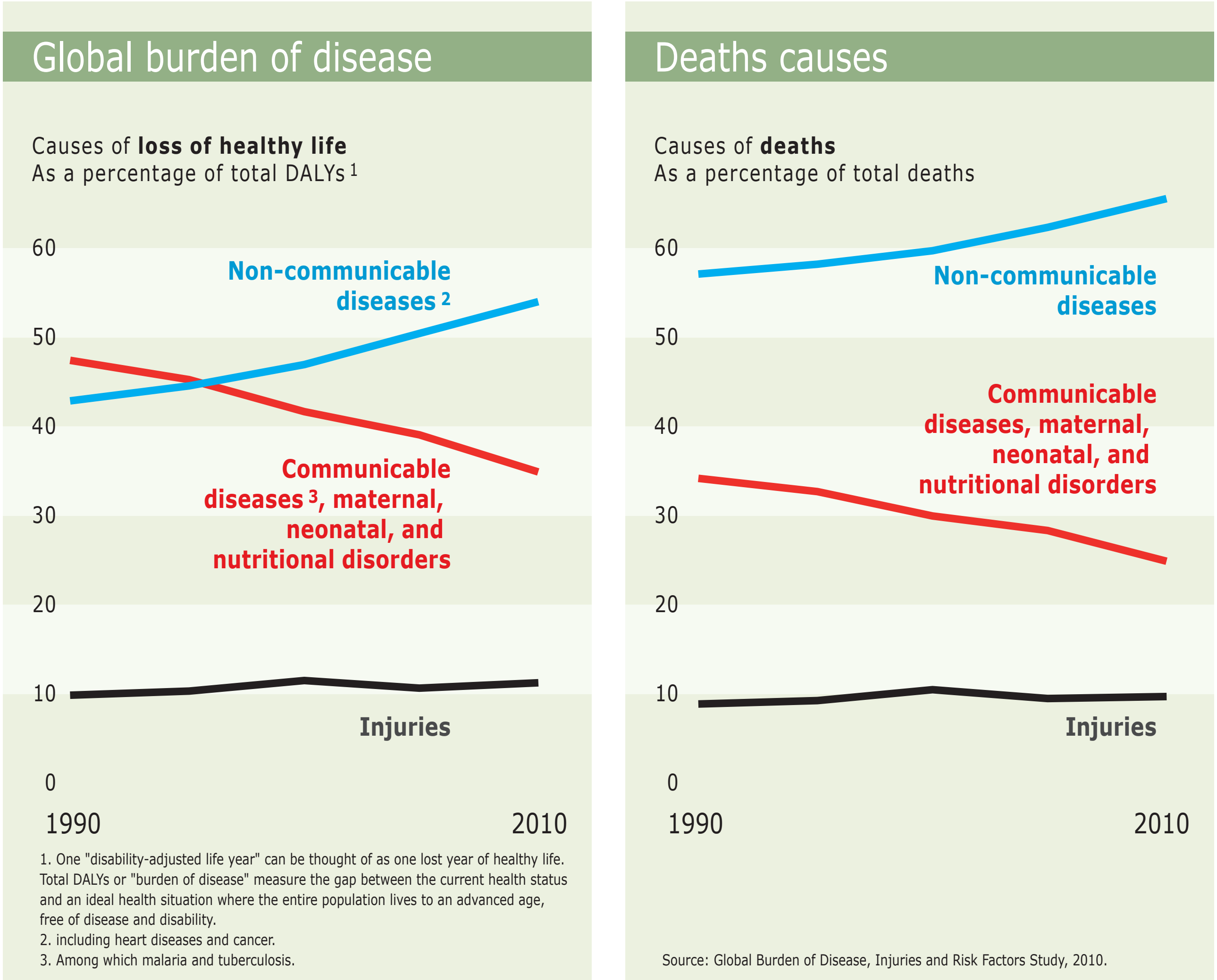


Figure 3.2 **Global burden of disease and death from communicable and non-communicable disease and injuries**



3.1 Drivers

Economic growth, urbanisation and changing lifestyles and diets

Economic growth

The coming decades are expected to see huge increases in economic output and urban populations across the world, in particular in developing countries (see GMT 2 and 5). These trends will affect global health outcomes in several important ways. Economic growth will provide resources to finance health research, health care and improved sanitation. Possible further declining global poverty (Edward et al., 2013; EUISS, 2012) and better education (Lutz, 2010) are also linked to better health. However, the increasing global trade and travel that have accompanied economic growth risk spreading communicable diseases and pandemics.

The World Health Organization (WHO, 2014b) has identified four main lifestyle risk factors for non-communicable disease: tobacco consumption, insufficient physical activity, unhealthy diets, and harmful use of alcohol. Wealth and urbanisation can promote lifestyles that exacerbate these risk factors. For example, as people move to service sector jobs and, in cities lacking sustainable transit policies, they increasingly travel by private car then their physical inactivity is likely to grow. Growing food consumption has reduced undernourishment but has also led to higher levels of obesity and lack of some vital vitamins or minerals due to an unbalanced diet.

Persistent economic inequality (UNDP, 2013) will continue to affect health outcomes within and across countries. Globally, the differences between rich and poor are striking. The top fifth of the global population secured 70% of world income in 2008, whereas bottom fifth received only 2% (Ortiz and Cummins, 2011).

Of particular concern for health outcomes are those who live in extreme poverty. The UN Millennium Development Goal target in this area — to halve, from 1990 to 2015, the share of people in the world with an income under USD 1.25 per day — was met by 2010. The share of developing country residents living on less than USD 1.25 a day fell from 47% in 1990 to 22% in 2010 (UN, 2013b). Looking ahead, one important uncertainty for health outcomes is the extent to which future economic growth will reduce inequalities and improve the lives of the poorest in society (Edward et al., 2013).

Urbanisation and slums

By 2010, more than half of the world population lived in urban areas. By 2050, this proportion is projected to reach two-thirds, with Asia and Africa accounting for most of the increase (see GMT 2). Urban areas concentrate economic and social opportunities, including better education and higher-paid jobs. Health care opportunities are often also better in urban areas (UN Habitat, 2013).

However, the world's fast-growing cities also concentrate environmental health risks, including air and noise pollution, and allow communicable diseases to spread quickly. In many countries, health inequalities are highest in urban areas, which bring together the very rich and the very poor. Many cities in developing countries are growing faster than governments can provide sanitation or health services. The poor, in particular, suffer from the lack of these services (WHO, 2010b).

Urban health problems are most acute in slums, where residents suffer from poor access to sanitation and safe drinking water, overcrowding, insecure residence and poor housing structures. In 2012, an estimated 863 million people lived in slum conditions, with more than 90% in developing countries. The target under the Millennium Development Goals to 'achieve, by 2020, a significant improvement in the lives of at least 100 million slum dwellers' — by providing improved water sources and sanitation facilities, more durable housing or sufficient living space — has been met (UN, 2013; UN, 2014). Despite this achievement, the absolute number of slum inhabitants has risen 33% since 1990.

In sub-Saharan Africa, the region of the world with the highest urban growth, 62% of urban residents lived in slum conditions in 2012 (UN Habitat, 2013). Changes in slum conditions in future decades will depend both on other trends, such as economic trends and policy actions, and thus are uncertain.

Diet and nutrition

The United Nations Food and Agriculture Organization (FAO) has affirmed that 'good nutrition is the foundation for human health and well-being, physical and cognitive development, and economic productivity' (FAO, 2013). In the period 2011–2013, about 842 million people worldwide, 12% of the world population, suffered from undernourishment ([1]). In at least 26 countries, one-quarter or more of the population faced undernourishment in this period (Figure 3.3).

Over the long term, both the share and, more slowly, the total number of undernourished people have fallen. In 1947, about half of the world population suffered from undernourishment (FAO et al., 2013). The UN (2013) reports that the MDG target of halving the share of the world population facing hunger by 2015 (compared to 1990) is 'within reach'. In coming decades, the share and total number of people facing undernourishment is expected to continue to fall as personal incomes rise around the world (FAO, 2012).

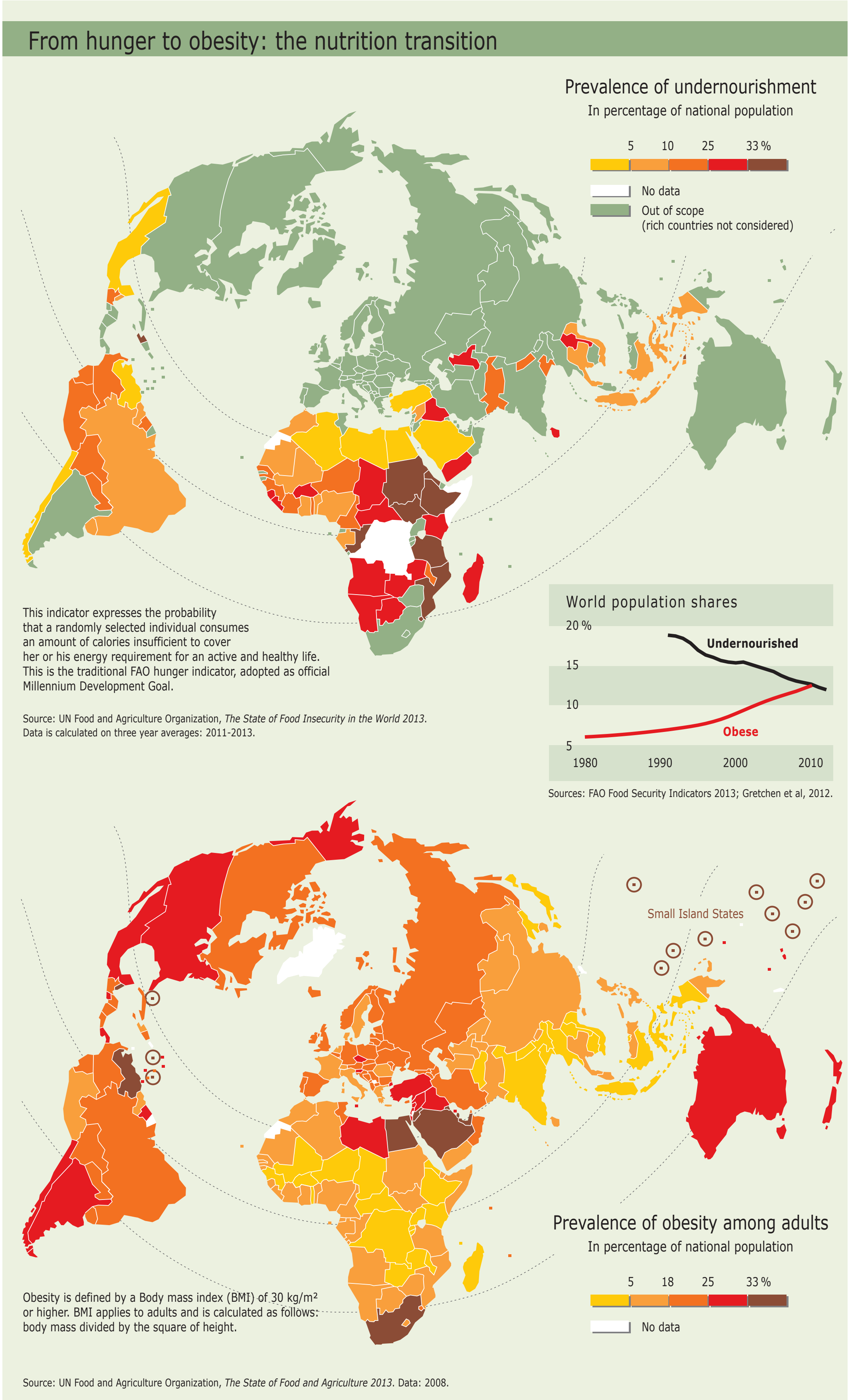
While undernourishment is falling, excess body weight and obesity represent growing global health concerns. With rising personal incomes, many developing countries are seeing a move towards 'Western' diets with high levels of fat, sugar, salt and carbohydrates. Over-nutrition can coincide with deficiencies in one or more vitamins and minerals vital for human health, stemming from inappropriate dietary composition and disease. Such micronutrient deficiencies affect about 2 billion people (FAO, 2013).

Future trends in undernourishment and obesity will depend on a range of factors, including the evolution of global agricultural systems. The global growth in intensive production of livestock for meat consumption also brings a series of health risks (Liverani et al., 2013) (Box 3.1).

Obesity could be addressed through health and social policies to tackle unhealthy diets and inactivity. Lifestyle trends also vary greatly and in high-income countries many wealthier inhabitants now increasingly seek out high-quality, often organic foods (Dixon et al., 2007).

([1]) Undernourishment is defined by FAO as a level of food intake over at least a year insufficient to meet dietary needs, i.e. chronic hunger.

Figure 3.3 **From hunger to obesity: the nutrition transition**



Box 3.1 Intensive livestock raising and risks to human health and environment

Recent studies indicate that more than three-quarters of communicable human diseases are zoonotic in origin (Woolhouse et al., 2005).

In coming decades, intensive livestock is expected to expand around the globe to meet the rising demands of the world's growing urban middle classes, in particular in developing countries, creating many health risks and environmental impacts. By one estimate, intensive methods already produce about 70% of the world's poultry and eggs (Liverani et al, 2013). In China, intensive production supplies half of the nation's pork. The co-existence of both small-scale, traditional livestock methods and industrial production in developing countries, together with the conversion of wild areas to agricultural land, can exacerbate the risks of disease transmission from wildlife to livestock and then to humans (Liverani et al., 2013).

Intensive livestock raising creates several health risks, including pandemics. Humans share many infectious diseases, such as influenza, with animals (transmitted from animals to humans or from humans to animals). While this link has always existed, the spread of intensive livestock raising threatens to increase the health risks. Moreover, intensive methods concentrate large numbers of animals in confined units, providing potential 'incubators' for existing and new diseases; the most intensive operations use antibiotics against these threats and also to boost production, a practice that contributes to worrying drug resistance; and the transport of increasing numbers of livestock can also spread disease. Wastes from livestock are also a growing risk to human health and the environment. Already, according to WHO, the world's poultry generate as much faecal pollution as humans, and cattle produce four times as much (Dufour et al. (WHO), 2012).

Demographic change: rising life expectancy and increasing global migration

The global average life expectancy at birth rose to 71 in 2012, an increase of seven years since 1990. This improvement reflects decreased mortality levels across all age groups as a result of improved economic and social conditions (UN, 2013b). The rise has not, however, been steady in all parts of the world: in Africa, average life expectancy declined in the 1990s due in part to the HIV/AIDS pandemic, though it has since improved (WHO, 2014b). Life expectancy also varies greatly across regions but is projected to converge slowly in coming decades (Figure 3.4).

One consequence of higher life expectancy is that health care for the elderly is a growing issue in many countries, including in Europe (see GMT 1). Around the world, social and demographic changes will mean fewer older people will have the support of families (WHO, 2011). Older populations will face new patterns of disease, such as rising levels of Alzheimer's and dementia (see Section 3.1).

Migration will also affect global health trends (see GMT 1 and 2). The number of migrants between countries increased from 155 million in 1990 to 214 million in 2010. Since 1990, migration flows have become increasingly diverse, with growing migration among developing countries (UN ECOSOC, 2013). Most migration occurs within countries, however, in particular from rural to urban areas.

Migration can enable people access to higher incomes, better health care and improved health outcomes. But migration can also increase risks of increased transfer of infectious diseases. A further concern is that many health professionals migrate to take advantage of opportunities in higher income countries, and in doing so leave a labour shortage in the health care systems of their home countries (IOM, 2013b).

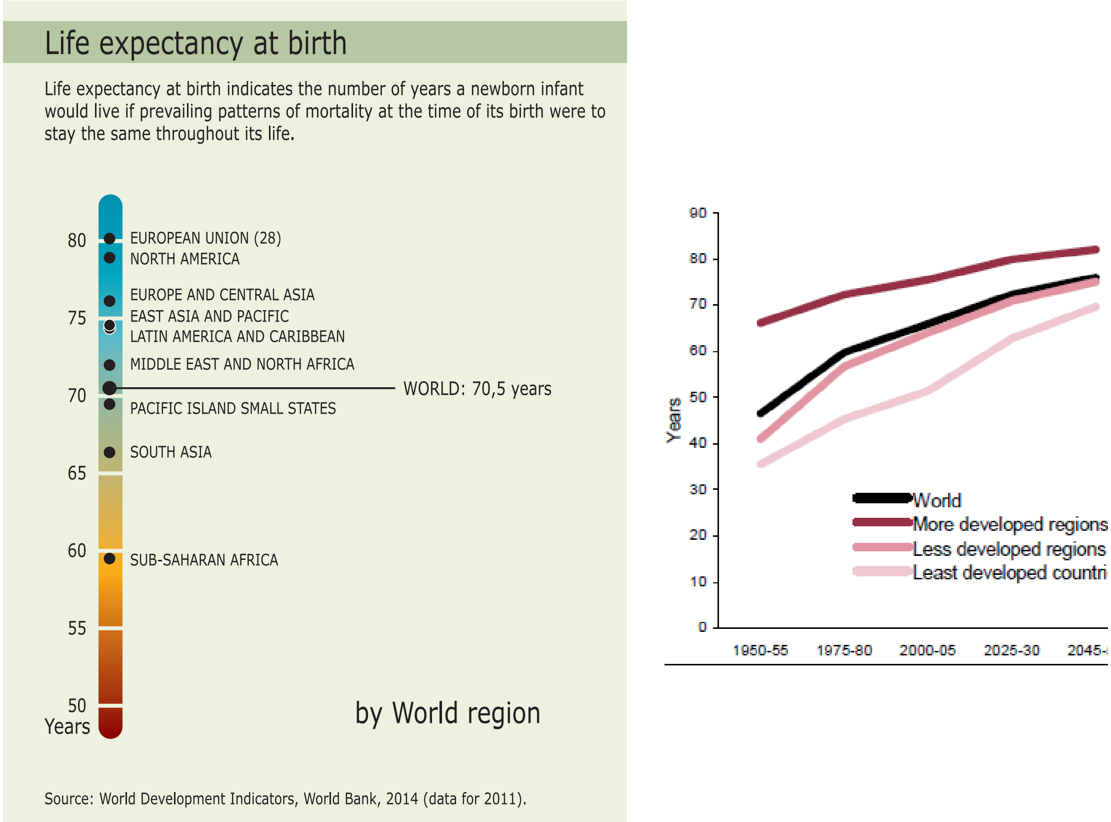
A particular concern is the forced displacement of people due to war and disaster, which reached almost 40 million globally in 2013 (Figure 3.5). Many refugees face mental and physical stress, poor living conditions and lack of health care, and are particularly vulnerable to disease (IOM, 2013).

The coming decades are likely to see continuing migration and growing movements among developing countries, in particular those with strong economic growth. Environmental degradation and climate change are expected to play an increasing role in migration (IPCC, 2014). Future trends for conflict-related migrants and refugees are very uncertain.

Growing environmental problems that affect health

A range of environmental problems affect human health. Overall 24% of the global burden of disease and 23% of premature deaths are attributed to environmental causes. Some 36% of the disease burden in children is caused by environmental factors.

Figure 3.4 Life expectancy across world regions in 2011 (left) and 1950–2050 (right)



Source: UN, 2002 (http://www.un.org/esa/population/publications/worldageing19502050/regions.htm).

Particulate matter, ground-level ozone, indoor air pollution and unsafe water supply and sanitation are the main causes of premature deaths globally.

The most serious health risks come from outdoor air pollution. Epidemiological studies attribute the most severe effects to particulate matter (PM_{10}) and fine particular matter ($PM_{2.5}$) and, to a lesser extent, to ground-level ozone. Road transport, industry, power plants, households and agricultural activities are important sources of PM and ozone pollution (OECD, 2012).

Recent WHO work estimates that in 2012 3.7 million premature deaths ([2]) (including urban and rural population) were globally attributed to outdoor air pollution (WHO, 2014a). The Organisation for Economic Co-operation and Development (OECD), which has made forecasts related only to urban population, projects that if current trends continue, annual global premature deaths from particulate matter will more than double by 2050 and cases of premature deaths caused by ground-level ozone will double by 2050 ([3]).

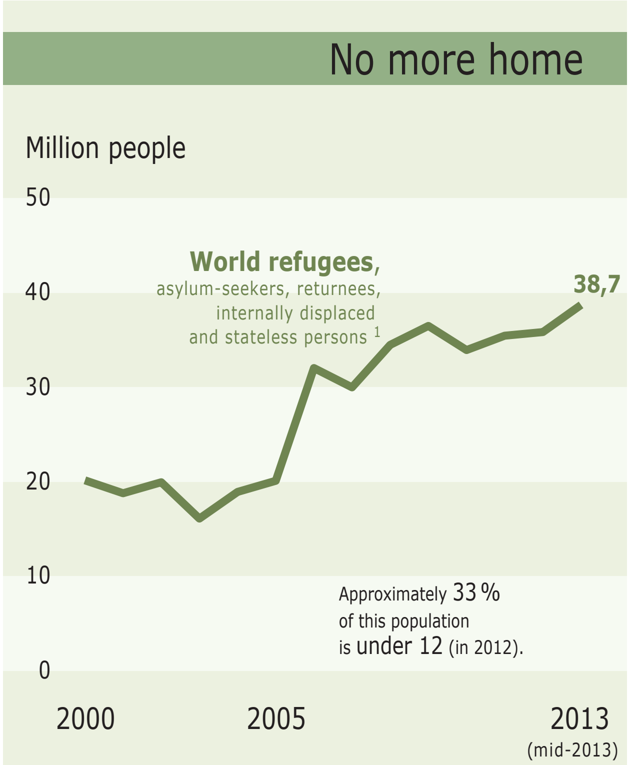
More than 80% of those occurred in developing countries (WHO, 2014a) where in many large cities levels of ambient air pollution are very high and are projected to continue rising in the coming decades (WHO, 2014d; OECD, 2012).

WHO has estimated that current levels of indoor air pollution are estimated to result in about 4.3 million premature deaths per year in 2012 due to the combustion of coal, wood, dung and other biomass (WHO, 2014a). Almost all occurred in developing countries and about half of these deaths are children, in

([2]) The new WHO estimates are not only based on more knowledge about the diseases caused by air pollution, but also upon better assessment of human exposure to air pollutants through the use of improved measurements and technology. This has enabled scientists to make a more detailed analysis of health risks from a wider demographic spread that now includes rural as well as urban areas.

([3]) The OECD's forecasts are based on modelling and thus depend on a range of assumptions about current and future air pollution and its interaction with other determinants of health, including the potential gains from air and climate policies. The forecasts consider only urban population and include the projected ageing of populations in the coming decades. EU countries make up close to half of the OECD population.

Figure 3.5 **World refugees, asylum-seekers, returnees, internally displaced and stateless persons**



1. and other UNHCR population of concern.

Source: United Nations High Commissioner for Refugees (UNHCR), 2013.

particular in South-east Asia and Africa, as well as China. The OECD forecasts that this level will decline slowly in coming decades: as people move out of poverty, they switch to using cleaner fuels such as natural gas and live in homes with ventilated stoves. In developed countries, indoor air pollution from chemicals, for example in cleaning fluids, carpets and other products, is a rising concern (OECD, 2012).

Unsafe water supply and sanitation are also major causes of health problems, with the resulting deaths primarily affecting children. Impacts are seen almost entirely in developing countries, in particular in sub-Saharan Africa and India.

In recent years, access to improved sources of drinking water has risen significantly, from 76% of the global population in 1990 to 89% in 2010. As a result, the MDG target in this area — to halve those without access to safe drinking water between 1990 and 2015 — has been met, according to official reporting (UN, 2013b). Poor access remains a problem in particular in developing countries and among disadvantaged groups. More than four-fifths of those without access live in rural areas (UN, 2013b). Moreover, the United Nations notes that there are concerns about the quality of many improved water sources. It is possible that the number of people without access is higher than official estimates. Moreover, many people have access only to public water points, not piped water at home (UN, 2013b).

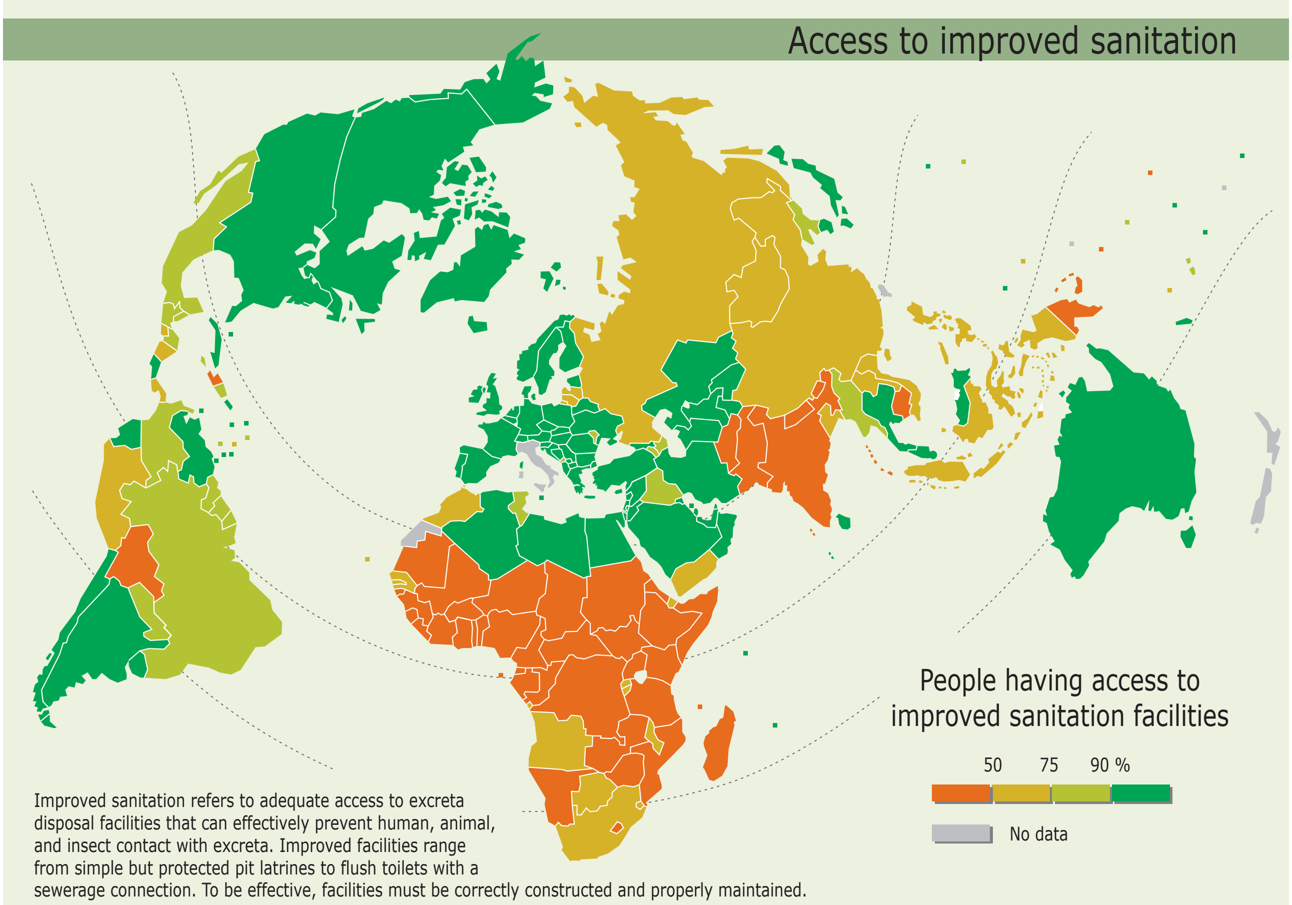
In contrast, the MDG target to reduce the number of people without access to improved sanitation by half has not yet been met, though it may be achieved by 2015 (UN, 2013b). Coverage rose to 64% in 2011 but would need to reach 75% to meet the target (Figure 3.6). The greatest improvements were seen in eastern Asia, where access rose from 27% in 1990 to 67% in 2011. Despite these improvements, about half of those without access — approximately one billion people — lack any sanitation facilities and use open defecation, a practice that creates strong risks of disease, in particular in villages and urban areas (UN, 2013b).

Around the world, people are exposed to an increasing number of chemicals, as global chemical production has risen steadily (EEA, 2013). According to the WHO, impacts from acute poisoning, workplace exposure to chemicals and exposure to lead reached about one million premature deaths per year in 2004. Exposure routes include the dismantling of electronic waste in developing countries, a problem that may grow as developing countries consume an increasing number of computers and other electronic and electrical goods (Riederer et al., 2013).

Chemicals used in mining have brought acute exposure to local areas in developing countries. Moreover children and adults around the world are affected by low levels of lead contamination. WHO has estimated that overall, lead poisoning of children accounts for 0.6% of the world's global disease burden, which can lead to long-term mental retardation and heart risks (WHO, 2010a). Additionally, recent research brought increasing concerns about chemical exposure and brain health. Chemicals such as lead, mercury, polychlorinated biphenyls (PCBs), arsenic, and certain solvents and pesticides pose an insidious threat to the development of the next generation's brains (i.e. 'chemical brain drain') (Philippe Grandjean, http://braindrain.dk).

Exposure to pesticides through inadequate safety measures is another concern, along with stocks of obsolete pesticides (WHO, 2013f). Small-scale mining has led to acute exposure to lead, mercury and other heavy metals in countries from Nigeria to Colombia (Siegel, 2011). Children and adults around the world are also affected by low levels of lead contamination. The WHO has estimated that overall, lead poisoning of children accounts for 0.6% of the world's global disease burden, due to long-term mental retardation and heart risks (WHO, 2010a), and low-level exposure

Figure 3.6 **Proportion of the population with access to improved sanitation, 2011**



Source: WHO and UNICEF Joint Monitoring Programme, *Progress on sanitation and drinking water*, 2013 update (data for 2011).

to mercury and other heavy metals are also a serious health concern (EEA, 2013).

Understanding of the health impacts of persistent exposure to chemicals remains limited. The effects of persistent, bio-accumulative and toxic chemicals are of particular concern. Nanomaterials, made of particles in the range of 1 to 100 nanometres, are of growing concern due to their widespread and growing use in consumer and industrial products, including medical equipment (see GMT 4); little systematic information is available, however, on human exposure and health impacts (EEA, 2013).

Climate change (see GMT 9) can directly and indirectly affect human health via changing weather and extreme events, impacts on ecosystems and agriculture, and contributing to existing problems such as air pollution, water scarcity and poor water quality. In terms of extreme weather events, the Intergovernmental Panel on Climate Change (IPCC) has found some evidence that heat waves, floods and droughts have increased in parts of the world since 1950 (IPCC, 2012). Heat waves in particular are expected to bring further health impacts in coming decades. Climate change can also affect the range of communicable diseases spread by unsafe food and water, by vectors such as mosquitoes (see Section 2.3 and Box 3.1) and by the movement of people (see Section 1.2.). In addition, climate change will create higher risks of under-nutrition in poor regions due to diminished food production. Some health improvements may also be seen, due to a reduction in cold extremes, although such benefits are expected to be much more limited than the negative impacts (IPCC, 2014).

A range of other environmental problems create health risks. These include noise from traffic and other sources, and contamination from poor management of solid waste. Intensified competition for global resources could have indirect impacts; for example, marine fish provide 6% of global protein and are a vital element of food security for some low-income countries but current pressure on fisheries puts this resource at risk (EMB, 2014).

Expanding medical research and technology

The pace of technological innovation is accelerating, and health care is one of the key areas expected to benefit from the fast-changing fields of nanotechnology, biotechnology and information technologies (see GMT 4). The range of treatable diseases is increasing, moving from infectious diseases to major NCDs, to medical issues which previously would have been considered a normal (if unfortunate) part of life (Heath, 2005). For example, the growing links between nanotechnology and information technology are producing miniature sensors that can be used for healthcare, including wearable and ingestible sensors to monitor the health of chronic patients at home, with results connected via Internet to medical centres.

Artificial intelligence will increasingly be able to support doctors in diagnoses and possibly replace them in some tasks. Crowd-sourced information via cell phones could monitor disease outbreaks (MGI, 2013). Genomic sequencing is being used for drug discovery (MGI, 2013). Techniques are also being developed to improve the delivery of drugs. For example, 'nanocapsules' can delay release of the active molecule until it reaches the desired location within the body (Mitchell Crow, 2013). New human organs to replace or enhance existing ones could be grown from the stem cells of the patient, thus eliminating the risk of organ rejection (Coghlan, 2013; Murphy and Atala, 2012).

While new technologies promise future advances in medicine, drug research and discovery has slowed in particular in the area of antibiotics (as discussed in Section 3.2). A further concern is that new medicines and techniques focus on diseases, particularly non-communicable diseases, in high-income countries that represent business opportunities (see Section 3.2). A number of international activities has been launched recently to address 'neglected' tropical diseases found mainly in developing countries.

3.2 Trends

Growing levels of non-communicable diseases

Non-communicable diseases (NCDs), also known as chronic diseases, constitute one of the major challenges for development in the twenty-first century. NCDs cannot be passed from person to person and are generally of long duration and slow progression. The four main types of non-communicable diseases are cardiovascular disease (such as heart attacks and stroke), cancers, chronic respiratory diseases (such as asthma and chronic obstructed pulmonary disease) and diabetes.

According to projections by the World Health Organization, the total annual number of deaths from NCDs will increase from 36 million in 2008 to 55 million by 2030 if current trends continue (WHO, 2013). The four main types of non-communicable diseases today account for 60% of deaths worldwide, and their impact is projected to grow in coming decades (Figure 3.7 and Box 3.1). These trends reflect a shift away from traditional health risks such as inadequate nutrition or unsafe water and sanitation, which particularly influence communicable diseases in children, towards unhealthy lifestyles, which increase risks such as obesity and early deaths, particularly in adults (Lim et al., 2012; Lozano et al., 2012).

NCDs have long been predominant in developed countries but they are no longer limited to affluent societies. In 2011, more than two thirds of all premature deaths (individuals between the age of 30 to 70) due to NCDs occurred in developing countries (WHO, 2011b). The probability of dying from any of the major NCDs ranges from 87% in developed countries to 58% in developing countries (Kuipers et al., 2014). The prevalence of NCDs is expected to further increase in developing countries and to continue to accompany socioeconomic development.

The industrialisation of food production processes combined with the globalisation of food marketing and distribution, has made processed foods, rich in fat, sugar, and salt, yet low in essential nutrients, much more accessible all over the world, and as such contributes to the rise of chronic diseases (non-communicable). Obesity and type 2 diabetes, strongly linked to unhealthy diets, have reached epidemic proportions in Asia, where the nutritional transition has been exceptionally rapid. People in that part of the world are developing diabetes in greater numbers and at a younger age than in Europe and North America, and they are dying sooner. Diabetes is an especially costly disease: costly for societies, costly in terms of chronic care, and extremely costly in terms of hospital care for well-known complications such as health disease (EFT, 2006).

In addition to these four non-communicable disease types, the incidence of mental disorders such as depression, dementia and substance use disorders is rising. The WHO (2011a) cites projections from Alzheimer's Disease International that suggest that 135 million people worldwide will be living with dementia in 2050, with a markedly increasing proportion of that total in developing countries (Figure 3.8).

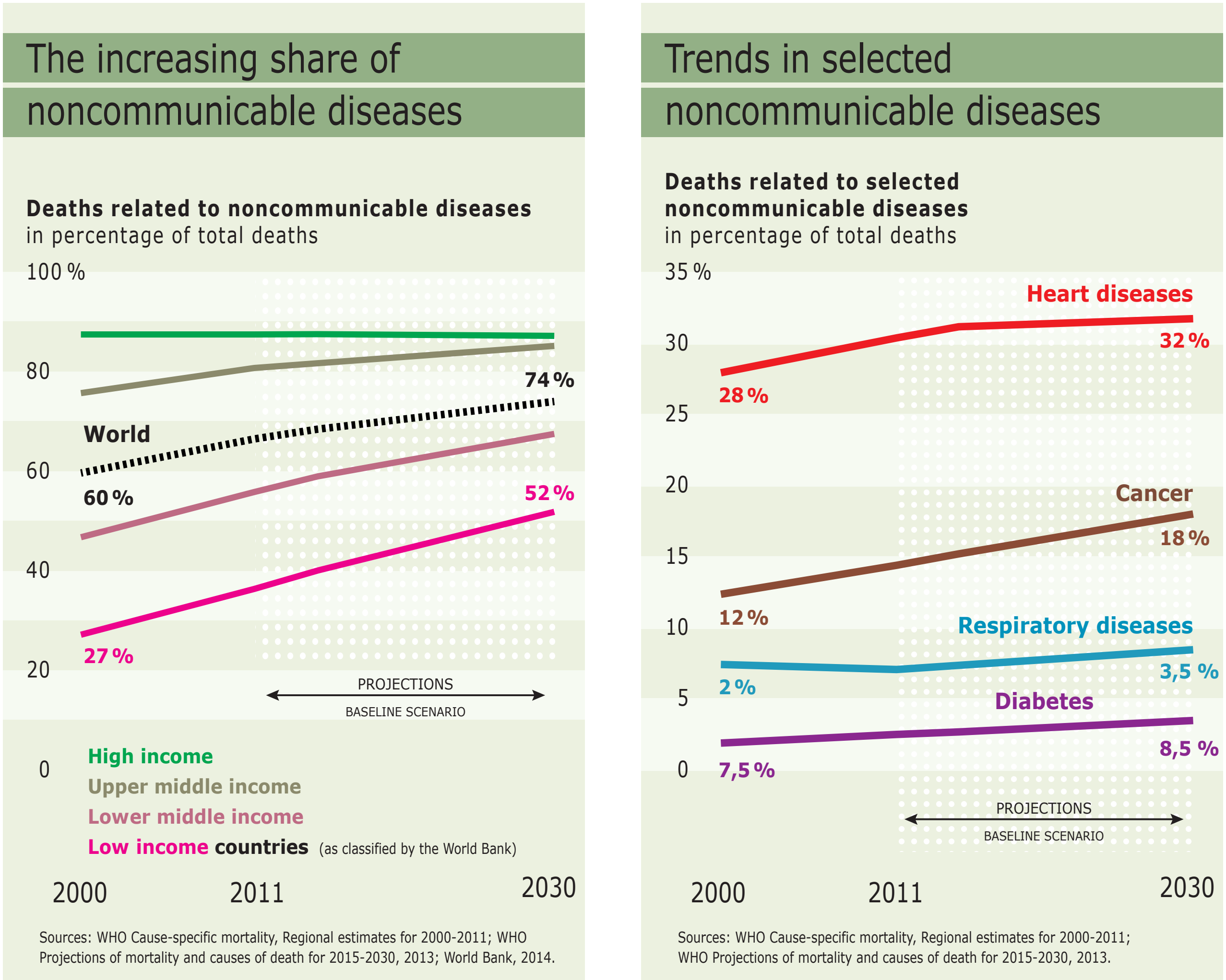
According to one estimate, these diseases will result in losses of USD 7.3 trillion over the next

15 years (Table 3.1), including health costs and lost productivity (WEF, 2011). The growing burden of NCDs threatens to impose substantial economic costs on developing countries (the annual loss of approximately USD 500 billion amounts to roughly 4% of GDP for low- and middle-income countries in 2010) ([4]). In every income group that was analysed, losses from NCDs are greater than public spending on health, assuming that inflation-adjusted levels of such spending remain at their 2009 levels for the period 2011–2025 (Based on *The Global Economic Burden of Non-communicable Diseases* by the World Economic Forum and the Harvard School of Public Health, 2011).

Persistence of communicable diseases

While non-communicable diseases are sweeping the globe, communicable diseases still pose a significant burden. In developing countries, infectious diseases remain the leading cause of mortality and morbidity: in 2010, 94% of all deaths due to communicable diseases occurred in developing countries (WHO, 2011b). However, developed countries are also still affected by communicable diseases and in some cases their incidence is growing. This is mainly linked to drug resistance, as discussed in Section 3.3.

Figure 3.7 Trends in non-communicable disease, 2008 to 2030



([4]) The focus of analysis in this report is on Low and middle income countries (as defined by World Bank: http://siteresources.worldbank.org/DATASTATISTICS/Resources/CLASS.XLS), which account for 84% of the world's population and 83% of the non-communicable disease burden (as measured by DALYs (disability-adjusted life years).

Box 3.2 Non-communicable diseases: facts and figures

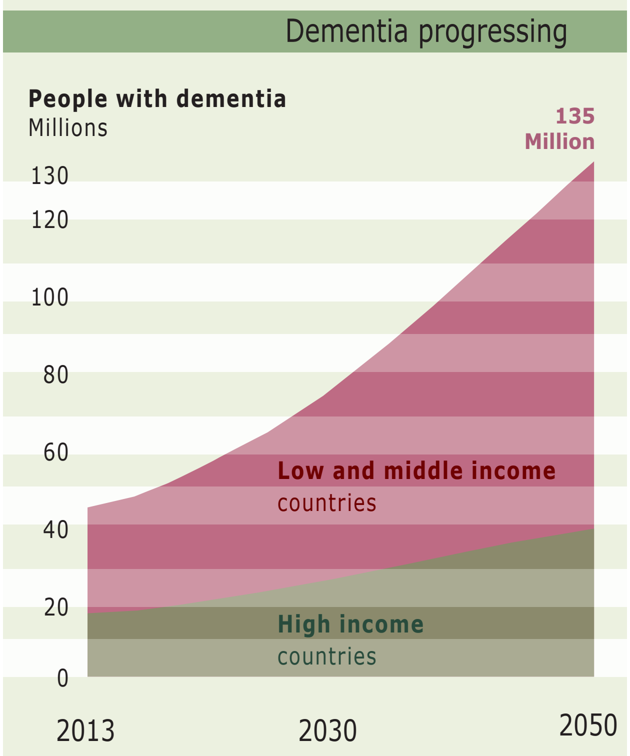
Cardiovascular diseases are the number one cause of death in the world. While deaths from such conditions have actually been declining in high-income countries, they have been increasing at very fast rates in low- and middle-income countries (WHO, 2011d).

A report by the International Agency for Research on Cancer shows that cancer is the biggest cause of mortality worldwide (IARC, 2014). In 2012, 32.6 million people were living with cancer and 8.2 million people worldwide died that year from the disease. Cancer cases are forecast to rise by 75% over the next two decades.

Chronic respiratory diseases (asthma and respiratory allergies, chronic obstructive pulmonary disease), occupational lung diseases, and pulmonary hypertension are responsible for four million deaths each year. Almost 90% of deaths due to chronic obstructive pulmonary disease occur in low- and middle-income countries, due to tobacco smoke but also indoor and outdoor air pollution, occupational dust and chemicals and frequent lower respiratory infections during childhood (WHO, 2010d).

The latest edition of the IDF Diabetes Atlas (IDF, 2013) shows that today there are 382 million people living with diabetes globally and this number is set to reach 471 million by 2035. Diabetes is increasing all over the world and 80% of people with diabetes live in low- and middle-income countries. The socially disadvantaged in any country are the most vulnerable to the disease.

Figure 3.8 Projected number of people with dementia, 2010–2050



Source: *The Global Impact of Dementia 2013–2050*, Alzheimer's Disease International, 2013.

At the end of 2012, there were 35.3 million people living with HIV/AIDS worldwide (0.8% of the population aged 15–49). In that year, 1.7 million people died of AIDS-related illnesses, including 230 000 children (UNAIDS, 2012). The burden of this disease varies considerably between countries and regions. Sub-Saharan Africa is the most affected region, with nearly 1 in every 20 adults living with HIV today (UNAIDS, 2012).

Due to a 40-fold increase in access to anti-retroviral therapy, the number of new HIV infections and deaths due to AIDS is decreasing globally, while the number of people living with HIV is increasing due to better access to anti-viral therapy (Figure 3.9).

Many developing countries face 'neglected tropical diseases', a group of parasitic and bacterial diseases such as dengue and leprosy which often lack adequate vaccination programmes and health responses. Neglected tropical diseases persist especially in the poorest, most marginalised communities and conflict areas where access to treatment is low. Until recently global public health investment has been limited.

At the same time, several contagious diseases persist despite the availability of effective vaccines for over 50 years. One example is measles, a highly contagious disease that remains one of the leading causes of

Table 3.1 Economic burden of NCDs, 2011–2025 (trillion USD in 2008)

Country income group	Diabetes	Cardiovascular diseases	Respiratory diseases	Cancer	Total
Upper middle	0.31	2.52	1.09	1.20	5.12
Lower middle	0.09	1.07	0.44	0.26	1.85
Low income	0.02	0.17	0.06	0.05	0.31
Total of low and middle	0.42	3.76	1.59	1.51	7.28

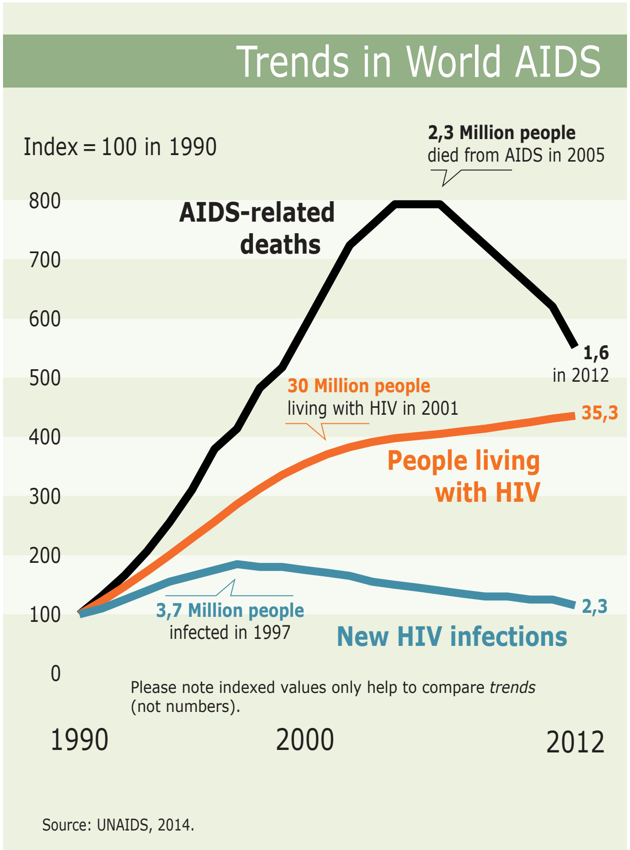
Source: WEF, 2011. http://www3.weforum.org/docs/WEF_WHO_HE_ReducingNonCommunicableDiseases_2011.pdf.

death among young children, particularly in developing countries. In 2012, more than 20 million people were affected by measles, of whom 122 000 died (WHO, 2014b).

Infants and children are particularly affected by communicable diseases. An estimated 6.6 million children under the age of five died in 2012 ([5]). 44% of all child deaths occur within the first month of life (WHO, 2014b). Poor sanitation, malnutrition and lack of vaccination particularly increase the susceptibility to infections. Additionally, almost two million children die each year because of lower respiratory infections such as pneumonia. For nearly half of these deaths, air pollution, particularly indoor air pollution, is a factor. Children in sub-Saharan Africa are about over 16 times more likely to die before the age of five than children in developed regions (WHO, 2014b). Overall, substantial progress has been made towards achieving Millennium Development Goal (MDG) 4. Since 1990 the global under-five mortality rate has dropped from 90 deaths per 1000 live births in 1990 to 48 in 2012. But the rate of this reduction is still insufficient to reach the MDG target of a two-thirds reduction of 1990 mortality levels by 2015.

Despite the success of vaccination and prevention programmes, communicable diseases are thus a persistent problem. As discussed in Section 3.3, risks of pandemic outbreaks of infectious diseases are a further concern.

Figure 3.9 HIV infections and AIDS deaths, 2001–2012



Growing risks of pandemics

Emerging and re-emerging infectious diseases that can rapidly spread across continents have always represented a threat to human health. Several pandemics — epidemics that occur worldwide or over a wide area crossing international boundaries and affecting a large number of people (Last, 2001) — have occurred during recent years. Infections can spread quickly due to high levels of international movement and viruses, such as influenza, can rapidly mutate and jump from animals to human (see Box 3.1). The WHO in 2011 described the world as 'ill-prepared to respond to severe pandemics or any other similar global, sustained and threatening public health emergency' (WHO, 2011e).

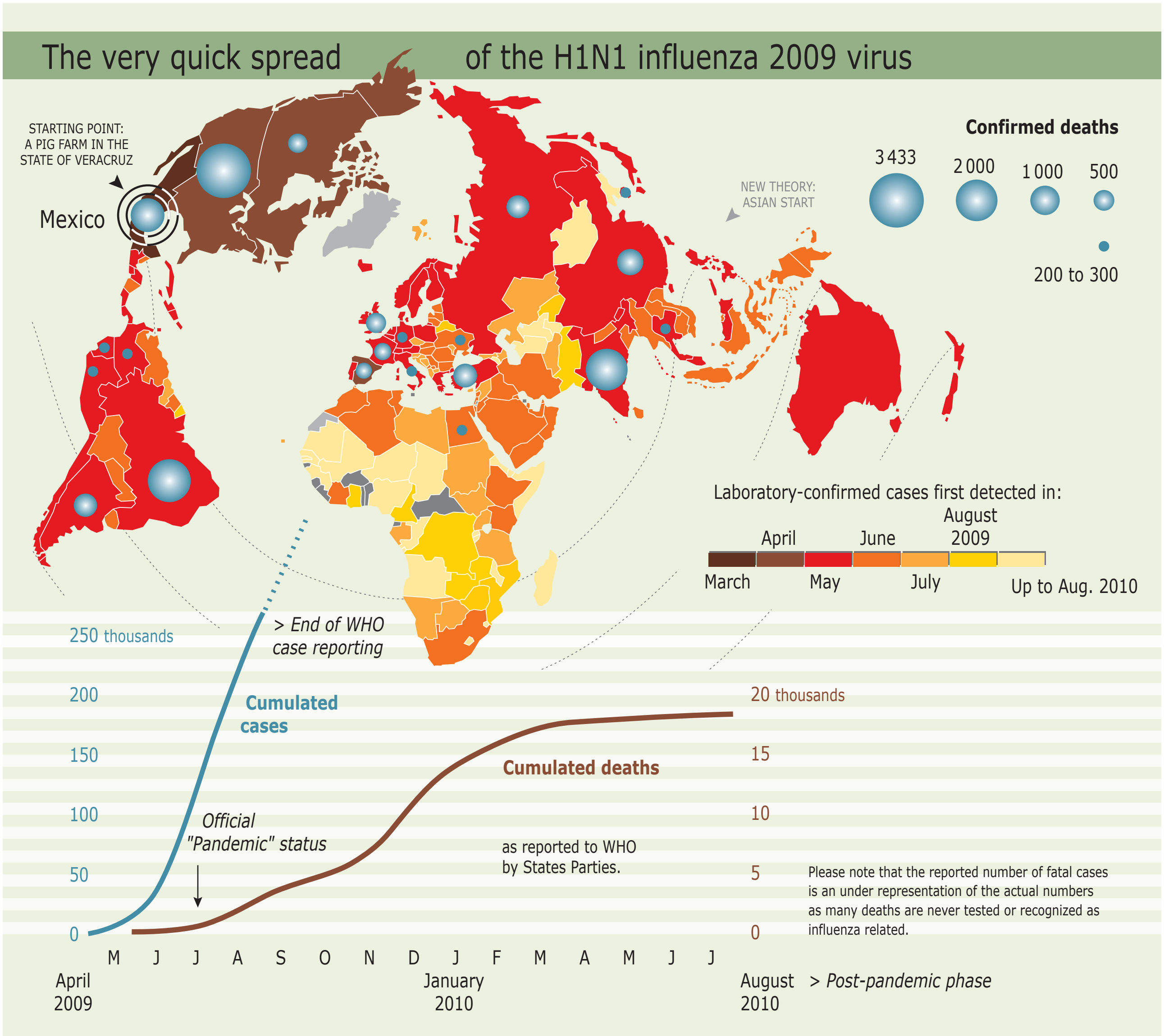
([5]) A child is defined by the Convention on the Rights of the Child (CRC) as 'Every human being below the age of 18 years unless under the law applicable under the child majority is attained earlier'.

The outbreak of the H1N1 swine-origin influenza virus commenced in April 2009. The first pandemic of the 21st century, it has been estimated to kill more than 18 000 people from more than 214 countries (WHO, 2014c). Figure 3.10 shows the rapid outbreak of the H1N1 virus around the world within a few months. The WHO announced in August 2010 that the H1N1 influenza virus had officially moved into the post-pandemic period but localised outbreaks have continued.

In 2013, the WHO redefined its pandemic alert system, putting in place a four-phase system to track new outbreaks of diseases from the first few infections in humans through to a pandemic (WHO, 2013h). The outbreak of the Severe Acute Respiratory Syndrome (SARS) in 2002 for example, which (as it was registered) infected more than 8 000 people and killed nearly 800, did not reach the pandemic stage. Due to an early disease recognition and rapid implementation of global and national actions, its transmission was slowed and the chain of the transmission broken before it could become pandemic. The disease has not been eradicated, however, and could thus re-emerge.

Another factor that can contribute to or cause outbreaks of infectious diseases is the development of resistance to antibiotics. These medicines have been one of the most effective and common means to protect human health. Bacteria are increasingly showing resistance to existing antibiotics, due in part to their overuse by humans and

Figure 3.10 Outbreak and spread of the H1N1 influenza virus in 2009



Sources: WHO Maps of affected countries and deaths; WHO Global Alert and Response Pandemic (H1N1) 2009 updates.

on livestock. The pace of development of new antibiotics has slowed, however, and not all drugs currently under development are proven effective against bacteria that have developed resistance to current antibiotics (Borer et al., 2009).

In the USA, it is estimated that two million people a year become infected with bacteria that are resistant to at least one antibiotic. Direct deaths are estimated at over 20 000 a year (CDC, 2013). In Europe, meticillin-resistant Staphylococcus aureus, better known as MRSA, a source of infection in particular in hospitals, is stabilising and possibly decreasing, but not as quickly as had previously been projected. Meanwhile, the incidence of Klebsiella pneumonia infections resistant to three classes of antibiotic is growing (Figure 3.11). And a strain of Enterobacteriaceae, a source of bladder, lung and blood infections, has become resistant to all antibiotics (McKenna, 2013). Experts are therefore starting to prepare for situations in which all antibiotics will be ineffective, even for treating the most common infections. Such scenarios could result in higher mortality rates globally (WEF, 2013).

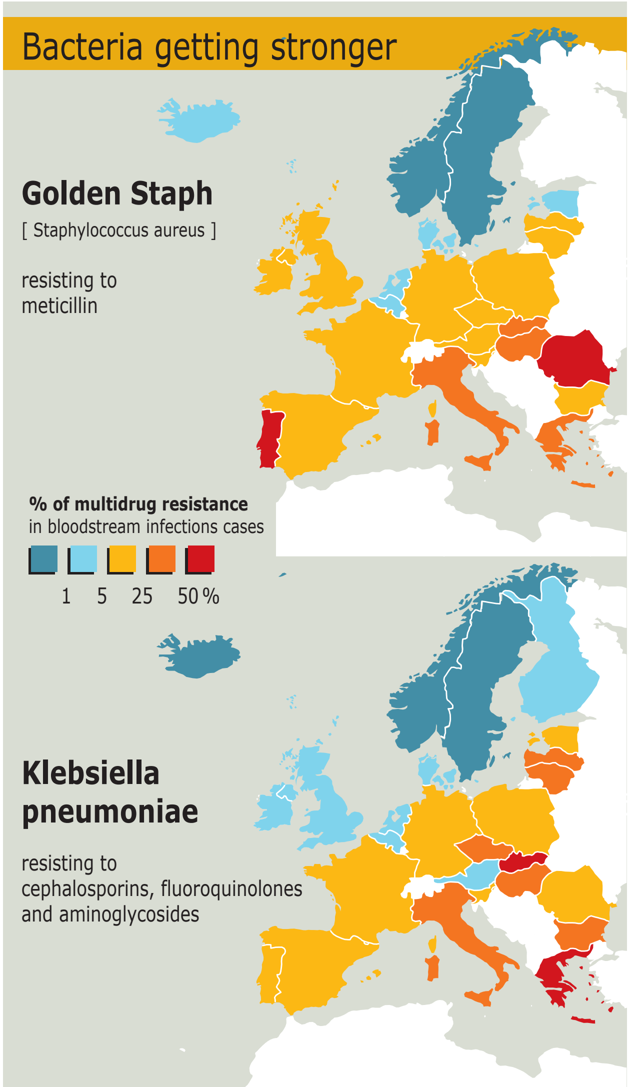
Antibiotic-resistant infections already result in significant costs for the health care systems. In Europe, antibiotic-resistant bacteria infections cause over 20 000 deaths and cost over EUR 1.5 billion per year. Elsewhere losses to GDP have been estimated at 0.4–1.6% (WEF, 2013; Spellberg et al., 2011; White, 2011). Moreover, antibiotic-resistant bacteria could affect livestock, probably resulting in shortages of food and restrictions on trade (WEF, 2013).

Another concern is multi-drug resistant tuberculosis. After HIV, tuberculosis (TB) is the greatest killer globally due to a single infectious agent. In 2012, 8.6 million people developed TB, of whom 1.3 million died. Due to global healthcare efforts, TB rates have declined by more than one-third worldwide since 2004 (UNAIDS, 2013). However, due to drug resistance TB has re-emerged in some developed countries (e.g. Denmark) where it had historically been reduced to very low levels (IOM, 2013). Of particular concern are cases resistant to at least two key drugs used for treatment (isoniazid and rifampicin). These rose to about 5% all cases in 2011 and are found in over 80 countries. In Russia, for example, more than 15% of new tuberculosis cases are multi-drug resistant.

Climate change, including natural disasters and extreme weather conditions, will influence the prevalence of communicable diseases, particularly vector-borne diseases (i.e. diseases transmitted by bites of infected carriers such as mosquitos). Rising temperatures can influence the distribution patterns and reproduction rates of vectors, and humidity and the availability of water will have an impact on breeding sites, behaviour and longevity. Climate change can also influence the incubation period of pathogens inside the vectors; a warmer temperature often results in a shorter incubation period and thus a more rapid spread of disease. Additionally, human exploitation of tropical rainforests, deforestation, population growth, increasing immigration and international air travel and tourism to tropical regions also contribute to the increased incidence of vector-borne diseases.

Malaria and dengue are two vector-borne diseases that are endemic (i.e. there is a constant or usual presence among a population within a certain geographic area)

Figure 3.11 **Multi-drug resistance in Europe: *Staphylococcus aureus* and *Klebsiella pneumonia***



Source: European Center for Disease Prevention and Control, EARS-Net, 2012.

and sudden outbreaks can occur. For example, periodic flooding linked to the El Nino-Southern Oscillation has been associated with malaria epidemics in the dry coastal region of northern Peru (Gagnon et al., 2002). Dengue caused an explosive local outbreak in the state of Rio de Janeiro in Brazil as a result of heavy rains, with more than 158 000 cases and 230 deaths reported in the first four months of 2008 (WHO, 2012c).

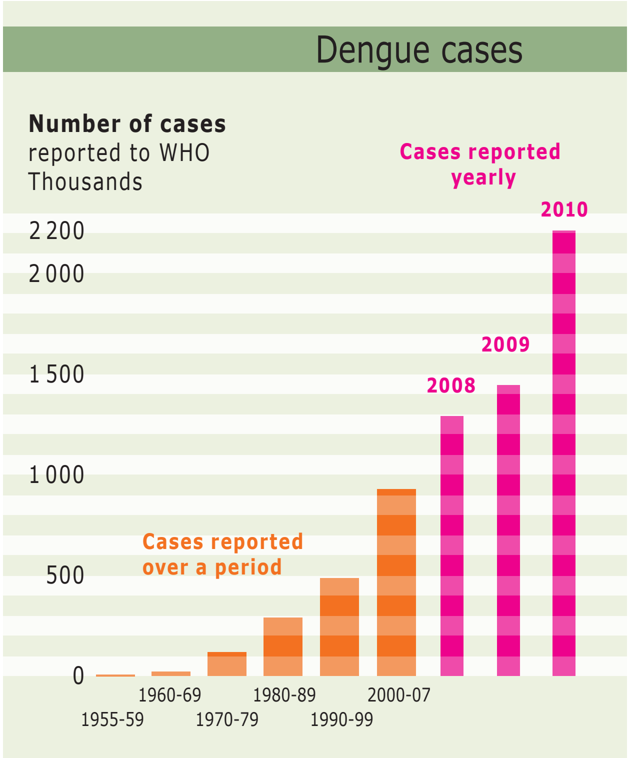
According to estimates released in December 2013, there were around 207 million cases of malaria in 2012 and an estimated 627 000 deaths; 86% of them were children under the age of five (WHO, 2013c; WHO, 2013e). While malaria mortality rates have dropped by 45% globally since 2000, drug resistance poses a growing problem. Resistance has developed to every anti-malarial medicine used so far (WHO, 2010c). Resistance to the drug artemisinin — the key component of artemisinin-combination therapies (ACTs), which are currently the best available anti-malarial drugs — has been detected in the Greater Mekong sub-region.

Dengue fever, together with associated dengue haemorrhagic fever (DHF), is the world's fastest growing vector-borne disease. The worldwide incidence of dengue has risen 30-fold compared to the situation 50 years ago (Figure 3.12), and an increasing number of countries are reporting their first outbreaks (WHO, 2012b). These numbers are probably underestimations, as severe underreporting and misclassification of dengue cases have been documented. Almost half of the world's population lives in areas where dengue is endemic.

Persistent health inequalities between and within countries

While average life expectancies and health standards have improved globally over recent decades, significant differences still exist both between and within countries. Nearly half the world's deaths under five years old are concentrated in sub-Saharan Africa (UNICEF et al., 2013). Whereas a child born in Sierra Leone has a life expectancy of 47 years, a child in Japan can expect to live 36 years longer (WHO, 2014b). Disparities also exist within countries, as people with lower levels of education, lower occupational classes and lower levels of income have a higher prevalence of health problems and tend to die at a younger age. For example, a child born in Bangladesh to a woman with no education has an infant mortality rate of 71%, while a child born to a woman with secondary education level or higher has a probability of dying between birth and age one of 41%. (WHO, 2014e).

Figure 3.12 Dengue cases reported to WHO annually: averages for 1995–2007 and yearly for 2008 to 2010



Source: WHO, *Global Strategy for Dengue Prevention and Control 2012-2020.*

Disparities in health outcomes are linked to a wide range of socio-economic determinants. One key factor is access to and differences in health care (Table 3.2).

Large disparities in health are often found between rural and urban areas as well as across urban neighbourhoods. These differences can be influenced by economic conditions as well as social and health policies. For example, in Colombia, a middle-income country, there is little difference in child mortality between rural and urban areas. But in Mali, a low-income country, these differences persist (WHO, 2014b). Further information about how urbanisation is linked with rural-urban disparities in living standards and opportunities can be found in GMT 2.

Around the world, many disadvantaged groups also face higher risks of environmental health impacts due to poor housing conditions, inadequate sanitary equipment, lack of access to clean drinking water, high levels of noise and frequent injuries due to unsafe environments. Slums can concentrate these risks. These groups also have more limited capacities to adapt to a changing climate.

The substantial increase in education, especially of women, and the reversal of the gender gap have important implications not only for health but also for the status and roles of women in society. The continued increase in educational attainment even in some of the poorest countries suggests that rapid progress in terms of Millennium Development Goal 4 might be possible (Gakifou, E. et al., 2010) (Figure 3.13).

Although there is limited quantitative information available relating to inequalities, some data indicate a decline in health inequalities across the world. The UN's Human Development Report (UN, 2013c) found declines in health inequalities between 1990 and 2010 in all regions of the world. These declines were strongest in several developing regions, especially in south Asia; they were weakest in developed countries including European countries (UN, 2013c). Among the factors driving reduced inequality are improvements in education, especially for women, and falling poverty levels.

Despite these declines, significant health inequalities remain within and between countries and regions globally. According to the World Health Organization, each year an estimated 150 million around the world face financial ruin to pay for medical expenses (WHO, 2013g). Surveys undertaken by the WHO from 2007 to 2011 indicate that in the public health sector, the average availability of generic medicines in developing countries was only 52% (WHO, 2011f). Due to this scarcity, people are forced to turn to the private sector to obtain their medication, where prices are often significantly higher. The economic crisis has also taken a toll on households' health care budgets around the world (see Box 3.3).

As stated in the final report of the WHO Commission on Social Determinants of Health: 'Putting health inequities right is a matter of social justice. The right to the highest attainable standard of health is enshrined in the Constitution of the World Health Organization (WHO) and numerous international treaties. But the degree to which these rights are met from one place to another around the world is glaringly unequal. Social injustice is killing people on a grand scale' (EFC, 2006).

3.3 Implications

Global health trends have wide-ranging implications, including for economic and social development.

The processes of globalisation are creating new threats to health and its determinants. Health issues that transcend national boundaries include environmental degradation, inequality and lifestyle changes, access to medicines and health knowledge, as well as new and re-emerging diseases. Global health threats are increasingly described as a generational challenge to sustainable development, since if they are not addressed now, they will become uncontrollable threats to the health and security of future generations (EFT, 2006). Changes in the make-up of the disease burden worldwide can put a strain on health systems, deepen inequalities and increase poverty and health costs (Lancet, 2013).

Despite the remarkable achievements in improved health care in many parts of the world, a large share of the world's population will continue to face poor health care — as well as poor environmental conditions. Many of these people will live in the growing mega-cities in developing countries. These places may become breeding grounds for further spread of diseases and social unrest.

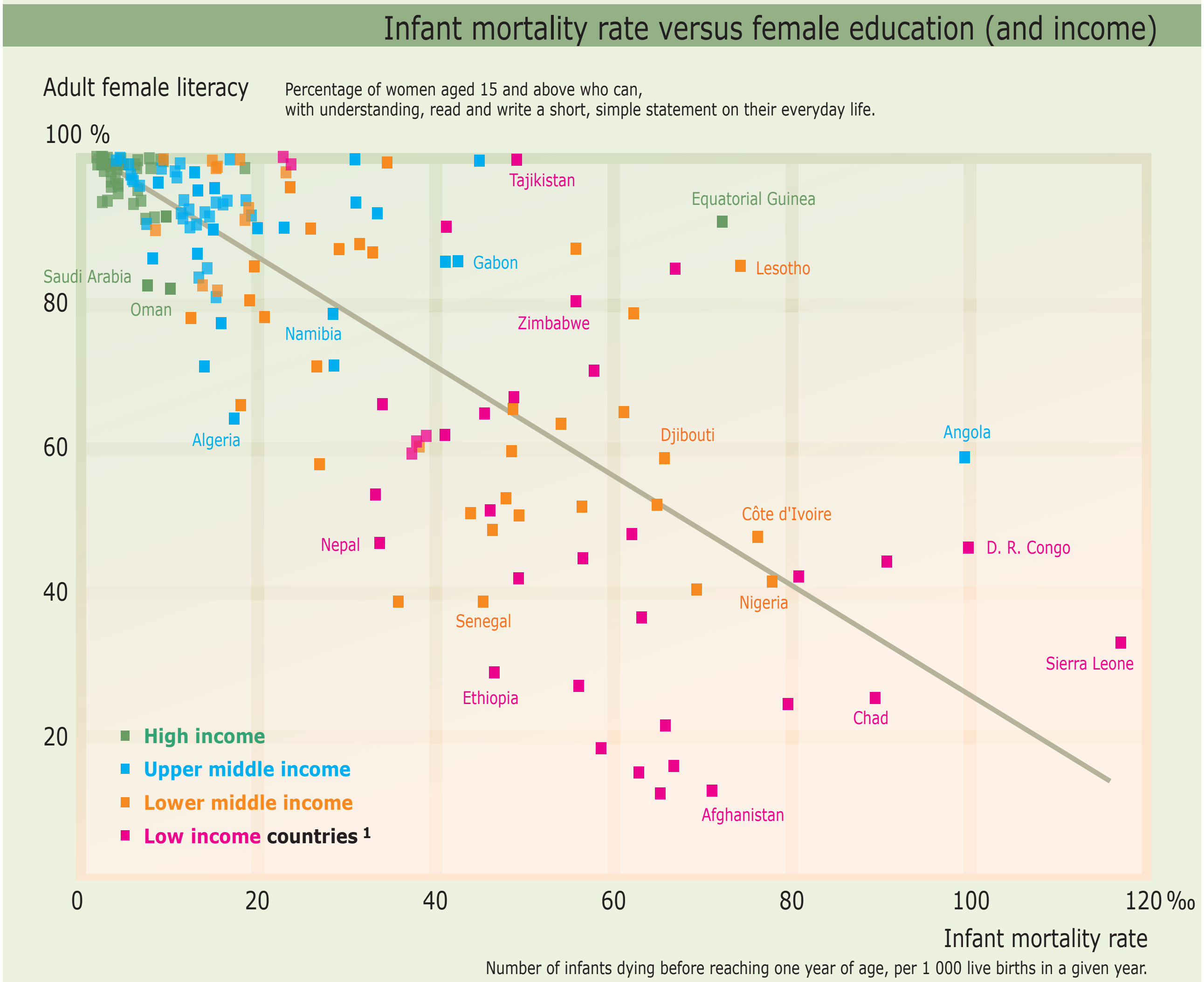
Moreover, if current trends continue (including demographic, urbanisation, economic and health trends and related inequalities — GMT 1, 2, 5 and 6) many developing countries will need to deal with the 'multiple burden' of disease, comprising communicable diseases, pandemics and life-style diseases

Table 3.2 Physicians and health expenditures by WHO region, 2010

WHO region	Physicians per 10 000 population	Health expenditures	
		% GDP	USD/cap PPP
African	2.5	6.2	154
Americas	20.4	14.3	3454
South-East Asia	5.5	3.6	125
European	33.3	9.3	2282
Eastern Mediterranean	10.8	4.5	326
Western Pacific	15.2	6.4	650

Source: WHO, 2014f.

Figure 3.13 Infant mortality rates compared with female education levels



1. as classified by the World Bank, according to 2012 Gross National Income per capita. The groups are: low income, 1 035 $ or less; lower middle income, 1 036 to 4 085 $; upper middle income, 4 086 to 12 615 $ and high income, 12 616 $ or more.

Sources: World Bank Development Indicators, 2014; UNESCO; Gapminder; CIA World Factbook, 2013.

Box 3.3 The impact of the global economic crisis

Analysis of the health impacts of the global economic crisis indicates that a common 'coping mechanism' among those impacted by low employment and poverty has been reduced expenditure on healthcare. UNICEF (2012) reports that 'in a number of developing countries, in particular, households have consistently reported lower healthcare spending and service utilization, which has exposed many people to a higher risk of sickness, disability or even death.'

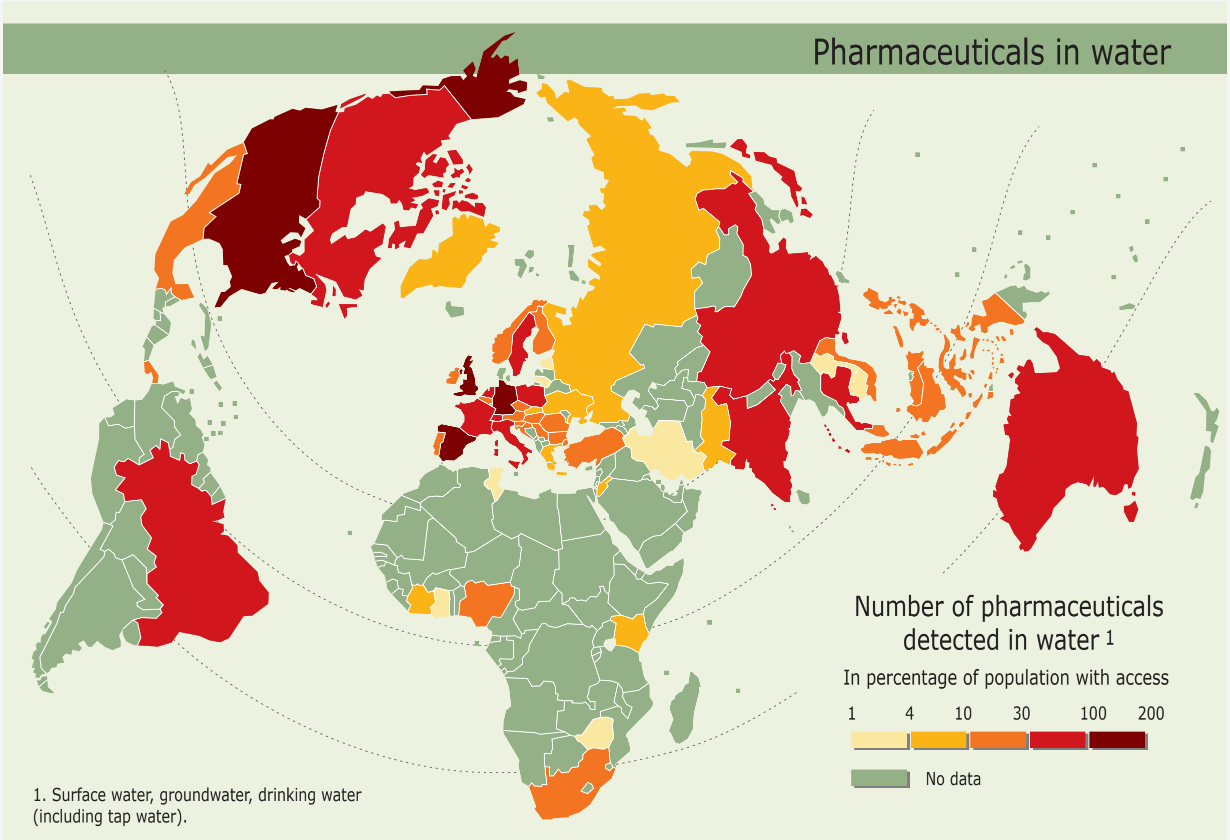
Moreover, the WHO's Twelfth Work Programme reports that reduced public spending in some developed countries following the crisis may affect their ability to respond to outbreaks of infectious diseases. For example, Greece, a country hit hard by the global financial upheaval, has been suffering a variety of health problems since the start of the economic crisis. These include a disproportionately high morbidity and mortality burden of influenza, the emergence and spread of West Nile virus, the appearance of clusters of non–imported malaria and the outbreak of HIV infection among people who inject drugs (Bonovas, 2012).

Box 3.4 Pharmaceuticals and the environment

A recent review (Sumpter and Roig, 2012) found that pharmaceuticals have been identified in water bodies in more than 70 countries (Figure 3.14). Information is strongest for developed economies but many pharmaceuticals have also been detected in developing countries.

Most discharges appear to come after human use of pharmaceuticals, often flowing through urban sewer and wastewater treatment systems. Urban wastewater treatment plants usually have only a limited effect, reducing the load of pharmaceutical products by about 20% before they reach water bodies. While some pharmaceuticals are biodegradable or photodegradable, others are not. Other sources include pharmaceutical production and also use in agriculture and aquaculture. The issue of pharmaceuticals in the environment is being studied by SAICM (the Strategic Approach to International Chemicals Management), a global initiative for the sound management of chemicals.

Figure 3.14 Pharmaceuticals detected in surface water, groundwater and drinking water



Source: Frank-Andreas Weber, IWW Rheinisch-Westfälisches Institut für Wasser, 2013.

(non-communicable diseases) with resulting increases in adult mortality and morbidity. This burden will be felt particularly acutely in rapidly-growing urban areas, especially slums (WHO, 2013a), appearing together with high levels of violence and injuries. Health and economic inequalities can have knock-on effects elsewhere in society.

Non-communicable diseases already threaten the finances of developing countries, both directly via high healthcare costs and indirectly via lost productivity. For developed countries, costs related to ageing and health could increase fiscal pressures and affect future social cohesion and wellbeing (OECD, 2014). Communicable diseases, maternal, neonatal and nutritional deficits are persisting and are still posing a significant threat to human health, particularly in developing countries. And a global disease outbreak could lead to significant human and financial losses all around the world.

These developments have implications for global governance systems and structures. Threats to health are increasingly created, or amplified, by policies made in non-health sectors and require, a coherent response across sectors, governments and geographic boundaries in order to address the global burden effectively. A combination of actions for sanitation, health care, economic development, climate change adaptation and more, are needed to address problems that impact the poor in the world's megacities. The importance of doing so is explicitly acknowledged in the recent Parma Declaration on Environment and Health. That document recognizes the increasingly critical role of economic arguments in developing sound policies across all sectors.

The environment and human health are linked via a complex set of interactions (highlighted in Section 3.1.3). Addressing air and water pollution as well as chemical risks will have direct benefits for

Box 3.5 European health trends

While communicable diseases impose a relatively low burden in Europe, intensive travel and migration links to all regions of the world increase exposure to possible future pandemics. Moreover, antibiotic resistance is of growing concern in Europe (Figure 3.11). Progress in reducing HIV transmission is positive overall, except among people who inject drugs. Evidence suggests that in several countries in eastern Europe HIV incidence is growing (UNAIDS, 2013).

With its rapidly ageing population, NCDs are of particular concern for Europe. Social and lifestyle factors are also important, including high levels of alcohol and tobacco consumption and growing obesity. As a result, across the WHO European area, including Russia and eastern Europe, five NCDs — diabetes, cardiovascular diseases, cancer, chronic respiratory diseases and mental disorders — cause 86% of premature deaths and 77% of the disease burden (WHO Europe, 2014).

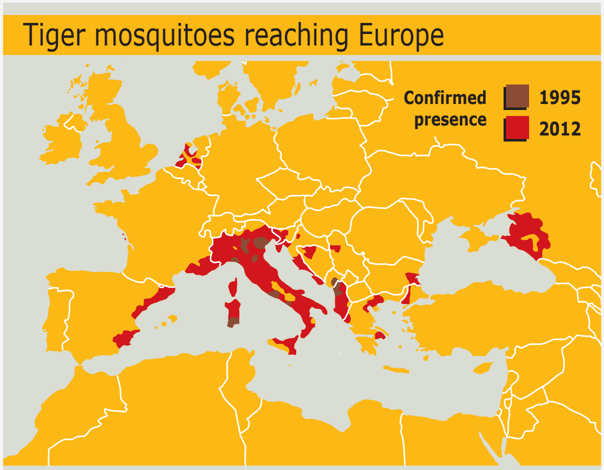
Pollution and other environmental issues remain a concern for health in Europe. While access to safe drinking water and improved sanitation is nearly universal, air pollution levels remain a health concern that particularly affects vulnerable groups such as the ill and ageing, as well as children, for whom it increases sensitivity to respiratory problems such as asthma (EEA and JRC, 2013).

Climate change is a concern for coming decades, as it bring new disease vectors. For example, the geographical distribution of disease-transmitting ticks in Europe has changed since the early 1980s and ticks are now found at higher latitudes and altitudes where the seasons were previously too short or too cold for ticks to survive and establish new populations. Asian tiger mosquitoes, which are capable of spreading dengue fever and other tropical diseases, are now established in southern Europe and parts of the Netherlands and are likely to spread further in Europe with climate change (Figure 3.15).

A recent report by the European Commission (EC, 2013) confirms that significant health inequalities still exist between and within EU Member States, however, some key indicators have improved: for example, infant mortality rates in the EU have decreased by 26% between 2000 and 2010 and the European population lives longer than in many other parts of the world (EEA and JRC, 2013).

Health inequities also have an environmental dimension, and in 2010, ministers of environment and health of the WHO European Region signed the 'Parma Declaration on Environment and Health', and committed themselves to act on socio-economic and gender inequalities in environment and health as one of the key environment and health challenges (WHO Europe, 2010).

Figure 3.15 Spread of Asian tiger mosquitoes in southern Europe



The Tiger mosquito (*Aedes albopictus*) is an important vector for the transmission of the Yellow fever, Dengue fever and Chikungunya fever.

Source: European Center for Disease Prevention and Control, EARS-Net, 2012.

human health. Climate change will create a series of direct and indirect impacts for health.

Attention to health and environment in urban areas will be particularly important, as a growing majority of the world's population live in cities. Cities can put in place more sustainable transport systems, provide access to drinking water and sanitation, and ensure health care for all segments of the population (WHO, 2010b). In addition, a range of studies have shown that access to green areas can bring health benefits for urban residents (EEA and JRC, 2013).

In rural areas, an integrated assessment of the health and interactions between wildlife, domestic animals and human health can address growing risks of disease transmission across species (see Box 3.1): this is the goal of the 'one health' approach (Choffnies et al., 2012).

One facet of the link between environment and health is the impact of pharmaceuticals on the environment, in particular via water pollution (Box 3.4), which is receiving growing attention in Europe and elsewhere.

These and other interactions call for stronger integration between environmental and health initiatives at all scales, from global to local (EEA and JRC, 2013).

Importance for Europe

European countries have achieved major improvements in public health in recent decades, mostly due to improvements in living and working conditions and progress in medical care. Although most European countries have relatively strong social safety nets and public health care systems, significant health inequalities remain both within and across countries. Worryingly, progress appears to be stalling: health inequalities were as serious in 2013 as they were in 2006 (EC, 2013). Antibiotic resistance, non-communicable diseases, and ambient air pollution levels are of major concern in Europe. Additionally, health challenges linked to the ageing population and to the impacts of climate change may increase in the coming years (EEA and JRC, 2013) (GMT 1, 2 and 10) (see Box 3.5)

These factors, coupled with the increasing cost of supporting long-term care and the declines in informal care threaten the affordability of technical advances in health and care. It seems likely that many EU countries will not be able to afford the levels of health and care service expected by their citizens unless they can address the underlying causes of poor health, including the influence of globalisation (EFT, 2006).

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Global megatrend 4 — Accelerating technological change

The pace of technological change is accelerating. The shifts in technological paradigms that once were separated by centuries or millennia — such as the development of agriculture or the industrial revolutions based on steam and then electric power — are now occurring within a single lifetime. Indeed, the pace at which new technologies are being adopted by the market and used in society has rocketed over the past century and a half. In the early 1900s, it took more than 30 years for a quarter of the US population to adopt telephones and radios — but more recently, the World Wide Web reached this level in only seven years.

Today, research and development around the world are accelerating — in particular for nanotechnologies, biotechnology and information and computer technology. Moreover, the integration of techniques and knowledge across these three areas as well as closely related ones is speeding up the pace of discovery. The new products and innovations emerging from this 'NBIC cluster' can increase resource efficiency and support the shift to low-carbon economies. In this process, technological change may transform energy, manufacturing, health care and many other sectors over the coming decades.

Along with the opportunities, accelerating change will also create new risks for society, for health and for the environment. Institutional and policy innovations will be needed to minimise the emerging risks and promote technological change that supports public goals.

4.1 Drivers

Economic and social megatrends are driving the ever-faster pace of technological development and market adoption. Ongoing economic growth, in particular in Asia and other developing regions, will support greater research and development around the world. The growing middle class in the emerging economies of an increasingly multipolar world will bring new and larger markets for innovative products (GMT 5 and GMT 6). These economies are expected to see rising levels of education, boosting the human capital for research and innovation (GMT 1). The Organisation for Economic Co-operation and Development (OECD) projects that, in coming decades, the number of young people with a tertiary education will be higher and grow fastest in such non-OECD G20 countries such as Brazil, China and India (OECD, 2013). Already, the numbers of engineering graduates in these countries has grown rapidly in recent years (Loyalka et al., 2013).

The growing urban areas of the developing world, including megacities from Kuala Lumpur to Sao Paolo, are expected to further drive innovation, as they create a critical mass of education, research, markets and social needs to sustain it. Cities will, however, need effective planning and strong investment in infrastructure in order to achieve and maintain innovation, for example by attracting and keeping skilled workers (GMT 2).

Economic growth is thus driving technological development — and at the same time, policies support research and innovation as a driver for economic growth. Policy initiatives support new technology as a key to growth in Europe (EC, 2015c) and around the world; they follow in the footsteps of research by 1987 Nobel Prize winning economist Robert Solow, who showed that technological progress is one of the three key factors for economic growth, along with capital and labour — and in the long run, it becomes the dominant factor.

The growing global population and economy will lead to intensified competition for resources, from fossil fuels to critical raw materials: many of these non-renewable resources are scarce (particularly in Europe), costly to extract or unevenly distributed globally, creating risks of supply disruptions (GMT 7). This is a driver for technological development, as competition spurs research into alternative energy sources, substitutes for scarce materials and new extraction methods as well as more efficient ways of using these resources. Ecosystem degradation is threatening renewable resources such as timber (GMT 8): this may drive innovation to improve the efficiency of extraction and use and also to strengthen ecosystem protection and management. The growing threats of climate change (GMT 9) and environmental pollution (GMT 10) can also spur research and innovation for low-carbon and less pollution technologies.

Finally, technology itself is a driver: the Internet is facilitating new forms of communication, collaboration and access to information — factors that in accelerate scientific collaboration and innovation. At the same time, many inventions build on previous ones, and this means that technological changes are often 'path dependent' (Biois, 2013). Even with the changes from typewriters to tablet computers, the pattern of letters on keyboards — set over a century ago — remains in use. On a broader scale, over a century of research and infrastructure have the internal combustion engine a persistent feature of the modern world. As a result, it is vital to look ahead to possible technological developments and consider their benefits and risks ahead of time — rather than when they become pervasive in the economy and in our lives.

4.2 Trends

Many observers foresee that the core of the next, long-term wave of innovation and growth will be formed by links among: the rapidly emerging nanosciences and nanotechnologies, biotechnology and life-sciences, and information and computer technology (ICT) together with cognitive sciences and neurotechnologies — the 'NBIC cluster' (Nightingale et al., 2008; Silberglitt et al., 2002). Indeed, these areas of knowledge have already seen far-reaching advances, and much greater developments are foreseen in coming decades. Cycles of technology-induced social and economic change have accelerated in recent decades and are likely to move even faster: as described in the following pages, there is evidence of exponential rather than linear growth for some areas of technological progress.

Research is becoming more global, including for the NBIC cluster. New centres of innovation are taking seed in the developing world, heightening competition and shortening product innovation cycles. Europe trails the US and Japan in terms of global innovation performance, but remains ahead of others, although South Korea and China are developing rapidly (EC, 2014b). North America and Europe are expected to remain important centres of R&D, but there is a shift in the technological centre of gravity to fast-growing countries of Asia and Latin America (NIC, 2012). India, South Korea and particularly China are already increasing their share of patent filings, simultaneously providing markets for new products (WIPO, 2014). Asian economies, Latin America and other rising technology centres are expected to grow in importance in coming decades.

Although the acceleration of innovation and technological change is stable, its direction is uncertain. Many NBIC technologies are still in the laboratory, and future discoveries cannot be predicted — nor which innovations will be commercially viable. Besides technological constraints, key uncertainties relate to future levels of research funding and also to the role of public policy. Intellectual property regimes and the way they may shape development are also a major concern across new technologies (Biois, 2013).

Nanotechnology

Nanotechnology involves the manipulation of materials at minute scale: the United States National Nanotechnology Initiative defines nanotechnology as the 'understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications' (NNI, 2013). In 2011, the European Commission published a definition of nanomaterials (EC, 2011a) for European legislation and policy on nanotechnology:

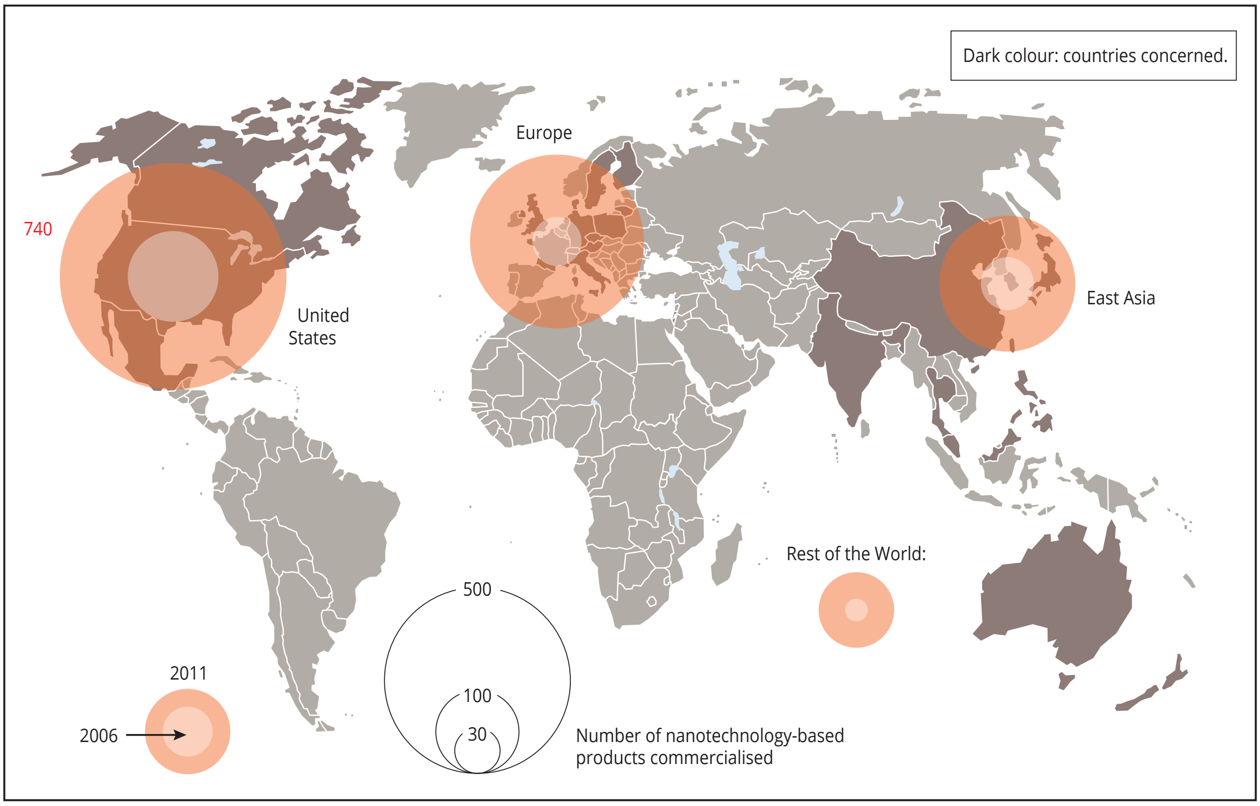
- 'Nanomaterial' means a material containing particles where for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1–100 nm.
- Includes aggregates and agglomerates.
- In specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50% may be replaced by a threshold between 1 and 50%.

This burgeoning field includes many different techniques, materials, applications and products. Nanomaterials are sought after for their special properties, such as greater reactivity, unusual electrical properties or enormous strength per unit of weight compared to normal materials.

Although nanotechnology is only a couple of decades old, it already plays a major role in at least eight major industries: aerospace, automotive, construction, electronics, energy and environment, manufacturing, medical and pharmaceutical, and oil and gas (Forfàs, 2010). Moreover, nanomaterials are increasingly found in consumer products such as cosmetics, personal care products and clothing: in 2013, the Wilson Canter's Project on Emerging Nanomaterials identified 1628 consumer products containing nanomaterials in 30 different countries (Figure 4.1), almost four times as many products compared to 2006.

Among the applications, researchers are seeking to use nanomaterials to create substitutes for critical raw materials, minerals that are at a high risk of supply

Figure 4.1 **Number of consumer products on the market containing nano-materials, by major world region**



Note: Europe data include United Kingdom, France, Germany, Finland, Switzerland, Italy, Sweden, Denmark, the Netherlands.

East Asia data include China, Taiwan, Korea, Japan.

Other data include Australia, Canada, Mexico, Israel, New Zealand, Malaysia, Thailand, Singapore, The Philippines, Malaysia.

Source: Wilson Center, 2013.

shortage (GMT 7). Some of these materials are used for key products such as advanced batteries and solar cells (Box 4.1).

Advances in the control of matter at the nanoscale continue, often with synergies from other emerging technologies. In 2010, for example, scientists succeeded in creating a DNA assembly line with the potential to create novel materials efficiently on the nanoscale (Gu et al., 2010). In 2013, researchers achieved the self-assembly of nanochains for the first time (Liu et al., 2013), a technique that could open a path for the creation of still new materials and products (Travesset, 2011).

Biotechnology

Biotechnology refers, broadly, to the 'application of science and technology to living organisms' (OECD, 2005), in particular their genomes. Biotechnology has contributed to a broad range of existing applications, including: the development of new medicines, health diagnostics and treatments for treatments such as dementia (Biois, 2013); testing methods for animal disease and food safety more generally; enzymes for chemical production, pulp and paper manufacturing, textile production and other industrial applications; (and also enzymes in consumer products, such as detergents); and microbes for the bioremediation of contaminated sites (JRC/IPTS, 2007).

Over the past decade, the costs of genomic sequencing, a key tool in biotechnology, have fallen exponentially: by 2013, a human genome could be sequenced in a few hours and for a few thousand dollars, a task that just over a decade ago took USD 2.7 billion and 13 years to accomplish during the Human Genome Project (Figure 4.2). This drop in price is expected to be a catalyst for biotechnology research and innovation.

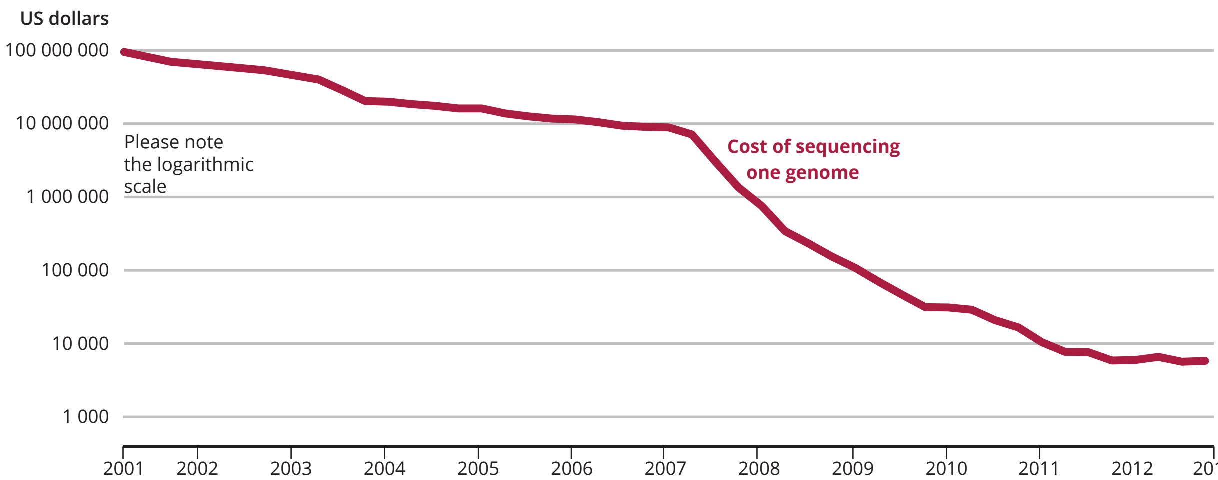
With these advances, biotechnology is profoundly changing healthcare. For example, genetic sequencing, already used for diagnosing health problems and

Box 4.1 Nanotechnology and critical raw materials

Indium, a critical raw material, is used in indium tin oxide (ITO) to make the organic light emitting diodes (OLEDs) for displays and touch screens and as a conductor in solar cells. Silver nanowires offer an alternative to ITO in touch screen displays, whereby genetically modified viruses are used to create transparent coatings made of silver nanowires. Another possible alternative is the use of nano graphene. While applications of both nano graphene and silver nanowires in products remain at the research stage, 2013 saw the commercialisation and mass production of a nanoparticle coating to produce transparent conductive films. These nanoscale substitutes could reduce the demand for indium and enable the continued growth of technologies dependent on transparent conductors (Johnson, 2013). Regarding the use of indium in solar cells, researchers in the Netherlands have created a possible synthetic replacement in the form of a composite of carbon nanotubes and plastic nanoparticles that could have the potential for high levels of electrical conductivity. Commercially, this could reduce the costs of solar cells (Kyrylyuk et al., 2011).

Research is also seeking to develop methods to synthesise nanomaterials using critical raw materials, in order to reduce the amounts needed. For example researchers have made progress in engineering gallium nitride nanotubes from gallium oxide powder, with potential application in photocatalysis, nanoelectronics, optoelectronics and biochemical sensors (Osborne, 2013, Jiang et al., 2013). Scientists have also succeeded in synthesising germanium nanomaterials, which could have applications in flash memories and lithium-ion batteries (Vaughn and Schaak, 2013). Semiconductor nanowires using indium phosphide and gallium arsenide have been developed, these may reduce the amounts of these materials needed to make solar cells by a factor of 1 000 (Heiss et al., 2013).

Figure 4.2 The falling cost of DNA sequencing



Source: NHGRI, 2013.

developing therapies, could become a common element in healthcare: it could, for example, create more effective, personalised treatments for many types of disease, including cancer. Genetic research is looking to regrow organs and even improve them (Subramanian, 2009). The synergies between bio and nanotechnologies and ICT could drive further innovations: for example, drugs for cancer could be embedded in nanoparticles for targeted release when they reach tumours (Manyika et al., 2013).

In recent years, a new field has emerged: synthetic biology, the design of new 'biological parts, devices, and systems' and the re-design of existing ones (SB, 2013). In the laboratory, synthetic biology techniques have been used to modify bacteria to produce artemisinin, a drug used for malaria treatment; a range of modified and new organisms could be used for health care in coming years. The widespread development of organisms 'by-design' would take biotechnology to a new level and could have a profound impact on sectors from healthcare to agriculture. One step has been the compilation of a registry of 'biological parts' at MIT (UK Foresight, 2012). Another one is the creation, in 2013, of the first 'synthetic cell', with a laboratory-produced genome (Calloway, 2013). These innovations could profoundly affect a range of sectors, including agriculture — and also raise questions about environmental risks (Section 4.3.3).

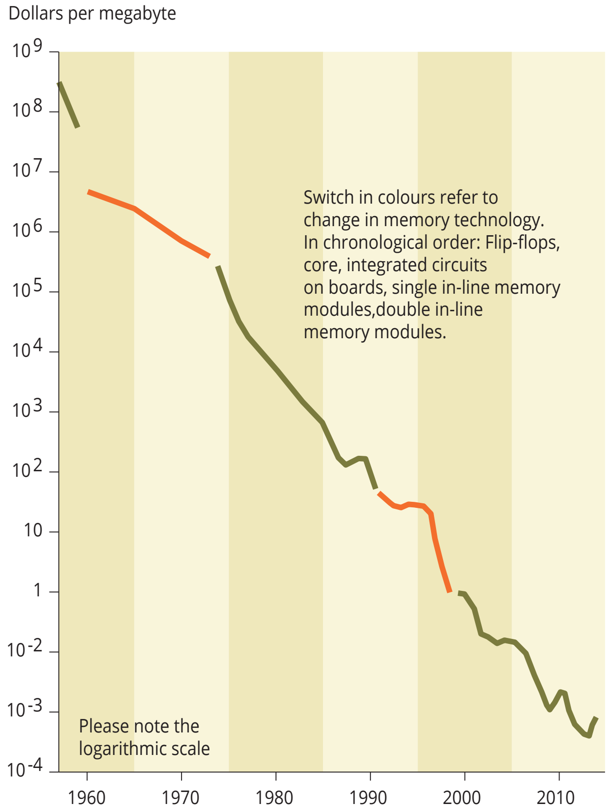
The ongoing information revolution

Information and communication technology (ICT) has become pervasive around the world, as the central 'functions' of ICT — processing, storing and transferring information — have all shown dramatic increases in performance, accompanied an exponential fall in costs. For example, one megabyte of computer memory cost almost USD 1 million in 1970, but it fell to well under USD 100 in 1990 and then to about USD 0.01 in 2010 (Figure 4.3).

As a result, networked computing is now used throughout the economy, for activities from retail payments to stock market sales to guidance and control systems for high-speed trains and commercial planes. Computers, the Internet and mobile phones have permeated communities around the world. The International Telecommunications Union estimates that by 2013 there were almost 7 billion mobile phone subscriptions — almost as many as the global population; in addition, 40% of the world's households had a computer (ITU, 2013). In contrast, the UN estimates that about one-third of the world's population, about 2.3 billion, lacked access to improved sanitation in 2011; moreover, the corresponding Millennium Development Goal — to reduce this share to 25% of the global population by 2015 — will not be met (UN, 2013). In other words, more people around the world have access to mobile phones than to improved sanitation.

The rapid pace of ICT developments is expected to continue in coming decades, fuelled in part by applications from nanotechnology. For example, an integrated circuit based on graphene — a substance first produced artificially in 2004 — was developed in 2011 (Yu-Ming et al., 2011). Nanotechnologies may lead to the construction of smaller circuits and computers that run faster and have longer lives, reducing resource requirements in the production of computer hardware. Likewise, nano-based supercapacitors offer the possibility of advances in battery capacity which could deliver comprehensive mobile internet access to areas lacking reliable electricity supplies. The development of nano-electromechanical machines, novel devices

Figure 4.3 The declining cost of computer memory



Source: McCallum, 2014.

which are able to generate, process and transmit multimedia content at the nanoscale, could lead to a range of mobile Internet devices (Jornet and Akyildiz, 2012).

The information revolution is spawning several new areas whose products and services are entering global markets. One of the key emerging fields for ICT is the '*Internet of Things*': the use of tiny identification tags with internet-linked sensors and actuators embedded in machines and products throughout the economy. Already, radio-frequency identification is used to track packages and products. The 'Internet of Things' would allow much greater automation and control of factories as well as more precise agricultural irrigation and pesticide application (Manyika et al., 2013).

Another major area of ICT development is '*big data*'. Computers are now able to store and process massive amounts of data: by one estimate, 2.5 trillion gigabytes of data were created every day around the world in 2012, a level that is doubling approximately every two years. Through machine learning techniques, computers have evolved in recent years from fixed algorithms that govern their actions to machine learning techniques, in which they analyse the 'big data' to alter their algorithms, (Manyika et al., 2013) giving them greater capacity for machine learning and 'intelligence'. The economic shift in global regions is an integral part of this growth: while developing countries accounted for about one-third of all data created in 2012, their share is forecast to reach nearly two-thirds of the worldwide total in 2020, with the strongest growth in Asia (IDC, 2012).

ICT is also spurring the development of *additive manufacturing*, also called 3D printing: this process makes three-dimensional solid objects from digital models. Additive technology allows more rapid prototyping of parts and complete products, offering greater room for experimentation and a shorter design-production cycle. It can also produce shapes that would be otherwise impossible or impractical to produce, and has already been used in the production of jet engines, resulting in novel designs that reduce weight and therefore fuel consumption. Future advances in layering techniques and materials are expected to enable increasingly complex goods to be printed at lower costs (UK Foresight, 2013).

Additive manufacturing can be applied to a broad range of materials: although most work now involves components and products made out of plastic and metals, researchers have successfully 'printed' simple prototypes of human organs using an inkjet printing technique to layer human stem cells with a supporting structure, and new 'bio-materials' could be created (UK Foresight, 2013). The use of additive methods for nano-materials is another area for research (Campbell et al., 2011).

Robotics is also benefitting from advances in ICT. Already, over 1.2 million industrial robots are in daily operation around the world (NIC, 2012); with lower ICT costs and more advanced programming and machine learning techniques, industrial robots are expanding their usefulness beyond the physically difficult, dangerous, or dirty jobs that they have occupied for the last few decades, and into less demanding tasks that were previously the realm of people — and thus, robots are taking over more manufacturing jobs (Biois, 2013).

Robots have entered the consumer market, in particular for cleaning. They are being tested for new and dangerous activities, such as emergency response. Robots include autonomous vehicles: already, vehicles remotely controlled by humans are used in industries such as mining and deep sea oil extraction; the use of autonomous vehicles in these sectors is forecast to grow in coming years in dangerous and remote situations. Other applications can include the inspection of remote power lines and oil pipelines. In developed countries, autonomous tractors may play a role in agriculture (NIC, 2012).

Self-driving cars are also an application of robotics: these use a variety of sensors to navigate crowded city streets. The prospect is reduced congestion, as autonomous vehicles can space themselves more efficiently than humans; reduced emissions through optimal driving; and fewer accidents, injuries and death. Self-driving cars can also free time for former drivers, who could spend travel times in leisure or work activities. They could also be a component of car-sharing models (Biois, 2013). Autonomous vehicles could transform both passenger and freight systems — but raise a number of challenges, including legal issues as well as the impact of computer viruses on safety (Hodson, 2015).

Robots are also being created at nano-scale. Future medical nanotechnology could involve the injection of nanorobots into the patient in order to deliver targeted functions at the cellular level. A growing area for research is the brain-computer interface, such as methods for the handicapped to control artificial limbs, vehicles and computers (UK Foresight, 2012).

Among the sectors that ICT is transforming is that of science and technology development itself. Communication technologies allows scientists across the world to work together, while extensive data is now available online from sources such as GenBank, an annotated collection of all publically available DNA sequences maintained by the US National Institutes of Health (NCBI, 2013). The new 'networked science' can itself accelerate discovery; at the same time, this new 'open science' raises questions for intellectual property, including patents (Nielsen, 2012).

4.3 Implications

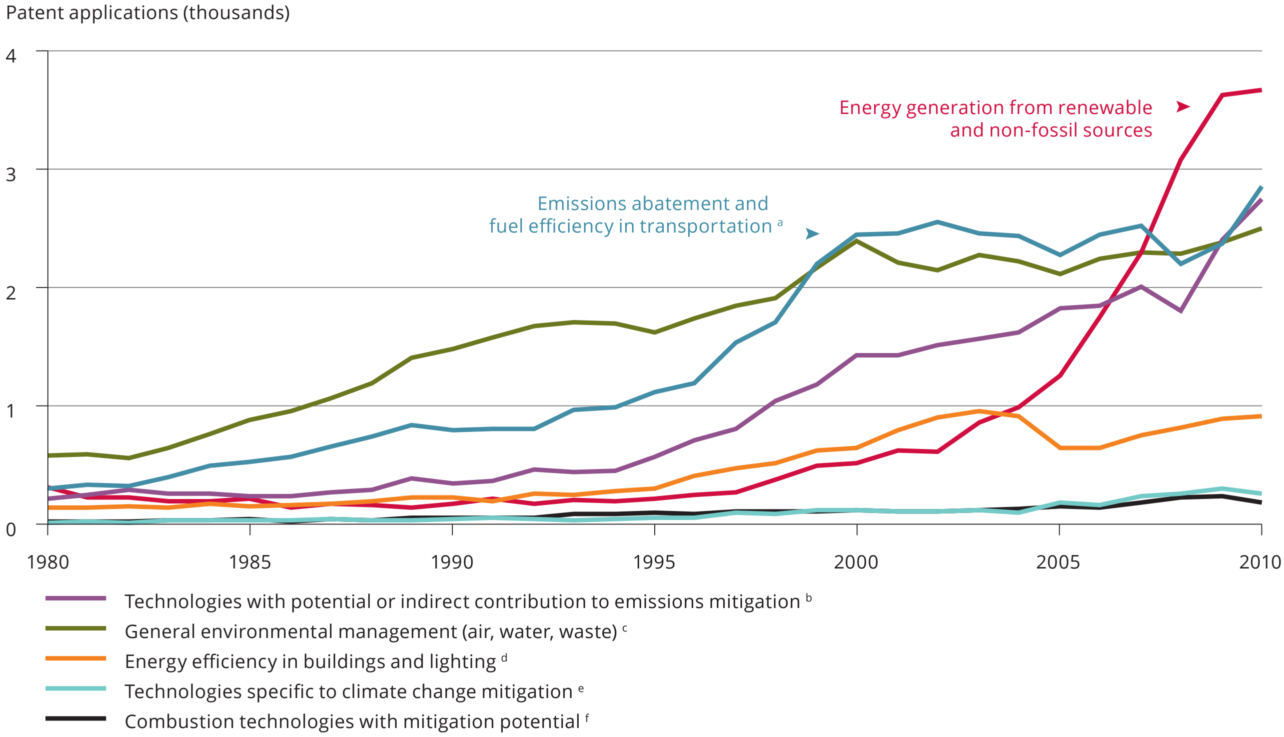
Supporting resource efficiency and the shift to a low-carbon economy

By 2040–2050, nano- and biotechnologies are expected to be pervasive, diverse and integrated into all aspects of life (Subramanian, 2009). The NBIC cluster will bring a range of opportunities and risks for both people and the environment (Biois, 2013). One important area of opportunity is to develop products and research that increase resource efficiency and promote the shift to a low-carbon economy (UNEP, 2011). In recent decades, environment-related applications to the European Patent Office have steadily increased, with those targeting emission mitigation and energy showing significant growth (Figure 4.4). Examples could include the use of biotechnology to develop new environmental remediation techniques. Nanomaterials are yielding advances in energy storage, stronger and lighter construction materials and new filters for water treatment and saltwater desalinisation (UBA, 2010).

Opportunities for key economic sectors
In manufacturing, additive manufacturing could reduce energy and materials consumption: rather than cutting away material that would then need to be recycled or discarded, this technique uses nearly the exact amount of material needed in the final part, greatly reducing (though not eliminating) waste (Biois, 2013).

For the chemical industry, green chemistry approaches could change the sector's environmental impacts. Green chemistry involves the 'design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances' (USEPA, 2013). It promotes the use of renewable feedstocks, including agricultural products and waste, rather than non-renewable resources from mining

Figure 4.4 Environment-related patent applications to the European Patent Office, 1980–2010



Note: The graph shows the development in total patent applications (direct and patent cooperation treaty national phase entries); for the world's seven largest filing offices.

a. Technologies specific to propulsion using internal combustion engine (ICE) (e.g. conventional petrol/diesel vehicle, hybrid vehicle with ICE); technologies specific to propulsion using electric motor (e.g. electric vehicle, hybrid vehicle); technologies specific to hybrid propulsion (e.g. hybrid vehicle propelled by electric motor and internal combustion engine); fuel efficiency-improving vehicle design (e.g. streamlining).

b. Energy storage; hydrogen production (from non-carbon sources), distribution, storage; fuel cells.

c. Air pollution abatement (from stationary sources); water pollution abatement; waste management; soil remediation; environmental monitoring.

d. Insulation (including thermal insulation, double-glazing); heating (including water and space heating; air-conditioning); lighting (including compact fluorescent lamps, light-emitting diodes).

e. Capture, storage, sequestration or disposal of greenhouse gases.

f. Technologies for improved output efficiency (combined combustion); technologies for improved input efficiency (efficient combustion or heat usage).

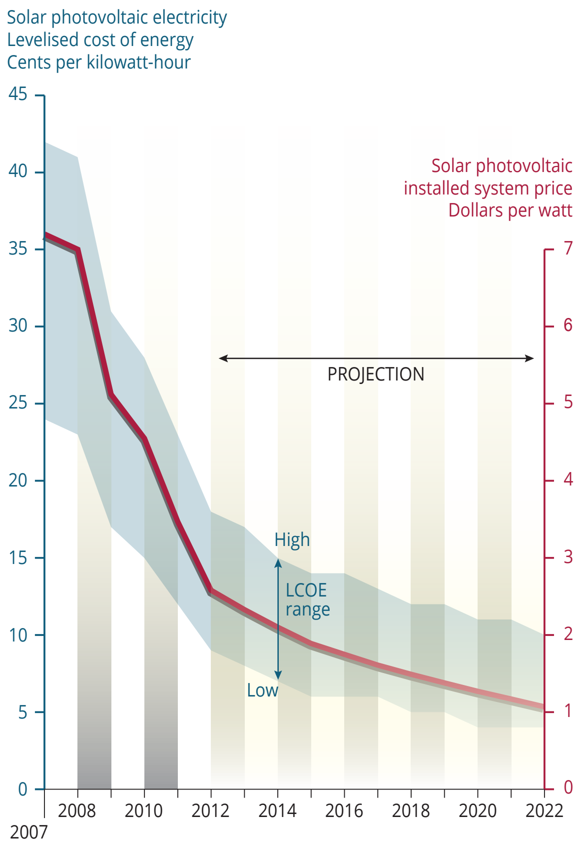
Source: OECD, 2014.

and oil and gas extraction. Bio-refineries, including those for bio-fuels, are currently in an early research and development phase; some studies foresee an integration of such plants with natural resource industries such as pulp and paper manufacturing, allowing them to use waste material and by-products (Hajkowicz et al., 2013). 'Bio-factories' that use modified micro-organisms to produce a range of specialty chemicals using sunlight, CO_2 and simple organic and inorganic ingredients (UK Foresight, 2012).

Nanotechnology can support the application of 'biomimicry': emulating natural forms, processes and systems to create more resource-efficient and sustainable products. Examples can surfaces with water-repellent nano-structures, such as those on lotus leaves, to reduce the need for cleaning; and surfaces with diffraction patterns for colouring rather than pigments (Biomimicry, 2013).

The NBIC cluster brings a range of new tools to improve resource efficiency in agriculture. For example, new diagnostic instruments could identify animal and plant diseases more quickly, and sensors could identify optimal moments to apply fertilisers and pesticides or irrigate fields. Some pesticides could be delivered in nanocapsules that would open when ingested by the target species (UK Foresight, 2012). These methods could reduce the amounts of agricultural chemicals released as well as their runoff and other impacts. A more speculative development is the commercialisation of 'synthetic meat' grown from tissue cultures rather than live animals (UK Foresight, 2013). So far only a laboratory product, artificial meat — if it becomes commercially viable — is expected to require a fraction of the land and water inputs of real meat (Tuomisto, 2011).

Figure 4.5 The declining price of solar photovoltaic systems



Note: Levelised cost of energy (LCOE) refers to global costs of an energy-generating system (here: solar photovoltaic) over its lifetime, including initial investment, operations, maintenance, cost of fuel and cost of capital.

Source: NREL, 2013; Pernick et al., 2013.

Transforming energy systems

Emerging technologies can also reduce the costs of renewable energy. In the area of power generation, technological advances have brought down the price of wind and solar renewable energy. One example is the costs of photovoltaic cells: the price of their electricity fell by over 60% from 1998 to 2008 (Jacobs, 2013). In the immediately coming years, further decreases are expected (Figure 4.5).

Biotechnology may yield new methods for biofuels, overcoming the problems seen in the current 'first generation' of biofuels: these can take land away from food crops and other uses and in some cases, land use changes have thwarted the expected reductions in greenhouse gas emissions (EEA, 2010). Research seeks to develop so-called 'second-generation' biofuels from cellulosic crops and wastes. The use of genetically modified algae to transform these materials into fuels is one of the approaches being pursued. Some advanced methods under development to produce biofuels may be carbon neutral or even carbon positive, producing carbon by-products that could be used in agriculture (Holmes, 2012). However, biofuels used in combustion would still have local air pollution impacts.

In terms of power transmission, ICT can support the introduction of 'smart grids' that use advanced monitoring and metering together with two-way communication between electricity suppliers and consumers to improve grid management and energy consumption. Smart grids are a vital tool for increasing the share of renewable energy, and their development is being supported by EU projects and other investments around the world (EC, 2011b). ICT can also yield advanced sensors and computing to help industrial plants, commercial buildings and eventually private homes employ 'energy intelligence'. Manufacturing processes could be adjusted to improve their energy efficiency and scheduled to take place at times when energy prices are lower (UK Foresight, 2013).

Nanotechnology and other materials advances have brought down the price of electricity storage, and offer significant promise for further progress. For example graphene or carbon nanotube based supercapacitor batteries could dramatically decrease battery charging time and increase storage capacity, as well as increasing the speed and power of electronic devices. Further improvements are expected in the coming decade, making electric and hybrid vehicles more competitive. Energy storage improvements would support the growth of renewable energy sources by allowing them to cope more efficiently with peak loads. They can also make small-scale, off-grid renewable energy systems viable (Manyika et al., 2013).

Not all energy research, however, supports a low-carbon shift. New technologies — including new drilling materials as well as the application of ICT in prospecting and development — could increase hydrocarbon production, in particular for fossil fuels. Already, hydraulic fracturing has significantly increased natural gas production in the US and other countries (IEA, 2012). New technologies may lead to the extraction of methane from clathrates, water ice structures found under the ocean beds, further increasing global natural gas production: Japan has tested extraction methods in the Nankai Trough off its coast (Reardon, 2013).

The rebound effect

Notwithstanding the promise of new technologies, their efficiency gains sometimes fail to reduce environmental pressures as make products cheaper, increasing consumption: the 'rebound effect'. Energy use by ICT is one dramatic example: despite new hardware with dramatically higher efficiencies, the huge expansion of computing has made this sector a major global energy user. In 2005, ICT equipment and infrastructure consumed about 8% of the EU's electricity and emitted 1.9% of CO_2 emissions; moreover, existing trends could push ICT emissions to 4.2% of CO_2 emissions in 2020 (Biois, 2008). ICT equipment creates an important stream of solid waste as well. In 2008, an estimated 0.8 million tonnes of old computer equipment were discarded in the EU (UNU, 2007). Waste computer equipment, mobile phones and other ICT items contain a range of hazardous materials (EEA, 2012). In coming decades, additive manufacturing lead to more traffic, as the growth of small and home manufacturing systems could increase the demand for deliveries in cities, counteracting some of the technique's resource efficiencies (UK Foresight, 2013). Reducing pressures therefore requires complementary policy measures that address consumption (EEA, 2015).

Impacts on economy and society

Employment

The new technologies are expected to bring a range of economic and social changes. Technological advances that enable machines to perform human tasks are likely to influence inequality and unemployment. Increasing use of machines may depress wages for some, while boosting demand for highly skilled labour and low-skilled service-sector work. The resulting polarisation of job opportunities could contribute to greater earnings inequality (Autor, 2010; Goos et al., 2009).

Robots, which are already used extensively in manufacturing, may play a key role in changing employment by taking on a growing range of service sector jobs: for example, a Spanish food processing company uses robots to inspect lettuce on a conveyor belt (Manyika et al., 2013). Robots are increasingly being used for personal care of older people — an application becoming common in advanced Asian economies such as Japan and Korea (Smith, 2012) and one that may be adopted globally as the numbers of the elderly grow in Europe and around the world (GMT 1).

In coming decades, new technologies could change managerial and professional work as well. In health care, computers trawling massive data sets could supplement and in some cases replace doctors in making patient diagnoses. Computers may play a similar role in other fields — carrying out legal research for law firms, replacing teachers in some roles and perhaps even grading written exams, and taking on some of the skilled work of engineers and scientists (Manyika et al., 2013).

By reducing demand for labour relative to machinery, new technologies can mean that returns to production increasingly accrue to the owners of physical capital. In many advanced countries and industries, labour's share in national income has declined significantly since the early-1980s; the growing role of ICT has been an important factor in this shift (Karabarbounis and Neiman, 2014).

The new technologies can lead to changes in our economic systems. Electricity, mass production and steam power, for example, transformed economic systems in Europe and North American in the late

18th and early 19th centuries (Manyika et al., 2013). Many elements created then, such as centralised electricity companies, remain part of today's economic structures. Technological changes are likely to bring new financial and institutional arrangements (UNEP, 2011). Additive manufacturing, for example, could have disruptive impacts on a range of sectors, including retail, logistics and freight transport at the global and local levels (Campbell et al., 2011). It may allow for 'mass customisation' of goods, and thus change consumption patterns (EC, 2014a), possibly via small-scale production as well as home printing; in doing so, it could bring some manufacturing back to Europe from low-income, mass-production economies.

Society and politics
New technologies could also bring new dilemmas for society. The 'Internet of Things' and the development of nanotechnology sensors raise further questions about surveillance and privacy — and also about intellectual property, including counterfeiting. The World Economic Forum warns of 'digital wildfires' for companies and markets, which could start with misinformation but spin out of control, with unexpected social and financial impacts; incidents of massive data fraud or theft and rising cyber-attacks are also growing risks (WEF, 2013). The 'Internet of Things' is expected to offer a new field for cyber-attacks. Organisations may be tempted to run their own networks, separate from the Internet (UK Foresight, 2013). Additive manufacturing creates new social risks, as the small-scale and home printing of personalised goods from toys and electrical fittings to medicines or weapons can create threats to life, health and the environment (UK Foresight, 2013).

The influence of new technologies on global and national politics is a further area of uncertainty. Already, social media provide a tool for social action, including organising against autocratic regimes. Social entrepreneurs can employ new technologies to address societal problems: for example, epidemiologists have used cell phone data to help stem malaria outbreaks (Talbot, 2013). At the same time, ICT provides new ways for governments to monitor citizens; future developments, such as miniature and nano-scale sensors, could even strengthen such monitoring. Finally, new technologies could support new types of weapons, including bioweapons. Cyber-attacks against countries have already been seen; the armed forces in the USA and other countries have developed cyber defence units (NIC, 2012).

A 'post-human' future?
The NBIC cluster is investigating systems that could bring unexpected changes in how we view ourselves as humans and our relationship with our machines. One growing area of ICT research is augmented reality, the addition of virtual objects and information into real scenes: if it becomes part of our daily lives, augmented reality could also fundamentally change the way we interact with our environment, both in leisure and work (EC, 2013a). Human-machine interfaces are a focus of work for healthcare: along with wearable sensors, whose use is growing for medicine and sports, we may have increasing numbers of nano-scale machines in our bodies to monitor, support and perhaps augment our health; another area of research seeks to link our brains directly with computers.

Biotechnology is also raising profound ethical issues regarding the value of human life and the extent to which living organisms can be manipulated (Manyika et al., 2013). New drugs could enhance natural human capacities, such as intelligence and concentration, and our moods. Genetic screening could become more sophisticated, not only allowing parents to terminate pregnancies when severe handicaps are identified but also to choose 'optimal offspring'. The 'benefits' of these new technologies may, however, be restricted to the wealthy, further increasing inequalities across and within countries. A more profound question is that we may be steadily moving towards a 'post-human' future without broad public discussion (Fukuyama, 2003).

Environmental risks

The risks and impacts of emerging technologies are difficult to predict: already in 2001, EEA's study on *Late lessons from early warnings* cautioned that: '... the growing innovative powers of science seem to be outstripping its ability to predict the consequences of its applications...' (EEA, 2001).

Nanotechnology, for example, offers extraordinary promise but scientific understanding of the risks to both human health and the environment remains patchy, due to major limitations in available data on hazards and, in particular, on exposure. The variation of hazard profiles amongst different nanoforms even of the same basic chemistry sets requirements for a case by case assessment of hazards, whilst methods to either measure or model exposure remain in an early stage of development. As the behaviour of nanoparticles in the environment is unknown, their application is likely to raise concerns. Nanoparticles' rapid transformation could, for example, render traditional approaches to describing, measuring and monitoring air or water quality inadequate (RCAP, 2008). There is a need for both precautionary and socially and economically responsive policy strategies in the field of nanotechnology in order to ensure the responsible development of nanotechnologies (EEA, 2013).

The risks related to biotechnology are equally hard to define. Genetically modified crops are already used around the world in agriculture, and future developments of synthetic biology create new issues for the protection of our natural environment (Box 4.2).

Policy frameworks

As much new, potentially disruptive technology is already available, preventive and proactive responses to deal with emerging problems and changing socio-political and environmental landscapes should become a priority. This is underlined in EEA's studies on *Late lessons from early warnings*: they conclude that new and unknown risks need a new approach, involving: broader application of the precautionary, prevention and polluter pays principles; improvements in the assessment of risks associated with new and emerging technologies, both in terms of considering systemic challenges and unknowns and also drawing on lay, local and traditional knowledge; and the strengthening of institutional structures to deal with multiple, systemic threats and surprises (EEA, 2013).

When considering options, societal problems can also be viewed as opportunities. This approach is seen in moves to orient science policy and funding towards 'responsible research' that supports societal goals (von Schomberg, 2013). The EU's Horizon 2020 Programme, for example, identifies seven 'societal challenges', including 'health, demographic changes and wellbeing' to 'smart, green and integrated transport', as well as renewable energy (EC, 2015a). Horizon 2020 moreover incorporates the goal of responsible research and innovation that engages stakeholders and anticipates potential impacts of research (EC, 2015b). Other EU programmes under the Europe 2020 Strategy also address societal goals as well as economic growth (Box 4.3). In a similar vein, the US National Nanotechnology Initiative includes among its four goals the 'responsible development of nanotechnology'.

Box 4.2 Biotechnology, agriculture and nature conservation

A controversial application of biotechnology is in agriculture. The global cultivation of genetically modified crops reached 150 million hectares in 2012, about 10 % of global cropland. The largest producing countries are Argentina, Canada and the United States; Brazil, China and India saw rising levels of production; GMO crops are now grown in 22 developed and developing countries around the world (FAO, 2012). At present, three types of crops account for nearly all GMO cultivation — cotton, maize (corn) and soybeans — with genetic manipulations that provide resistance to herbicides or to insects. New genetically modified crops reaching wide-scale production include potatoes, rapeseed and rice. Research is creating crops with new properties: greater drought resistance, the transfer of genes for nitrogen fixation of soils from legumes to other crops, and greater plant nutritional properties such as vitamin or protein content (UK Foresight, 2012).

The potential impacts of genetically modified crops on the environment are a topic of extensive research and debate. The fast-developing field of synthetic biology, raises new concerns. In a 2013 conference on potential interactions between synthetic biology and nature conservation, it was noted that this new field of research is often described in terms of either utopias or dystopias. In practice, the ongoing development of biotechnology and synthetic biology will pose a range of difficult questions for policy makers, stakeholders and society as a whole. The following are among the topics raised (WCS and TNC, 2013):

- Genetically modified plants and synthetic organisms that could be cultivated on marginal land could expand agriculture to protected and other high-biodiversity areas.
- New organisms are likely to interact, perhaps in unexpected ways, with existing protected species and protected ecosystems.
- In changing agriculture and other forms of resource extraction, these technologies might transform rural economies and their interactions with natural systems.
- If synthetic biology one day allows the possibility to 're-create' recently extinct species (e.g. Redford et al., 2013), should this be pursued?

Box 4.3 Innovation under the Europe 2020 Strategy

The Europe 2020 Strategy sets an objective of smart, sustainable and inclusive growth. Several of its 'flagship initiatives' support technology development, including the following (EC, 2013b):

- The Digital Agenda for Europe promotes the greater use of ICT in the economy and throughout society. Among its goals is boosting public funding for digital research and development.
- The Innovation Union seeks to increase the pace of development of new products and services, both through education as well as the removal of potential obstacles.
- A Resource Efficient Europe supports actions across a range of policy sectors to move towards a low-carbon, resource-efficient economy.

Moreover, a range of specific strategies support these goals. The European Commission unveiled in 2012 its strategy for key enabling technologies for the future, including nanotechnology, biotechnology and micro and nano-electronics: its support seeks to strengthen Europe's economic competitiveness and contribute to the move towards a low-carbon economy (EC, 2012).

The move towards better governance nonetheless faces several challenges. For one, 'precaution' is understood differently by different stakeholders, with voices warning that it can stifle research and economic growth. EEA's *Late lessons from early warnings* concludes that 'the timely use of the precautionary principle can often stimulate rather than hamper innovation, in part by promoting a diversity of technologies and activities, which can also help to increase the resilience of societies and ecosystems to future surprises' (EEA, 2013).

The global dimension of technology development raises a key challenge. Major differences are seen in approaches to addressing new risks, for example for nanotechnology regulation. Among advanced economies, current requirements as well as discussions on future regulation differ between Europe, which takes a more precautionary approach, and the US. Several fast-growing countries — including Brazil, China and India — support nanotechnology research but have less capacity to implement regulation; moreover, these countries are concerned that regulation in developed economies could be a trade barrier for them. Although informal international discussions have been held, in particular through the OECD, a convergence among the different approaches appears to be a distant prospect (Falkner and Jaspers, 2012).

Cooperation on responsible research also needs to be considered in the global context. In 2009, an EU Expert Group on the Global Governance of Science — with members from both Europe and around the world — proposed a set of recommendations for European funding that encourages global cooperation in promoting ethical governance of science and supporting fundamental rights (EC, 2009).

These moves are vital, as vulnerabilities are created when policies do not keep up with the opportunities and threats of unfolding dynamics, conditions and realities of socio-technological systems. A key consideration for innovation governance is an ability to react, learn and adapt. New governance paradigms that emphasise reflexivity create capacities for adaptive decision-making — interventions essential for coping with emerging impacts.

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Global megatrend 5 — Continued economic growth?

The financial and economic crisis of 2008 and 2009 significantly reduced economic output in many developed countries, particularly in Europe. Although the impacts of the crisis are still felt across the world, virtually all mainstream outlook studies foresee economic expansion globally in the coming decades as Asia's and Africa's huge populations continue their shift towards Western patterns of production and consumption. The OECD projects that economic output will treble between 2010 and 2050, although growth is expected to decelerate in many countries as they become more prosperous.

The implications of this enormous increase in global economic output are numerous. Rapid growth has brought reductions in global poverty and increases in well-being but it is also linked to growing inequality and escalating environmental pressures (addressed in GMTs 7–10). In Europe, slowing growth may strain public finances for environmental protection and increase social inequality.

The negative environmental and social impacts associated with Western consumption patterns have called into question prevailing models of development and the indicators that societies employ to quantify progress. In particular, the limitations of gross domestic product (GDP) as a measure of human well-being and the sustainability of growth have prompted international efforts to identify better measures.

5.1 Drivers

Globally, countries are continually seeking ways to stimulate economic growth as a means of providing jobs and improving living standards. At the most basic level, economic output can be broken down into two components: population size and output per person (productivity). Each has accounted for about half of the global economic growth since 1700 (Maddison, 2013).

While population growth is linked to fertility, mortality and migration rates (GMT 1), productivity has more complex determinants. Today it is understood to depend on the development of four key forms of capital: human capital (knowledge, skills and health); social capital (trust, norms and institutions); manufactured capital (machinery, technologies and infrastructure); and natural capital (resources and ecosystems) (World Bank, 2006). Natural capital is arguably the most 'fundamental' of the capitals. It provides the basic conditions for human existence (food, water, clean air); sets the 'ecological limits' for socio-economic systems, which require continuous flows of resources and ecosystem services; and provides the basis for generating manufactured capital.

Complementary forms of capital

Economic growth depends in large part on society's success in preserving and enhancing the underlying stocks of capital. There is some debate about what this means in practice. Proponents of 'weak sustainability' argue that economic development can be maintained if depletion of one stock (e.g. natural capital) is offset by augmenting another (e.g. physical capital). Advocates of 'strong sustainability' argue that substitution is possible only within capital types (e.g. a forest chopped down in one location can be offset by a plantation elsewhere). Some argue against substitutions of any sort (Pearce et al., 1989).

While the weak sustainability position has merits in some situations, the notion of offsetting depletion of one form of capital through the accumulation of another type clearly has its limits. In the case of natural capital, several related characteristics make it hard to replace it with other forms of capital. Ecosystems are complex, which means that the implications of ecosystem change are often highly uncertain and irreversible. Risks and uncertainties are exacerbated by non-linearities and discontinuities in relation to environmental pressures, ecosystem processes and related impacts (for example the collapse of fish stocks). And the multi-functionality of ecosystem components can seldom be replicated by physical capital.

For these reasons, investments that augment manufactured capital are likely to be counter-productive if they degrade essential environmental systems. As Daly (1992) summarises the point: 'what good is a sawmill without a forest?'

More generally, the capital stocks often appear to be complements rather than substitutes. In other words, the value of one form of capital depends on the presence of another. For example, if natural resource wealth is not accompanied by effective state institutions, it can fuel corruption and weaken competitiveness, thereby undermining economic growth (Rodrik et al., 2004). Similarly, the ability of a country to adopt and utilise advanced technologies will depend greatly on the level of education and skills in the workforce (Nelson and Phelps, 1966).

These interdependencies suggest that sustaining and enhancing economic production in the long term is best served by acknowledging the complementarity between the different forms of capital and developing them in tandem, rather than increasing some types at the expense of others.

Innovation and investment in capital stocks

Innovation plays a key role in the development of capital stocks, driving long-term growth and structural economic change — the transition from largely agrarian economies through industrialisation to largely service-based structures (GMT 6). An obvious example is the development of tools, machinery and technologies, which increase productivity.

Innovations can also take the form of new types of social organisation such as the aggregation of labour and businesses in urban settings, and the division of production processes into multiple stages handled by different workers (GMT 2). Such innovations all help enable society to maximise the economic returns on finite inputs of labour and resources.

As a result of innovation and investment, several of the capital stocks underpinning economic output have been increased markedly in recent decades. In developed countries, manufactured capital was worth 2.0–3.5 years of national income in 1970 but increased to 4.0–7.0 years of national income by 2010 (Piketty and Zucman, 2014). Workforces have also expanded. The global population of those aged between 15 and 64 tripled to 4.54 billion in the period 1950–2010 (UN, 2013b). Education, skills and human health are also improving rapidly, particularly in developing regions (GMTs 1, 3).

At the same time, however, natural capital is increasingly under pressure (GMTs 8, 9, 10). This trend raises serious concerns, suggesting that although population growth, technological advances and expanding infrastructure are driving short-term improvements in output and living standards, they may be jeopardising long-term prospects.

5.2 Trends

The spread of global growth

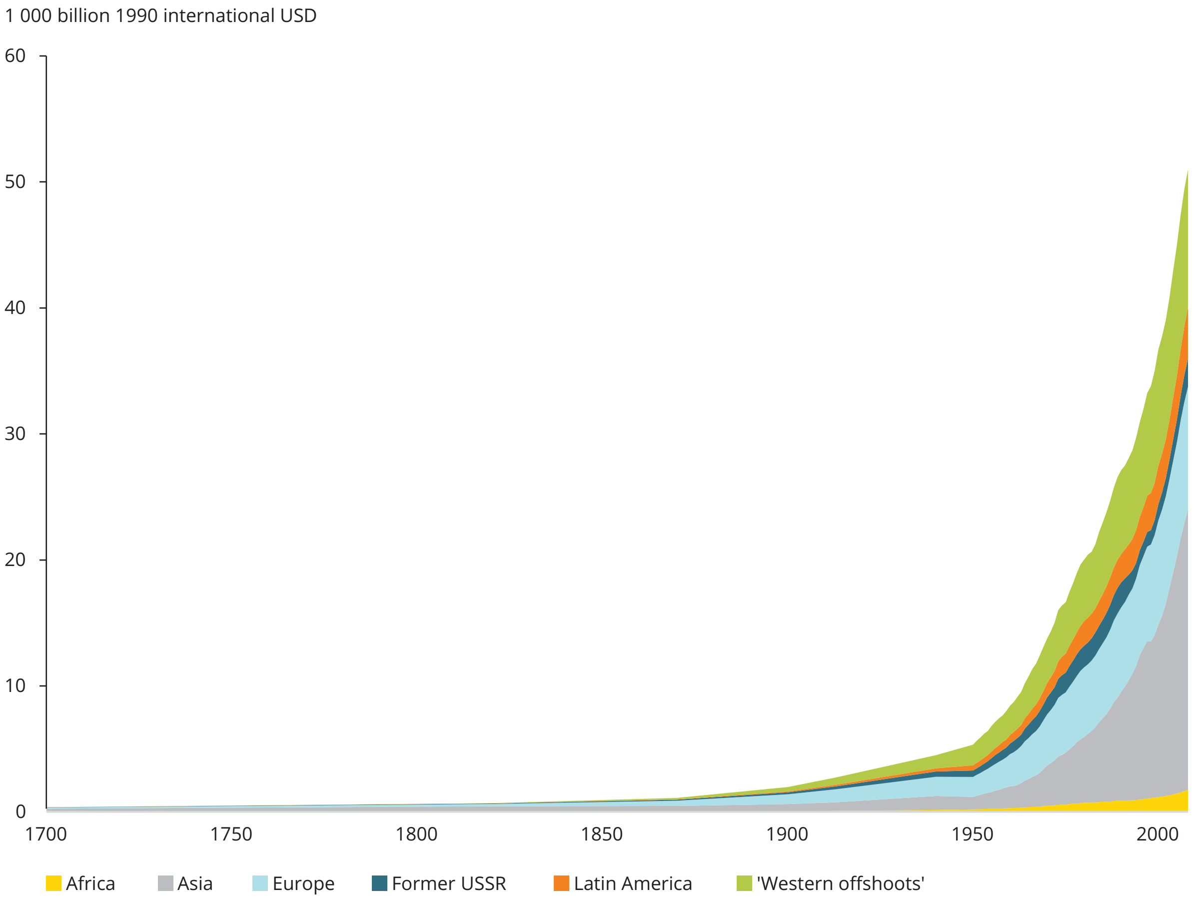
Rapid economic growth is a comparatively recent phenomenon. Productivity increases were negligible before 1700, implying that economic output rose no faster than the very modest rate of population growth — about 0.1% annually. In the 18th century, however, the agricultural and industrial revolutions in western Europe caused a fundamental shift, initiating a steady acceleration of economic growth. By the first half of the 20th century, average annual global GDP growth had reached 2% and this rose to 4% in the period 1950–2008 (Figure 5.1). As a result, world economic output increased 25-fold in the period 1900–2008 (Maddison, 2013).

The acceleration of global growth in recent decades was made possible by the exceptionally rapid economic expansion in some very large developing countries, which were able to import knowledge, practices and technologies rather than going through the slower process of developing them domestically. China is the most important example — its economy grew by an average of 9.8% per year in the period 1980–2013, doubling in size every seven years (World Bank, 2015a).

Continuously high economic growth in many Asian countries during recent decades has increased GDP per capita, cutting the gap in living standards relative to the most advanced economies. In 1980, GDP per capita (in current PPP USD) in China was 2.4% of the US level, while India stood at 4.5% and Indonesia at 10.7%. The IMF estimates that by 2013, China reached 22.4%, India 10.3% and Indonesia 18.2% of the US figure.

Again, China's achievement was particularly notable. GDP per capita increased from USD 302 to USD 11 868 (in current PPP USD), which equalled an annualised average growth rate of 11.8%. Over the same period, the US recorded an increase from USD 12 576 to USD 53 001 — an annualised average increase of 4.5 % (IMF, 2013)

Figure 5.1 Global gross domestic product since 1700



Note: The grouping of 'Western offshoots' comprises Australia, Canada, New Zealand and the US.

Source: Maddison, 2013.

Impacts of the financial crisis

The financial crisis of 2008 and subsequent economic turmoil had a major impact on economic growth globally. Developed regions were hit hardest. EU-28 gross domestic product (GDP) shrank by 4.4% in 2009 and some countries fared much worse. Estonia, Latvia and Lithuania each endured contractions of more than 14% in that year (Eurostat, 2015).

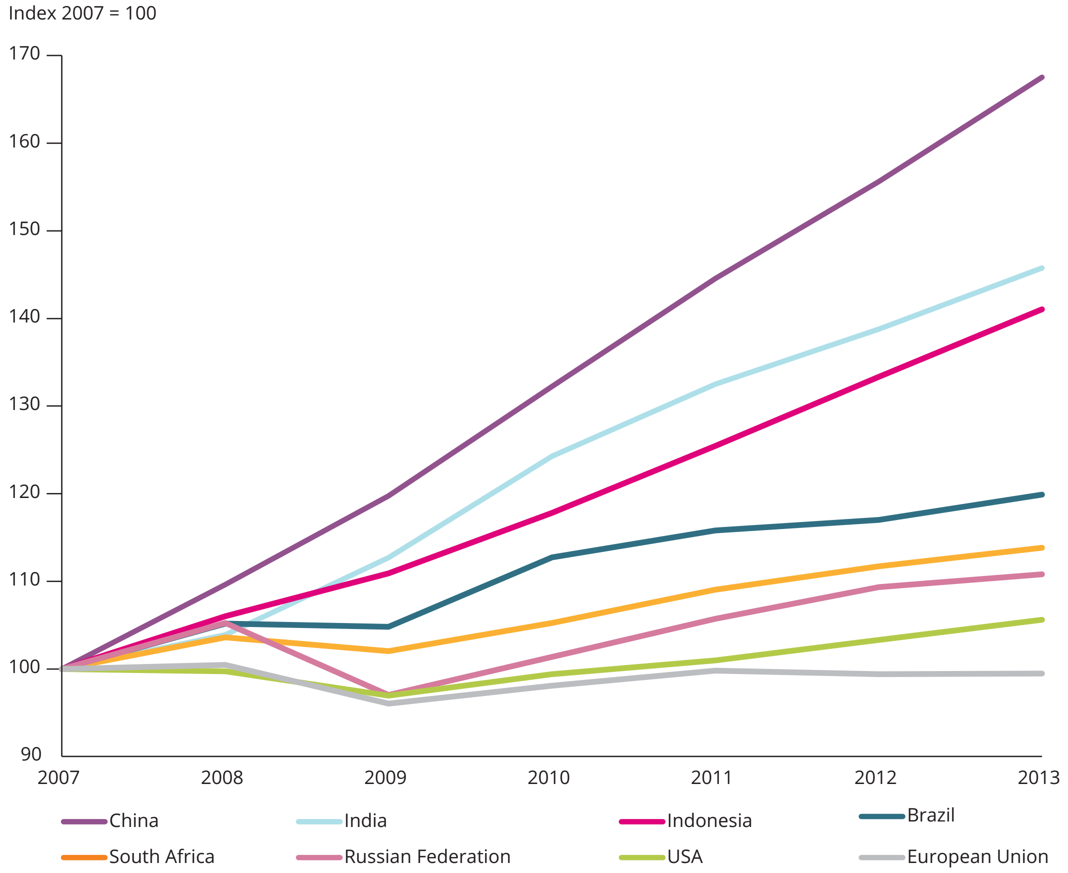
The subsequent recovery from the financial crisis in Europe has been very slow. By 2013 EU-28 economic output was still 0.9% below its 2007 level; Greece's GDP declined by 23.6% between 2007 and 2013 (Eurostat, 2015).

Major economies in developing regions, including Brazil, Russia and South Africa, also endured recessions, while others — notably China, India and Indonesia — faced an appreciable slow-down in growth. Nevertheless, these economies have since proven to be remarkably resilient, sustaining global growth despite stagnation is most advanced economies (Figure 5.2). In 2007–2013, India's GDP increased by 46 % and China's by 68% (World Bank, 2015a). As a result, the financial crisis greatly advanced the rebalancing of economic production across the world (GMT 6).

Decelerating growth in coming decades

While the underlying determinants of economic growth (such as education levels and physical capital stocks) are relatively stable, growth during individual years or even decades can be much more volatile, partly as a result of economic shocks (Easterly et al., 1993). In the wake of the financial crisis of 2008, many uncertainties surround the short-term outlook for global growth. These include concerns about the global impacts of slowing growth in China, linked to poor-quality investments (particularly since 2008) and needed rebalancing of the economy (Pettis, 2014; Wolf, 2014). In Europe, worries focus in particular on

Figure 5.2 **Gross domestic product growth since the financial crisis in the EU, the US and the BRIICS economies**



Note: The data are based on constant USD 2005.

Source: World Bank, 2015a.

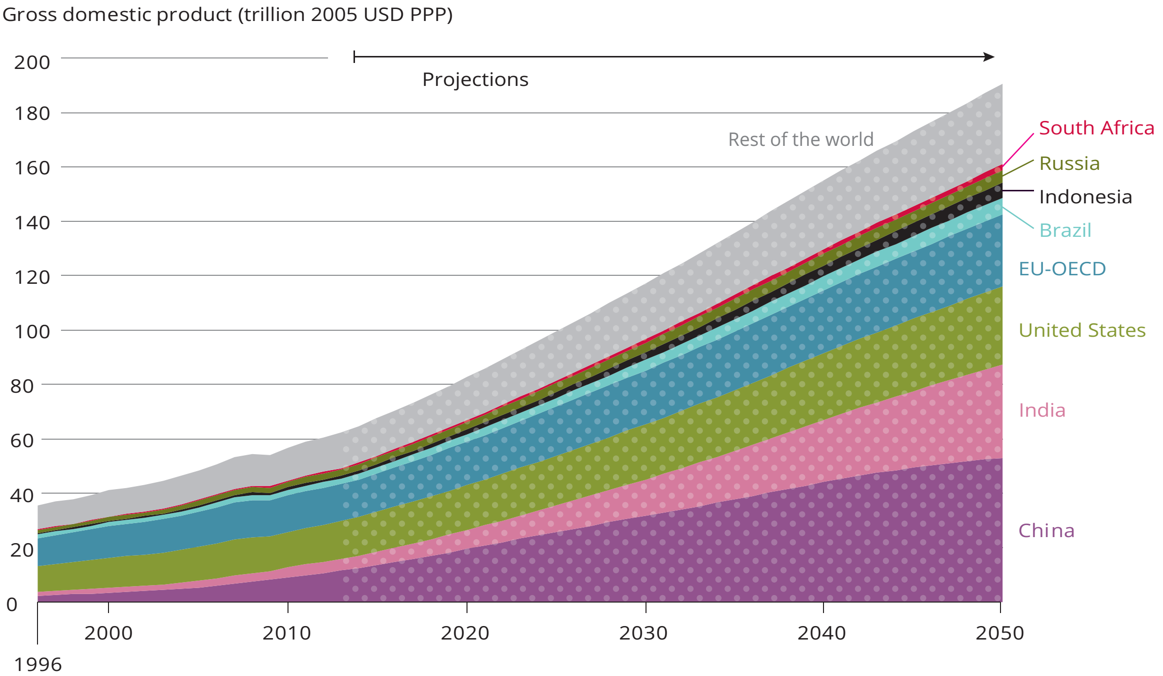
the prospects for continued economic integration, especially among the countries using the euro.

Although annual growth rates are likely to remain volatile and uncertain, the broad direction of global growth appears clearer in the medium and long term. World economic growth is projected to remain robust in coming decades as investment in human, social and manufactured capital enable developing countries to follow in China's footsteps. The Organisation for Economic Co-operation and Development (OECD) projects that global GDP will almost triple in the years 2010–2050 (Figure 5.3).

In 2013, GDP per capita (PPP) in China stood at 22% of the US level, while India's stood at 10%. As those countries' huge populations continue to shift towards the systems of production and consumption present in today's advanced economies, the expansion in GDP is likely to dwarf even that achieved by the US during the past century. By 2050, India's economic output is projected to be just 14% smaller than US economic output while China's is projected to be 40% larger. Clearly, however, such economic projections need to be interpreted with great caution (Box 5.1).

The OECD expects that global economic growth will decelerate steadily in the coming decades, from a postcrisis peak of 4.3% in 2017 to just under 2% a year in 2050. Economic expansion in China is projected to slow particularly sharply, from an average of 7.9% a year in 2010–2020 to 1.9% in 2040–2050. Meanwhile, India is expected to become the fastest growing economy among Brazil, Russian, India, Indonesia, China and South Africa (BRIICS), with an average annual increase of 5.9% in 2010–2050, although there too growth is projected to slow to below 4% by the end of the period. In the EU, demographic trends are projected to contribute to a fall in GDP growth, from 1.7% a year in 2020 to 1.3% in 2050 (OECD, 2014).

Figure 5.3 Global gross domestic product is projected to triple by 2050



Note: EU-OECD refers to the EU Member States that are also members of the OECD. These countries accounted for approximately 97% of EU-28 GDP in 2012.

Source: OECD, 2014.

Box 5.1 Uncertainties in economic projections

Economic projection is the process of constructing future trends of economic and environmental variables based on a variety of assumptions. Projections do not deliver forecasts of future economic output. Rather, they provide insights into how an economy may develop if the underlying assumptions hold true. Projecting future economic trends is a challenging analytical exercise, which grows more complex and uncertain as the length of the projection period expands. This is in large part because many of the important parameters underpinning such analysis are very hard or impossible to anticipate.

One key uncertainty centres on the effects of intensifying resource scarcity. This includes short-term scarcity of essential resources of the sort reflected in the food and energy price spikes of 2007–2008. But even more uncertain are the impacts of long-term scarcity, such as the expected and feared 'peak oil'. Political responses, such as national policies and bilateral agreements to monopolise natural resources, are important and hard to predict. Equally, the pace of technological innovation needed to sustain economic growth in the context of higher resource prices and possible larger disruptions to supply is not known.

The list of important but uncertain assumptions is enormous, encompassing issues such as the stability of financial markets, socio-political developments (e.g. democratisation or adaptation to ageing populations), geopolitical stability and military conflicts. Taken together, they imply that economic projections must be used with considerable caution. At most, they can help decision-makers to anticipate some of the risks and opportunities that could lie ahead by delivering broad representations of potential futures.

5.3 Implications

The combination of rapid economic growth in developing regions and much slower growth in advanced economies creates a mixture of opportunities and concerns. While the link between GDP and human well-being is undoubtedly complex, it is clear that economic expansion delivers a range of important benefits for society.

Poverty alleviation in developing regions

Growth plays an important role in determining household earnings and sustaining employment levels. Furthermore, economic performance shapes the revenues available to governments and, correspondingly, the resources available for public infrastructure and services such as education, healthcare and various forms of social security.

The poverty gap — the proportion of the population living on less than USD 1.25 a day — has fallen globally in recent decades, although the pace has varied between regions. The fastest reduction was in the developing countries of east Asia and the Pacific, where the proportion fell from 35% in 1981 to just 2.8% in 2010. This performance contrasted sharply with the developing countries of sub-Saharan Africa, where the proportion increased from 22% in 1981 to 26% in 1996, before falling back to 21% in 2010 (World Bank, 2015a).

Despite the mixed progress in sub-Saharan Africa, the percentage of the global community living on less than USD 1.25 a day fell from 47% in 1990 to 22% in 2010 — a reduction of about 700 million people (UN, 2013a). As a result, the 2015 Millennium Development Goal (MDG) on cutting the extreme poverty rate to half its 1990 level has been achieved several years ahead of the target year 2015 (UN, 2012).

Managing environmental degradation

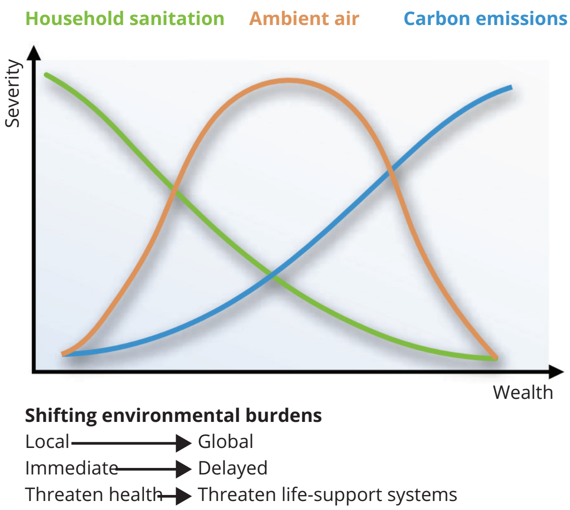
One major concern associated with economic expansion is the environmental degradation that often accompanies it. Economic growth tends to bring changes in consumption patterns, in particular in emerging countries with rapidly-growing consumer middle classes. Mobility increases, consumers replace durable consumption goods rather than repair them and high-calorie food displaces low-calorie alternatives. Growing demand for resources and emissions of pollutants increase pressures on the environment.

It is important to note that the relationship between economic growth and environmental pressures is seldom linear. Economic development is normally associated with the adoption of more efficient technologies and structural change from dominant agricultural and industry sectors towards less resource-intensive services. These changes can mean that the marginal increases in environmental pressures decline at higher output levels. In addition, as countries become wealthier, populations tend increasingly to prioritise a clean environment and governments acquire the administrative and financial resources to restrict pollution and invest in maintaining healthy ecosystems. For these reasons, the development of certain types of environmental pressures may follow an 'Environmental Kuznets Curve': increasing during early stages of development and subsequently levelling off and declining (Grossman and Krueger, 1995).

In general, however, economic development has not followed the relationship posited by the 'Environmental Kuznets Curve'. Although in many areas resource efficiency is increasing, the scale of economic activity globally is pushing resource use and emissions to higher absolute levels (GMTs 7, 8, 9, 10), with potentially huge impacts on natural cycles. In part, this may reflect the fact that the incentives and opportunities for individuals or communities to mitigate environmental harms alter fundamentally as impacts shift from local to global, from immediate to delayed, and from direct health risks to more fundamental threats to life-support systems (Figure 5.4).

While slowing growth in the EU and elsewhere during coming decades may alleviate environmental pressures, it may also weaken the capacity of states

Figure 5.4 Correlation of environmental pressures and economic development



Source: UNEP, 2011.

to manage environmental risks (Everett et al., 2010). In some EU countries, an expected rise in dependents relative to the working population is likely to undermine labour tax revenues while boosting the demand for pensions and public health expenditure (EC, 2012, 2014). And while the accumulating wealth that may accompany slow growth could provide an alternative tax base, governments face some difficulties in raising revenues from this source as liberalised financial markets enable investment and profits to shift to countries offering lower taxes (Piketty, 2014). Taken together, these fiscal pressures could weaken investment in environmental protection and motivate governments to relax environmental standards in order to boost economic growth.

Economic growth and inequality

Economic growth in both developing and developed regions is also associated with social and economic harm that threatens to undermine improvements in living standards. One key concern relates to the distribution of wealth and incomes. Although the rapid growth of developing regions is reducing inequality of living standards at the global scale, the trends within countries are often the opposite (Box 5.2).

Increased inequality has long been recognised as a potential side-effect of industrialisation, with wage disparities widening as a portion of the population moves from agricultural activities to more productive urban work (Kim, 2008). Later stages in structural economic change tend to see a convergence of rural and urban wages (GMT 2). Recent analysis suggests, however, that the sluggish growth in many advanced economies could augment inequality by leading to the accumulation and concentration of wealth (Piketty, 2014). Technological advances may further augment inequality (GMT 4). Mitigating the inequities that can arise from economic growth trends is, therefore, a governance challenge at all stages of economic development.

Moving beyond GDP

Worries about the social and environmental harm that can arise when governments focus too narrowly on economic growth have directed attention to the need for better measures of human well-being and economic robustness. Quality of life, it is argued, is shaped by numerous factors that are at most partially related to economic output. These include health, time with friends and family, access to resources and a pleasant living environment, education, social equity, leisure, political participation, and personal and economic security.

Equally important, GDP provides little indication of the status of the capital stocks that underpin output. Indeed, focusing just on GDP growth actually creates incentives to deplete capital stocks because the returns are treated as income.

A number of processes have been initiated in recent years to develop better indicators of progress by integrating environmental and social components. These include the EU's Beyond GDP initiative (EC, 2009, 2013), the Commission on the Measurement of Economic Performance and Social Progress initiated by the French government in 2008 (CMEPSP, 2013), the United Nations Human Development Index (UNDP, 2014), and the OECD Better Life Index (OECD, 2013). Stiglitz et al. capture the current mood with the observation that 'the time is ripe for our measurement system to shift emphasis from measuring economic production to measuring people's wellbeing' (Stiglitz et al., 2009).

Box 5.2 Rising or falling inequality?

Measuring trends in inequality poses significant challenges. Much depends on the definitions used. For example, the disparity between average incomes in two countries may be declining in proportional terms but increasing in absolute terms. Is inequality rising or falling in this case?

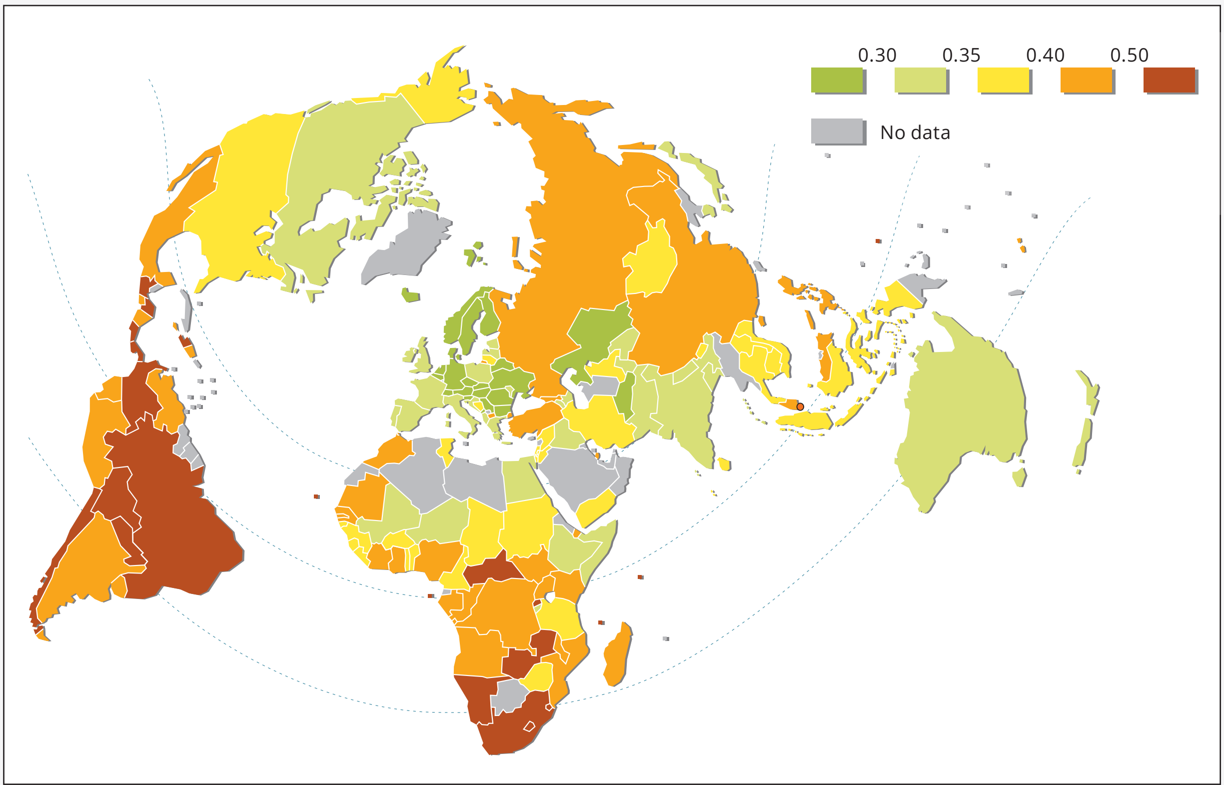
Equally, trends may vary at different scales and in contrasting contexts. In many advanced economies, the Gini coefficient (which quantifies how equally incomes or wealth are distributed across society) has risen during recent years. This indicates increased inequality, although the levels remain relatively low in most rich countries (Map 5.1). A shift away from planned economies in places such as Russia and China has also brought greater inequality, as has the explosion of executive salaries in the US and other advanced economies. Yet other regions, such as South America, have shown the opposite trend in recent years (UNDP, 2013; Stiglitz, 2013)

National Gini coefficient values

At the global scale, the current and anticipated convergence of GDP per capita can be interpreted as an indicator of reduced inequality of living standards. Yet even interpreting historical data can be controversial. The United Nations Human development report 2013 notes that: 'Virtually all studies agree that global income inequality is high, though there is no consensus on recent trends. One study that integrated the income distribution of 138 countries over 1970–2000 found that although mean income per capita has risen, inequality has not. Other studies conclude the opposite. Still others find no change at all.' (UNDP, 2013)

The same study also notes, however, that there have been much greater reductions in inequality in health and education during the last two decades, in part because measures such as life expectancy and years of schooling have upper bounds to which countries eventually converge. In general, it notes: 'Inequality reduces the pace of human development and in some cases may even prevent it entirely.

Map 5.1 GINI coefficient, based on 2000–2012 national data



Note: The Gini coefficient quantifies the inequality among the values in a frequency distribution. A value of 0 represents perfect equality, while a value of 1 denotes perfect inequality (i.e. all income in a population accrues to one individual, while the remainder receives nothing).

Source: CIA, 2012; OECD, 2015; World Bank, 2015b.

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Global megatrend 6 — An increasingly multipolar world

Globally, economic power is shifting. During the 20th century, a relatively small number of countries, together accounting for about a fifth of the world population, have dominated global economic production and consumption. Today, a significant rebalancing of power is under way.

Driven by structural change, fast-growing workforces and trade liberalisation, developing regions are rapidly increasing their share of global economic output, trade and investment. Economic and demographic projections suggest that the influence of today's wealthiest economies will continue to lessen as other countries and regional power blocs become increasingly important — economically, politically and diplomatically.

For Europe, this rebalancing presents competitive threats but also economic opportunities in meeting the demand of a fast growing global middle class. The emergence of a larger and more diverse mixture of major economic powers may, however, complicate global efforts to coordinate governance. And growing economic interdependence will make it harder to manage the social and environmental impacts associated with globalised supply chains.

6.1 Drivers

Structural convergence

Due to contrasting rates of growth, developing regions are gaining in importance and developed regions are becoming less dominant. These trends are linked to the process of structural economic development: the transition from agrarian societies, through industrialisation to service-based and knowledge economies.

In developed regions, industrialisation in the 19th and 20th centuries brought an unprecedented increase in economic output (GMT 5). Today, developing regions are undergoing the same transition but at much faster rates because they have been able to import and adapt existing technologies and production methods. In some countries, the process is already advanced; in 2012, the economic structure of East Asia and the Pacific was similar to the EU's in 1970 (Figure 6.1).

In contrast to the rapid growth in developing regions, structural and demographic factors have slowed growth in the advanced economies. The increasing contribution of services to economic output is important, since many branches of the service sector deliver modest productivity growth (Marota-Sanchez and Cuadrado-Roura, 2011). At the same time, lower birth rates mean that populations in many developed countries have stopped growing or started contracting, and labour forces are expected to decline further as the population ages (GMT 1).

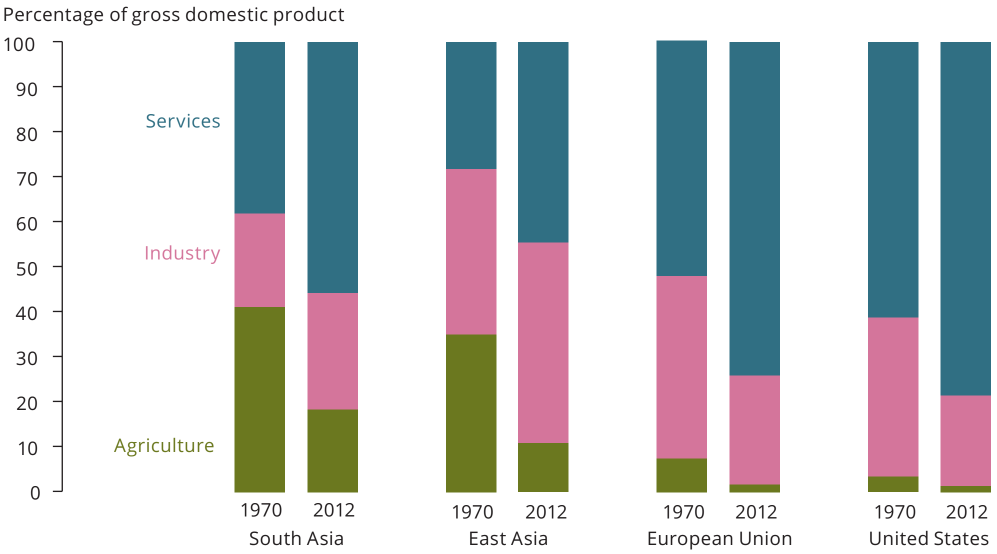
Factors affecting convergence

Historical data indicate that economic convergence is often conditional upon a variety of policies and institutional arrangements (Rodrik, 2011). These include factors such as the rate of investment, educational levels, the sophistication of the financial sector, the prudence of macroeconomic management generally and the security of property rights.

Trade liberalisation plays a particularly important role. Access to export markets promotes structural economic change because national production is no longer limited by domestic demand. Instead, a country can expand output of goods or services that it can produce relatively cheaply, thereby boosting aggregate productivity and increasing economic production. In developing countries, that often means increasing labour-intensive manufacturing and extraction or production of natural resources.

Regional integration and the formation of the General Agreement on Tariffs and Trade (GATT) and later the World Trade Organisation (WTO) have been major drivers of trade and market liberalisation, facilitating cuts in tariffs and the removal of non-tariff barriers to trade. The average level of tariffs on manufactured products in industrialised countries has dropped from 45–50% in 1948 to an average of about 3% in 2009 (Krueger, 2009). World exports grew at an average rate of 7.9% per year between 1990 and 2011, while global gross domestic product (GDP) increased by about 5.5% (in nominal terms) annually (World Bank, 2015).

Figure 6.1 **Structural breakdown of economic output in selected regions, 1970 and 2012**



Note: The graphs shows the contribution of service, industry and agriculture to total GDP. The composition of regional groupings corresponds to World Bank definitions (World Bank, 2014).

Source: World Bank, 2015.

Foreign direct investment (FDI) is also important because, in addition to financing accumulation of productive capital, it is associated with the diffusion of technologies, skills, institutions and management expertise (OECD, 2002). Some developing countries have facilitated technology transfer and the transition to post-industrial economic structures though major investments in education and health (GMT 2).

6.2 Trends

Declining dominance of advanced economies

Projections of global GDP underline the increased economic significance of today's developing and emerging economies. In 2000, the Organisation for Economic Co-operation and Development (OECD) member countries accounted for less than 20% of the global population but 77% of world economic output, but this share is projected to fall to 50% in 2030 and 42% in 2050 (Figure 6.2). The EU's share is projected to drop by around half between 2000 and 2050, falling from 28% to 14% (OECD, 2014).

In the short term, the financial crisis and subsequent economic stagnation in advanced economies has accelerated the global convergence of living standards (GMT 1). Even when steady growth returns to the EU, it is projected to be modest compared to the expansion in developing regions. By 2017, China is expected to have the world's largest economy, in purchasing-power parity (PPP) terms, although its share of global GDP is expected to wane slightly after 2045. India is likely to achieve similar growth, though from a significantly lower base, with its share of global economic output projected to rise from 4.3% in 2000 to 18% in 2050 (OECD, 2014).

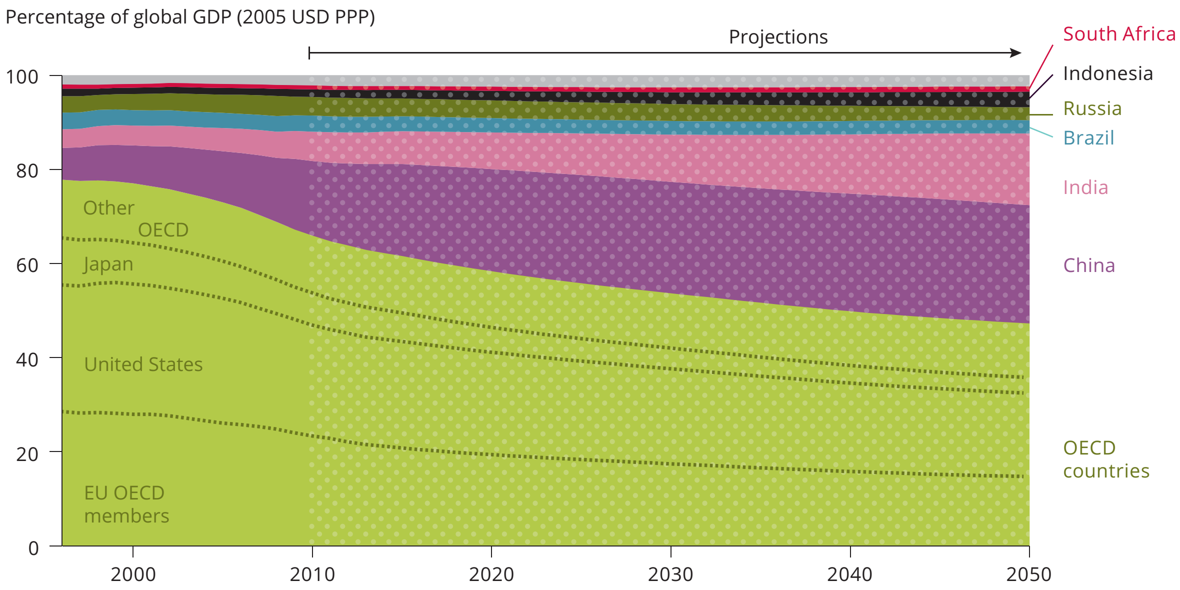
Continuing integration of global markets

The value of global exports of goods and services increased from 12.7% of world GDP in 1960 to 29.9% in 2013. During the same period, global GDP (in constant 2005 USD) increased more than six-fold (World Bank, 2015). The financial crisis of 2008–2009 had a substantial but only temporary effect on export volumes. The value of exports fell by 4 % of global GDP in 2009 but by 2011 it had already exceeded the pre-crisis levels.

The advanced economies have become less dominant in world trade, with China in particular emerging as a major exporter since the mid-1980s (Figure 6.3). Despite declining in recent decades, the EU still accounted for almost a third of international trade in 2013, although a substantial proportion of that constituted intra-EU trade.

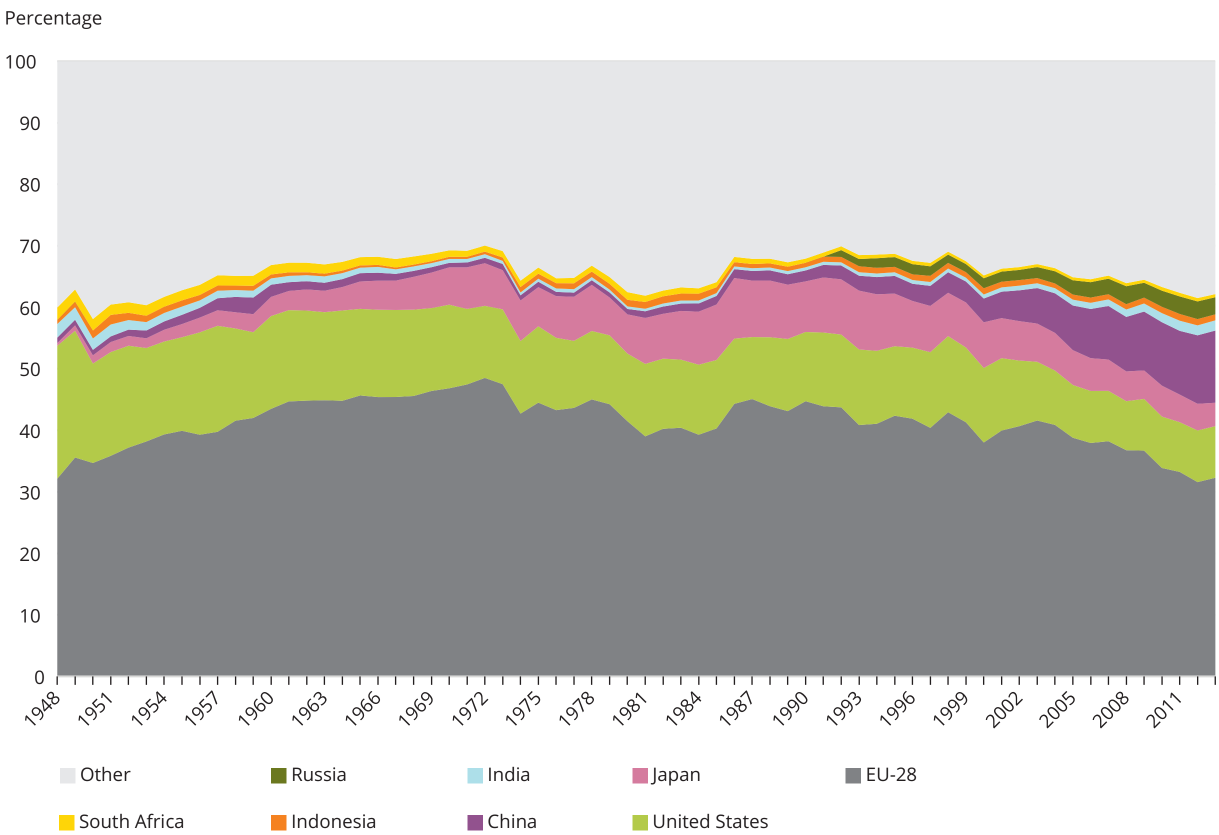
Excluding intra-EU trade, the EU accounted for 14.8% of global merchandise imports in 2013 and 15.3% of exports (WTO, 2015). As illustrated in Figure 6.4, these numbers were comparable to the contributions of the US (12.3% of imports and 8.4% of exports) and China (10.3% of imports and 11.7% of exports

Figure 6.2 **Contribution of major economies to global GDP, 1996–2050**



Source: OECD, 2014.

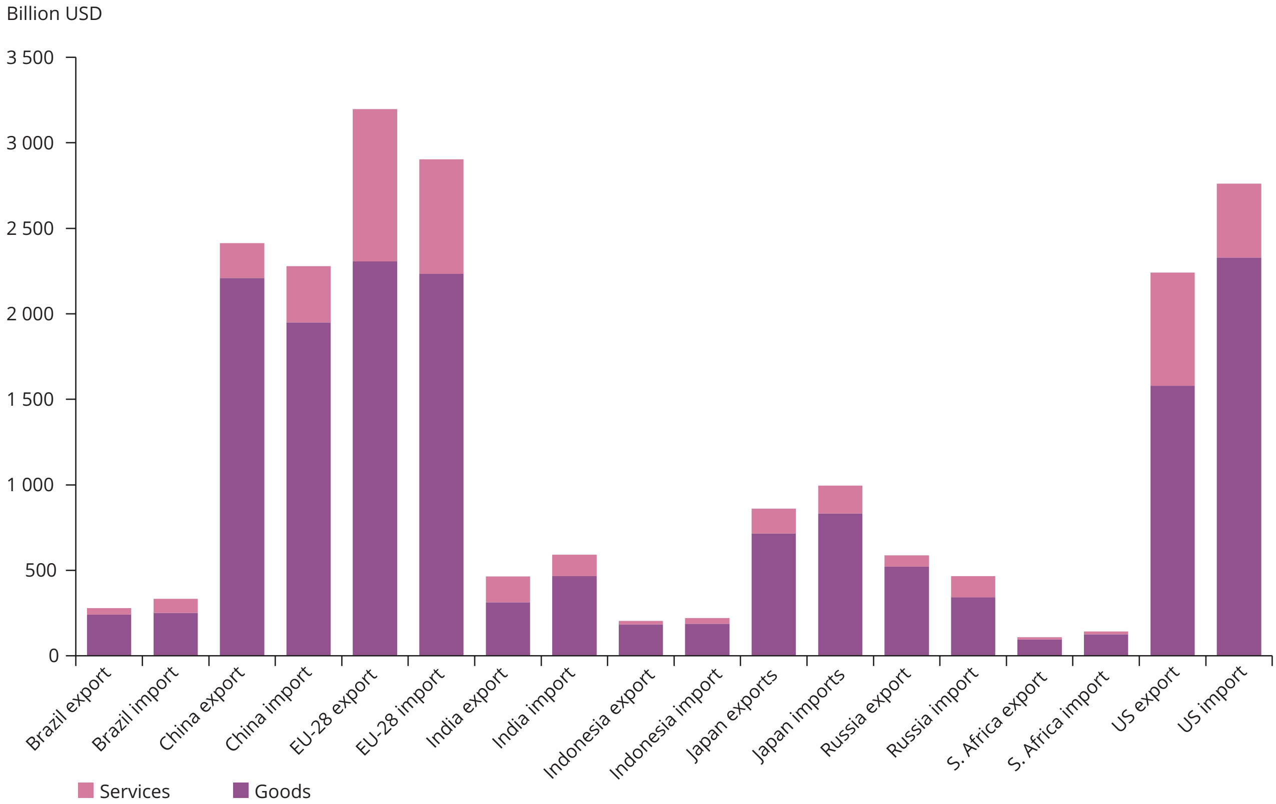
Figure 6.3 **National or regional exports as a percentage of total global exports (current USD and exchange rates), 1948–2013**



Note: Due to the absence of national data before 1994, figures or Russia for 1948–1993 are included in the 'Other' group.

Source: UnctadStat, 2015.

Figure 6.4 **Imports and exports of selected countries and regions, 2013**



Source: WTO, 2015.

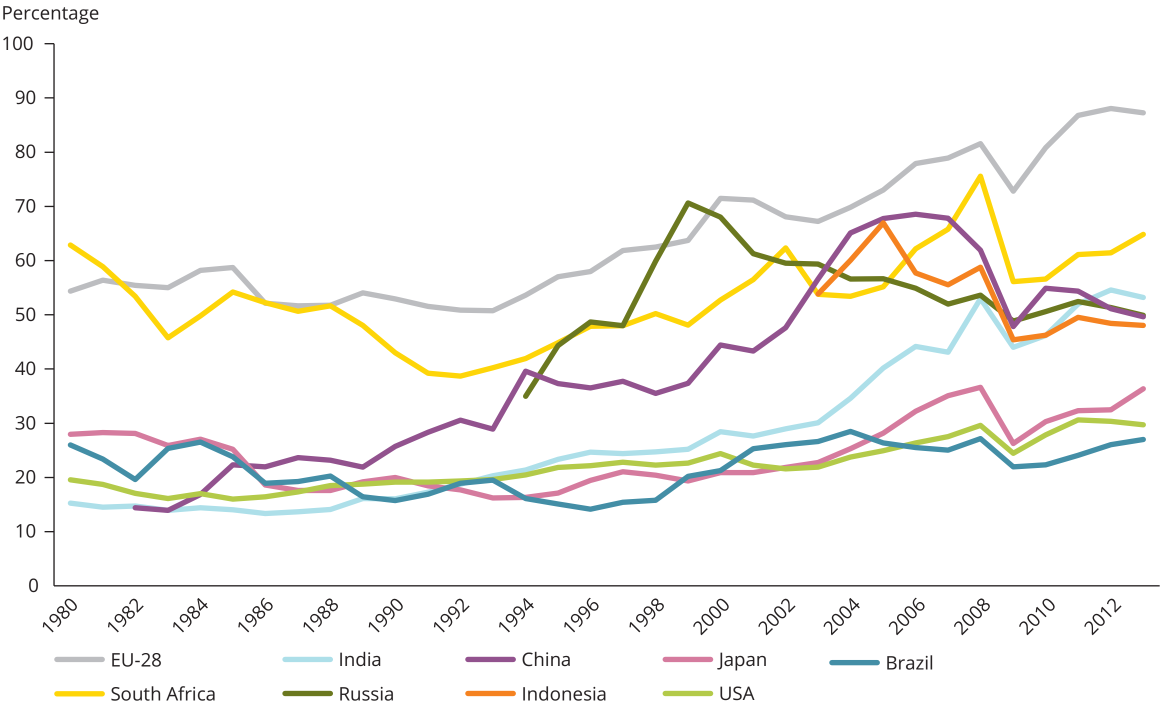
Recent data underline the importance of trade between developing countries. Such exports grew by 19% per year on average between 2001 and 2010, compared to a growth rate of 12% for total world exports. By far the biggest share of trade between developing countries (more than 80%) originates in Asia, underlining this region's growing economic importance (UNEP, 2013).

Integration into the world economy can also be measured by examining 'trade openness' — the dependence of domestic producers on foreign markets and the reliance of domestic demand on imports, quantified as the ratio of aggregate imports and exports to GDP. As illustrated in Figure 6.5, global trade openness has increased markedly in the last three decades, with particularly significant increases in China and India, from around 15% of GDP in 1980 to 50% or more in 2013.

The EU-28 is very open to trade, although again the data presented in Figure 6.5 include trade within the bloc. Focusing only on external trade, the EU figure drops to roughly the same level as Japan in 2013 (World Bank, 2015). External trade thus appears to plays a proportionally much larger role in the economic output of the BRIICS countries (with the exception of Brazil) than the advanced economies shown here — a reality that reflects the very different economic structures of those countries. Services tend to play a substantially larger role in GDP in advanced economies, accounting for approximately three-quarters of EU economic output (CIA, 2013), and few are traded across borders in significant quantities. In contrast, comparatively low labour costs have enabled the major developing economies to establish themselves as manufacturing bases for consumers globally, often importing raw materials and exporting finished products.

Looking ahead, global trade flows will continue evolving. For example, as China's economy develops, domestic consumption is likely to play an increasingly important role and as a driver of growth, with services contributing more to output. There are also some indications that rising wages in China are weakening its competitive advantage in some sectors. Some labour-intensive manufacturing industries have already relocated to other Asian countries such as Bangladesh, Indonesia and Vietnam (FT, 2012). Projections of wage costs and changes in productivity are subject to much uncertainty but outsourcing

Figure 6.5 **Trade openness — exports and imports relative to GDP between 1980 and 2013**



Source: UnctadStat, 2015.

to manufacturing companies outside China (e.g. Thailand, Malaysia or Vietnam) may become increasingly attractive for multinational companies (Accenture, 2011). So, while China's trade is likely to increase in absolute terms in coming decades, other countries may displace it in certain sectors.

The importance of regional power blocs and trade regimes

Regions differ in how far they have liberalised trade and developed trading blocs. Since the 1990s East Asian countries have been progressing towards an economic union, starting with multilateral free trade agreements (FTAs) between the members (1) of the Association of Southeast Asian Nations (ASEAN) in 1992. This process expanded shortly afterwards to encompass ASEAN and China, Korea, and Japan (ASEAN+3).

In 2003, the goal was set to create an ASEAN Economic Community by 2020. Free trade agreements with Australia and New Zealand were signed in 2009. At the beginning of 2013, the ASEAN member countries started negotiations with Australia, China, India, Japan, New Zealand and South Korea on establishing a Regional Comprehensive Economic Partnership. Parallel to this, regional cooperation progressed in South Asia (2) and the Gulf region (3) and in 2002 the Asia Cooperation Dialogue (ACD) was created to promote Asian cooperation at a continental level with the ultimate goal of transforming the continent into an Asian Community.

In Africa, several regional economic communities form the basis for the proposed African Economic Community (AEC). These regional blocs have the stated intention of becoming an economic and monetary union by 2028, and have progressed towards this goal at varying speeds.

(1) ASEAN's first members were Indonesia, Malaysia, the Philippines, Singapore and Thailand. Since then, membership has expanded to include Brunei, Burma (Myanmar), Cambodia, Laos, and Vietnam.
(2) The South Asian Association for Regional Cooperation (SAARC) is an economic and political organisation established on 8 December 1985 by Bangladesh, Bhutan, Maldives, Nepal, Pakistan, India and Sri Lanka.
(3) The Gulf Cooperation Council is a political and economic union involving the six Arab states of the Persian Gulf with many economic and social objectives.

In the Americas, the process of regional integration has so far reached the level of free trade areas (e.g. North American Free Trade Agreement (NAFTA) and the Latin American Integration Association (LAIA) ([4]). In 1991 Mercosur (Southern Common Market) was established with the purpose of promoting free trade and movement of goods, people and currency between the member states as well as the coordination of macroeconomic and sectoral policies ([5]).

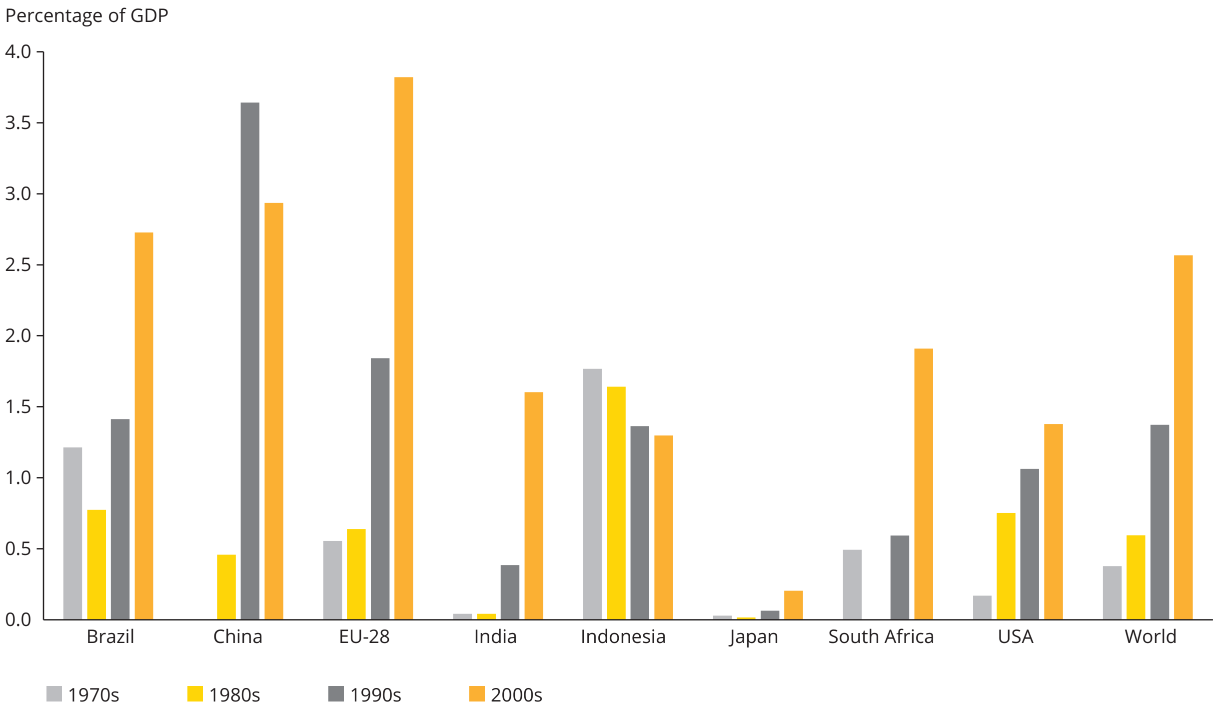
In comparison, economic integration in Europe is significantly more advanced. A system of economic and monetary union has been in place for several decades, with an internal market more recently accompanied by a single currency for many EU Member States. In spring 2013 the US and the EU agreed to launch a round of negotiations to create a new free trade agreement, the Transatlantic Trade and Investment Partnership (TTIP), in anticipation that it would boost economic output and create thousands of new jobs on both sides of the Atlantic.

Developing regions as key destinations and sources of investment

Foreign direct investment (FDI) is of considerable importance for the world economy, particularly in terms of facilitating economic progress in developing and emerging economies.

The global economy has become more balanced in recent decades in terms of investment flows. As illustrated in Figure 6.6, foreign direct investment has expanded enormously, from 0.4% of world GDP in the 1970s to 2.6% in the 2000s. At the same time, advanced economies have become less dominant, with the combined contribution to global FDI of the US, the EU-28 and Japan declining from almost 100% in the early 1970s to a little over 50% in 2013 (Figure 6.7). China's outward investment has grown rapidly in recent years, motivated by a desire to secure access to resources, technologies, expertise and brands (Fontagné and Py, 2010). In 2013, it accounted for 7.2 % of global FDI, up from just 1.2% in 2007.

Figure 6.6 **Foreign direct investment, net inflows**

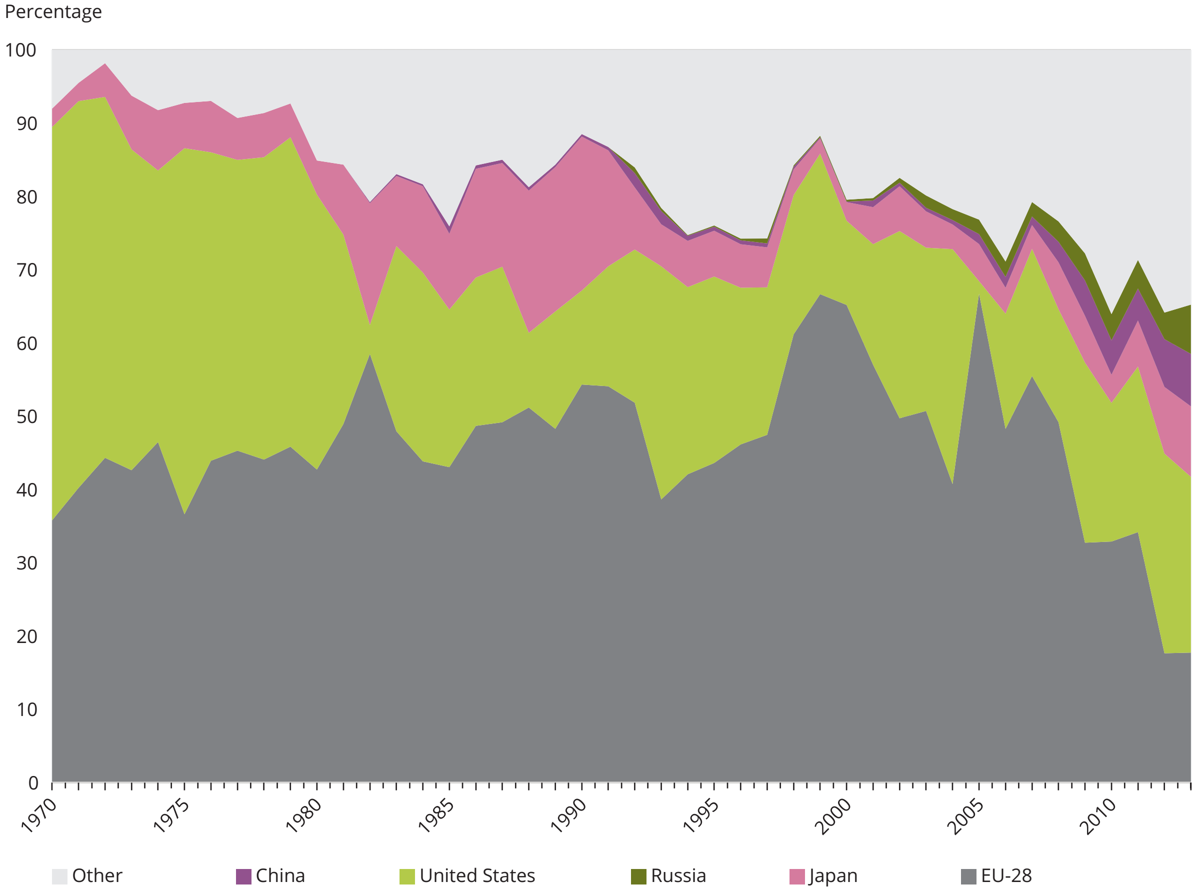


Source: UnctadStat, 2015

([4]) NAFTA's members are Canada, Mexico and the US. LAIA's members are Argentina, Bolivia, Brazil, Chile, Colombia, Cuba, Ecuador, Mexico, Paraguay, Peru and Uruguay and Venezuela.

([5]) The member states of Mercosur are Argentina, Brazil, Paraguay, Uruguay and Venezuela as well as Bolivia which became accessing member in December 2012.

Figure 6.7 **Percentage of total global net foreign direct investment outflows from selected source countries or regions, 1970–2013**



Source: UnctadStat, 2015.

Box 6.1 Uncertainties in the shift to a multipolar world economy

A variety of uncertainties surround the continuing shift towards a more geographically balanced global economy. Rodrik (2013, 2014) argues that although developing regions are likely to continue to close the gap in economic output with advanced economies, the convergence achieved in the last two decades is historically very unusual. Indeed, at the level of individual countries, 'convergence has been the exception rather than the rule'. Moreover, the very rapid economic convergence witnessed since 1990 was linked to a particular set of related factors, including high commodity prices, low interest rates and very rapid economic growth in China, which are unlikely to be sustained in coming years.

Other factors may also contribute to a slower convergence. For example, facing continuing economic difficulties, developed countries may become less tolerant of the policy interventions that underpinned the huge growth achieved in the most successful Asian economies, in particular systematic currency undervaluation and related imbalances in international flows of trade and capital. In addition, technological advances (such as robotics) that make the manufacturing sector more capital and skill intensive may undermine the competitive advantages of developing countries with low-cost labour (Rodrik, 2013).

Socio-political developments in developing countries — for example democratic processes and growing income disparities — are very hard to anticipate, as are the effects of shortages of skilled labour due to demographic changes, such as migration and population ageing. In terms of international relations, uncertainty surrounds the ability of emerging countries to develop economic cooperation mechanisms and undertake further economic integration, which could bolster their position on the global stage. Perhaps most important are the risks of geopolitical stability and military conflicts.

6.3 Implications

Variance in growth rates and economic restructuring linked to increasing wealth are set to shift global economic patterns. Countries and blocs will lose and gain competitive positions. Trade relationship will adjust and trade will become more diversified. This may fundamentally influence the way Europe conducts its economic activities, and where and how it earns income — with important economic, social and environmental consequences. More balanced, multipolar global growth may lead to a more resilient world economy, less vulnerable to boom and bust in a few wealthy economies. Equally, however, the integration of financial markets globally creates obvious interdependencies and risks of contagion.

Economic risks and opportunities for developed regions

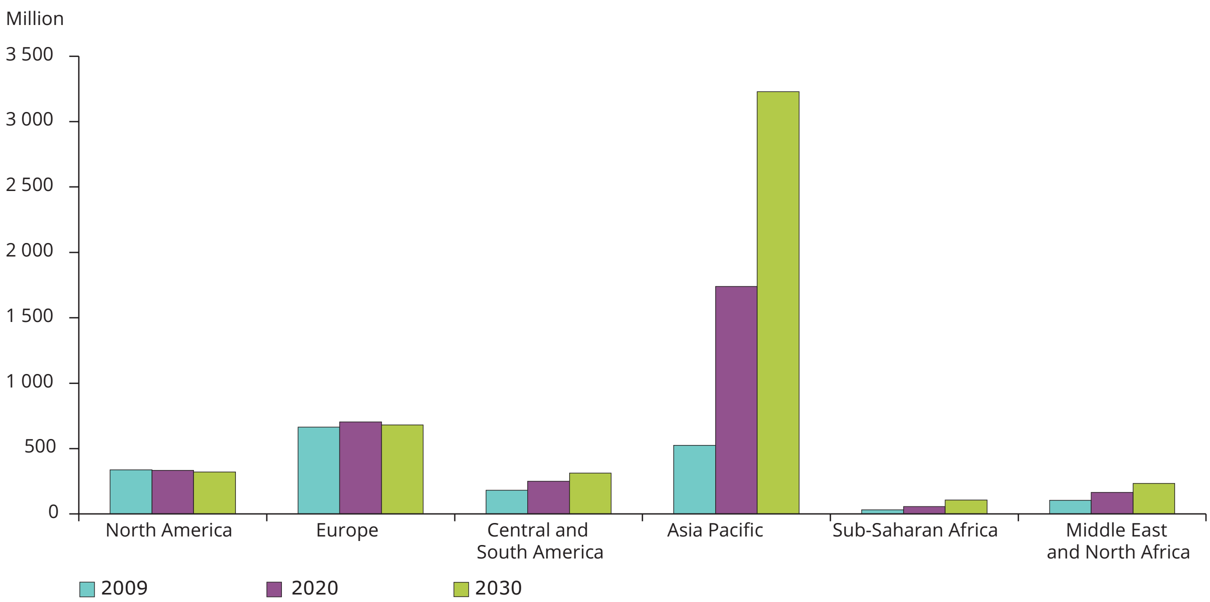
Emerging economies have competitive advantages in low-skilled, labour-intensive production and gain further when they build up their capital stock and increase the quality of their products (i.e. increase productivity). While this potentially affords Europeans access to relatively cheap imports, it clearly creates a competitive challenge, potentially putting downwards pressure on wages for low-skilled workers in Europe and other developed regions (Autor et al., 2012). And even if Europe manages to enhance its already high labour productivity through technological innovation, it seems sure to lose its share in some world markets such as agricultural products and basic manufacturing.

On the other hand, a variety of factors suggest that Europe is well positioned to compete in the evolving economic order. First, the competitiveness of emerging economies is sure to adjust over time, as they become increasingly prosperous. Cost advantages may level out and disappear in the long-term if these countries do not boost their productivity, perhaps ultimately leading to the repatriation ('backsourcing') of some production to today's advanced economies.

Second, although advanced economies will face increasing competition in areas where they currently dominate (e.g. high-tech industries or financial services), the restructuring of emerging economies towards largely non-traded services as they become wealthier may alleviate some of this competitive pressure. Services accounted for approximately 45% of China's GDP in 2012, against 80% in the US (CIA, 2013).

Third, increasing prosperity in developing regions potentially offers a growing, wealthy customer base for exports in areas of European specialisation, such as scientific innovation and luxury brands. The global middle class — defined as households with daily available funds of USD 10–100 (PPP) per person — is projected to increase from 27% of the world population of 6.8 billion in 2009 to 58% of more than 8.4 billion in 2030 (Figure 6.8). The Asia-Pacific region is projected to provide much of this growth, accounting

Figure 6.8 **Middle class population by world regions, 2009, 2020 and 2030**



Source: Kharas, 2010.

for 66% of the total world middle-class population in 2030, up from 28% in 2009 (Kharas, 2010). In addition to changing consumption patterns, this is likely to bring with it evolving norms, attitudes and expectations, with potentially far-reaching implications for social cohesion and political systems (Pezzini, 2012).

Certainly, Europe will need to find its own niche to maintain its income-earning capacity. Yet its relative resource poverty may lead to a more resource-efficient economic structure, leaning further towards profiling as a service economy. For example, with increasing purchasing power in emerging economies, Europe may become more and more attractive as a tourist destination.

New actors and new challenges in global governance

Until relatively recently, coordination of the international economy was largely handled by the small group of structurally similar states that accounted for most global production. The financial crisis of 2008 exposed a changing reality. Today, choices by large emerging economies — for example relating to the accumulation of foreign currency reserves — can have major effects on the entire global economy.

The relative decline of the G7/G8 and the emergence of the G20 as the locus of global economic planning reflect this transition. Brazil, Indonesia, Mexico, South Korea and Turkey, for example, now have a more important role in global governance. China and India are already major economic powers with related global social and environmental impacts and responsibilities. Yet they have acquired this status when their average per person income levels are quite low. They therefore face a set of internal development challenges and demands that are quite different from advanced economies (Spence, 2011).

The systemic importance of large emerging economies means that their engagement in international economic governance is essential. But the growing number and diversity of participants are also likely to make it harder to coordinate global activities and ensure economic stability. The EU will remain a powerful voice in these processes but its capacity to control external risks may decline.

The need for coordinated environmental governance is also growing as economic and social interactions intensify. Globalisation of trade flows has created economic benefits for exporting and importing countries but it also means that consumers are extremely unlikely to comprehend the full social and environmental implications of their purchases. National governments have very limited capacity to monitor or manage such impacts, in part because the international agreements that facilitate global trade prevent states from differentiating between imports based on production methods (WTO, 2013).

To some extent, the harm associated with globalised supply chains may abate as growing prosperity in developing regions brings popular demand for improved local environmental and social protection. However, such advances may do little to curb pressures on the global environmental commons. At present, therefore, the international community lacks effective institutions to coordinate its response to complex globalised challenges such as climate change and international financial instability. This is creating demand for new forms of governance (GMT 11).

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Global megatrend 7 — Intensified global competition for resources

As they grow, economies tend to use more resources — both renewable biological resources (see GMT 8) and non-renewable stocks of minerals, metals and fossil fuels (addressed in this chapter). Industrial and technological developments, and changing consumption patterns associated with growing prosperity all contribute to this increase in demand. New technologies can create novel uses for resources and new ways to locate and exploit deposits, potentially increasing the burden on the environment. But innovations can also enable societies to reduce their use of finite and polluting resources and shift towards more sustainable alternatives.

Global use of material resources has increased ten-fold since 1900 and is set to double again by 2030, creating obvious risks. In addition to the environmental harm associated with resource extraction and exploitation, the world is a closed material system, implying finite limits on the amounts of resources available. Even if they are not scarce in absolute terms, resources may be unevenly distributed globally, making access uncertain, increasing price volatility and potentially fostering conflict. Such concerns are particularly apparent with respect to a range of resources designated as 'critical raw materials'. For Europe this is a major concern as its economy is structurally dependent on imports.

7.1 Drivers

Demographic and economic change

Global demand for resources has increased substantially since the start of the 20th century, driven by a number of closely related trends. Across the world, countries have undergone structural economic change, shifting from agrarian societies, primarily reliant on biomass to meet energy and material needs, to urban, industrialised economies (GMTs 2 and 6). The technological advances that accompanied economic development have provided many more uses for resources, and greatly improved methods for locating and extracting them. Coupled with a quadrupling of the world's population in the 20th century (GMT 1), innovation has underpinned a 25-fold increase in economic output (GMT 5), bringing radical changes in consumption patterns.

Looking ahead, the global population may increase by more than a third by 2050, reaching 9.6 billion (UN, 2013). World economic output is projected to triple in the period 2010–2050 (OECD, 2014). And the middle class may increase from 27% of the world population of 6.8 billion in 2009 to 58% of more than 8.4 billion in 2030 (Kharas, 2010).

At the same time, however, some of the drivers of past increases in resource use could alleviate demand in the future. For example, continued structural economic change — away from industrialised systems and towards services and the knowledge economy — could offer ways to decouple further economic growth from resource use. Similarly, a continued shift from diffuse rural living to compact urban settlements could translate into less resource-intensive lifestyles (GMT 2).

Innovation and uncertainty

While continuing economic and population growth appear likely to drive a further increase in humanity's demand for resources in coming decades, estimating the future demand for specific resources is subject to significant uncertainties. Much depends on the interaction of three related strands of technological innovation.

The first consists of finding ways to exploit alternative resources that are more abundant or (ideally) non-depletable, for example wind and solar energy. Alternatives vary in their net benefits relative to traditional resources. For example, generating energy from combusting biomass may be less polluting than using fossil fuels but it can also reduce the land available for agriculture or forestry, with implications for food availability and prices, and carbon sequestration. Even exploiting wind and solar energy requires significant material resource inputs (including rare earth metals).

A second focus of innovation involves developing technologies and approaches (for example recycling, supply chain management, industrial ecology or behavioural change), that enable society to move towards a circular economy. Such an approach aims to shift from a linear 'take-make-consume-dispose' economic model towards a closed loop that enables more value to be extracted from resources before they are returned to natural systems as emissions and waste. Such innovations can include measures that allow people to meet their needs in less resource-intensive ways. For example, new communication technologies can reduce transport needs.

A third type of innovation is oriented towards finding new ways to locate and exploit traditional resources. Such activities may be at odds with the other two forms of innovation, in the sense that increased access to traditional resources reduces incentives to find alternatives and boost efficiency. Boxes 7.1 and 7.2, relating to shale gas and phosphorus, illustrate how advances in technology and market incentives can lead to very swift and radical changes in estimates of resource stocks and prices.

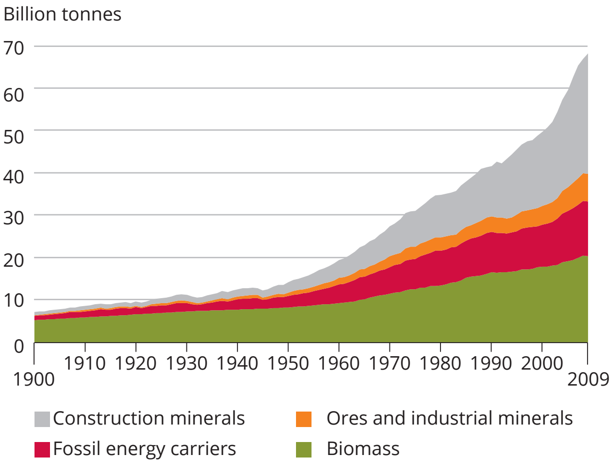
In addition to the fundamental uncertainty associated with the direction and pace of technological change, resource competition is also strongly influenced by political and social choices that are hard to anticipate. For example, global progress in environmental agreements (e.g. on strict preservation of the Arctic environment) could exclude or reduce the availability of resources.

7.2 Trends

Growing global demand

As illustrated in Figure 7.1, global materials use is estimated to have increased almost ten-fold since 1900, accelerating from annual growth of 1.3% in 1900–1949, to 2.6% in 1950–1999, and 3.6% annually in 2000–2009 (Krausmann et al., 2009).

Figure 7.1 Global total material use by resource type, 1900–2009



Source: Krausmann et al., 2009 (updated in 2011).

Developing regions account for an increasing proportion of global resource use. Whereas Europe was responsible for 19% of total resource extraction in 1980 and the US accounted for 18%, by 2009 both had fallen to 10%. Asia's share increased from 41% to 57% over the same period.

Changing resource demand at different stages of economic development

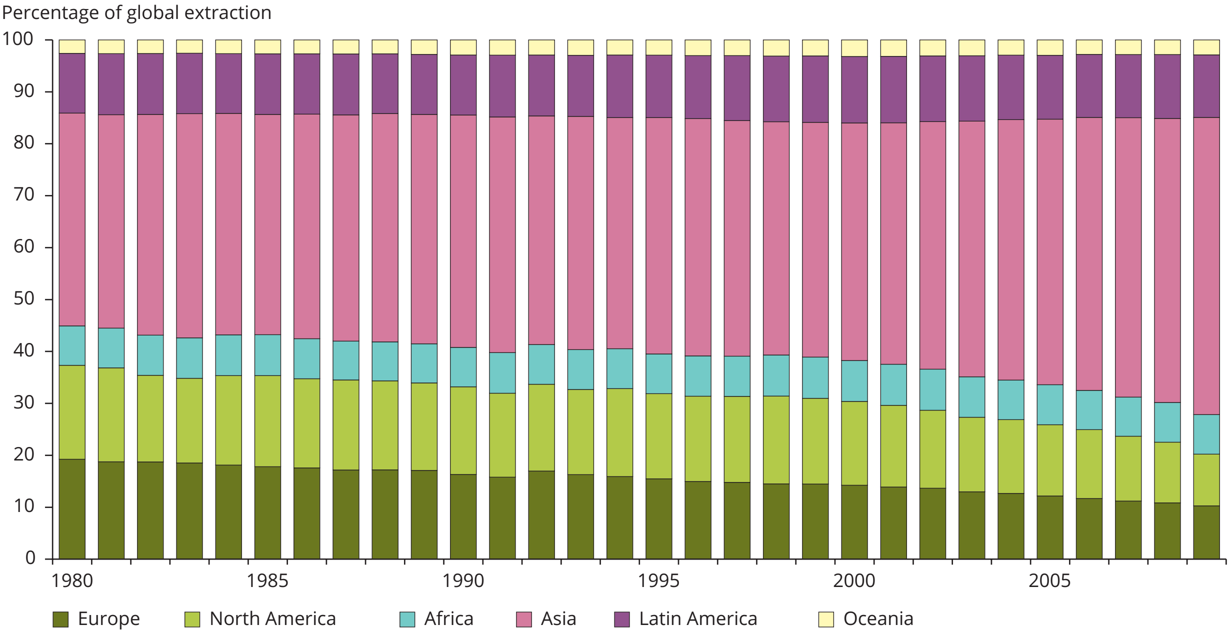
Resource use tends to rise as countries develop economically. However, there is evidence that growth slows or ceases at high income levels, as a consequence of reduced investment in infrastructure, structural economic change, efficiency improvements, and the relocation of some manufacturing to countries with lower labour costs.

International Monetary Fund analysis, for example, indicates that consumption of base metals and steel rises in step with per person gross domestic product (GDP) but reaches a saturation point at USD 15 000–20 000 (2000 PPP), except in countries, such as South Korea, where industrial production and construction continue to play a major role in economic growth (IMF, 2006). Döhrn and Krätschell (2014) likewise find that steel demand increases during an initial stage of economic development and declines after economies have reached a certain level of per capita income.

Consumption of energy resources follows a similar pattern. Cross-country analysis shows a strong correlation of energy use to economic output. As illustrated in Figure 7.3, individuals in countries with low GDP per person (e.g. India) use the least energy and consumption increases steadily up to the countries with the highest per person GDP (e.g. USA). Yet in many developed countries energy use has been stable for some decades, albeit at very different levels. In 2012, the citizens of EU-28 countries consumed roughly the same amount of energy as they did in the late-1970s. In the US, energy use per person has changed very little in almost half a century, while GDP per person has more than doubled.

While these trends indicate a huge improvement in energy efficiency, it is clear that advanced economies remain very resource intensive. If developing regions adopt similar systems of production and consumption it will have huge implications for global resource demand. For example, if the current global population increased average energy use to EU levels it would imply a 75% increase in world energy consumption. An increase to US levels would imply a 270% rise in world energy consumption.

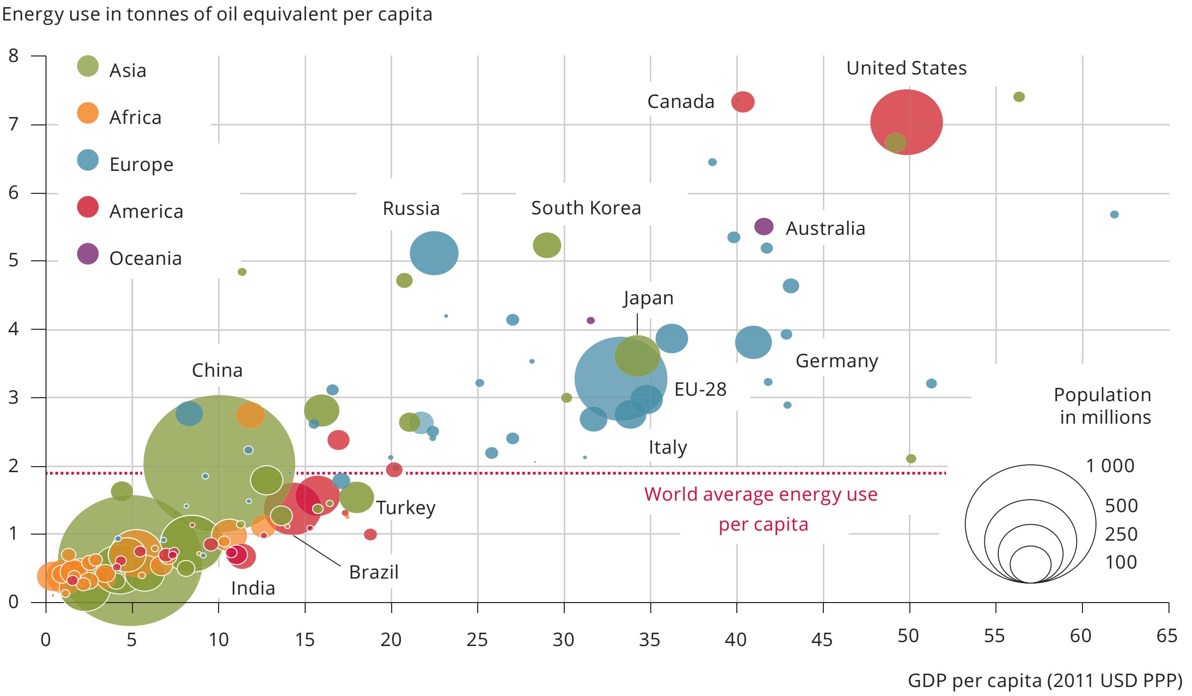
Figure 7.2 **Percentage of global resource extraction by world regions, 1980–2009**



Note: Global resource extraction is calculated by aggregating commodities based on weight.

Source: SERI, 2013.

Figure 7.3 **Correlation of energy use and GDP per person, 2011**



Note: The graph shows the correlation of national per capita energy consumption and per capita GDP. The size of the bubbles denotes total population per country. All values refer to the year 2011.

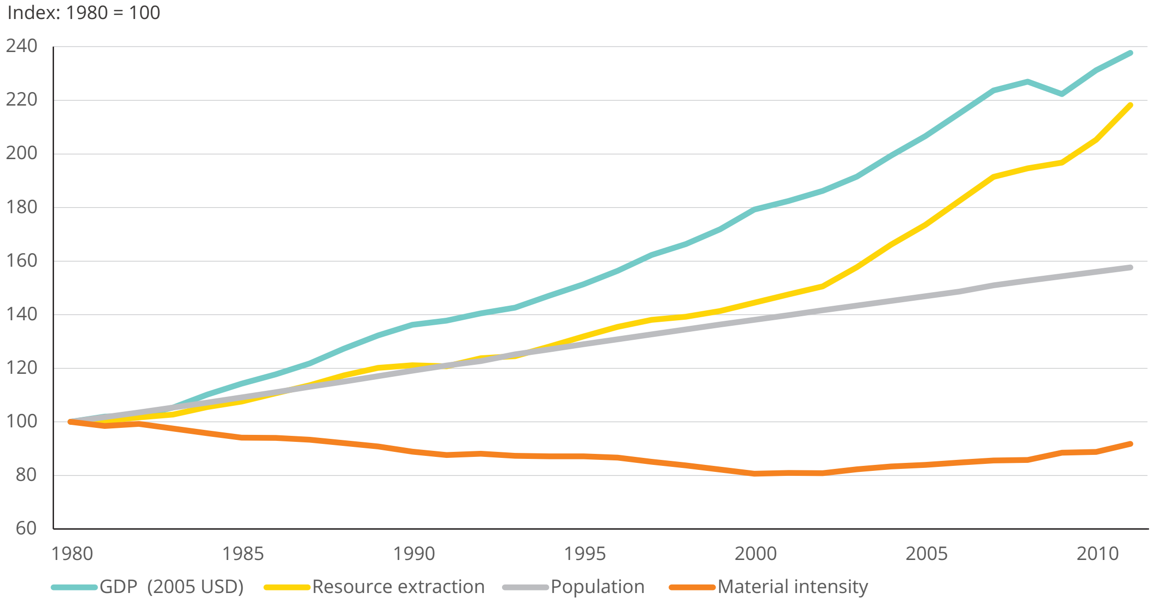
Source: World Bank, 2014.

Increasing resource use despite some decoupling from economic growth

At the global level, there are some indications of decoupling of resource extraction from economic output. While it is difficult to interpret aggregated measures of material resource use (because resources differ so greatly in their characteristics), Figure 7.4 shows that, despite almost doubling, global resource extraction has partially decoupled from economic growth since 1980. On the other hand, the overall trend of declining material intensity has reversed in the last decade, with resource extraction increasing faster than GDP.

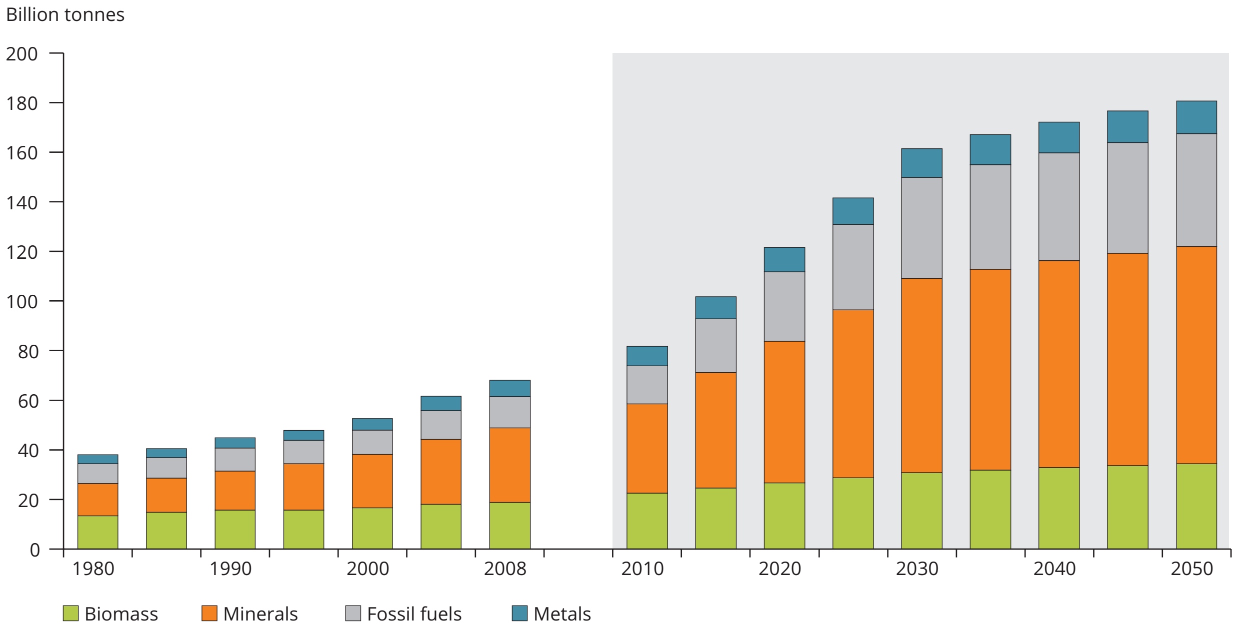
Projections of future resource use indicate that developing regions will drive up global resource

Figure 7.4 Global GDP, resource extraction, population and material intensity, 1980–2011



Source: SERI, 2015.

Figure 7.5 Global resource extraction by material category, 1980–2008 and projections for 2010–2050



Source: SERI, 2013.

demand in coming decades. The Sustainable Europe Research Institute (SERI) expects world resource use to double between 2010 and 2030 (SERI, 2013). The International Energy Agency likewise projects that global energy consumption will increase by 31% in the period 2012–2035, based on energy policies in place in early-2014 (IEA, 2014).

Risks of scarcity but innovation in extraction technologies

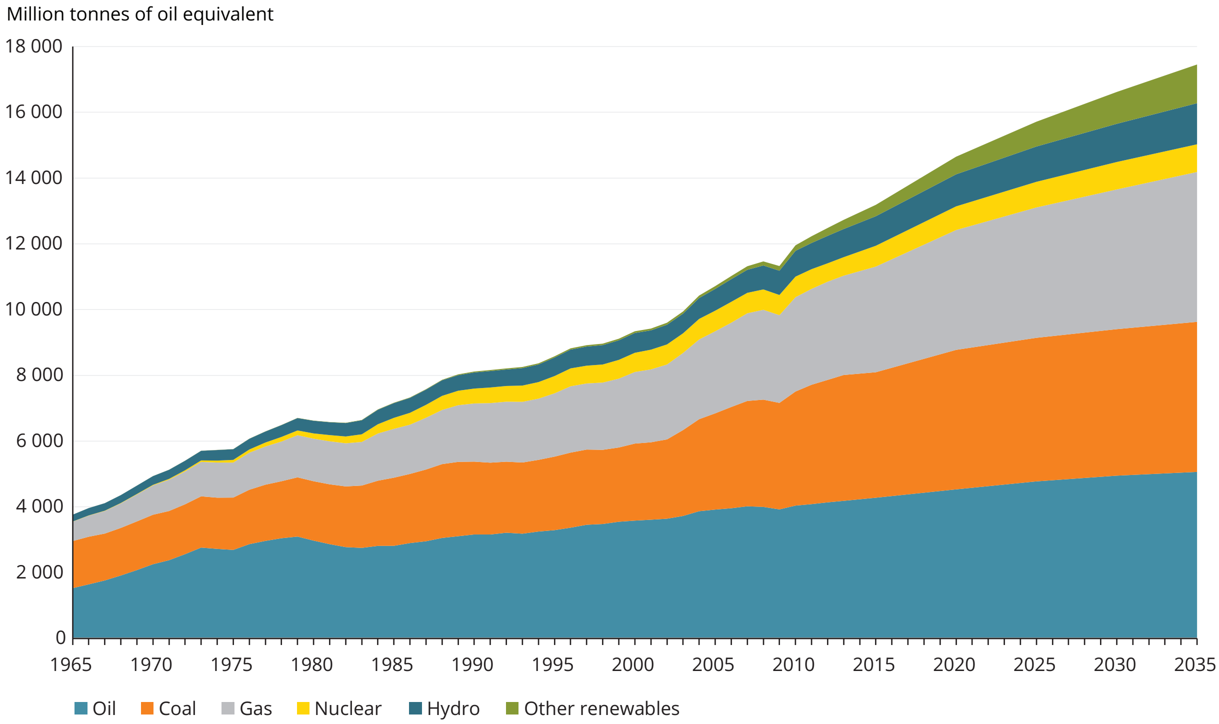
While global demand for resources is set to grow significantly in coming decades, the outlook for supplies is more uncertain. Geographic concentration of reserves in a limited number of countries is a concern since it affords suppliers considerable influence over global prices and supplies, as illustrated by the influence of the Organization of Petroleum Exporting Countries (OPEC) over global oil markets. Uncertainty regarding access to commodities increases if reserves are concentrated in politically unstable regions.

The energy sector illustrates many of these trends. Fossil fuel reserves are concentrated in a small number of countries. In 2014, just three countries — Venezuela, Saudi Arabia and Canada — accounted for 44% of proved global oil reserves. Similarly, Iran, Russia and Qatar held 48% of natural gas reserves, while the US, Russia and China hold 57% of coal reserves (BP, 2014b). The EU is heavily dependent on imports, which provided for 88% of its gross inland consumption of oil in 2012, 66% of natural gas and 42% of solid fuels (Eurostat, 2015a).

Uncertainty about resource supplies can create strong incentives for countries to identify other ways to meet their resource needs, either by locating new sources of traditional resources or identifying substitutes. For example, rising fossil fuel prices, coupled with state efforts to promote alternatives, have incentivised huge investment in renewable energy in recent years (REN21, 2014). Global investment rose from USD 40 billion in 2004 to USD 214 billion in 2013. Renewable power capacity, excluding hydropower, increased more than six-fold in this period.

Despite rapid growth in recent years, however, renewable technologies have yet to reduce the relative contribution of fossil fuels to total energy supply. Together, coal, gas and oil accounted for 87% of global energy output in 2013 — the same level as in 2000. Their contribution is projected to decline only slightly to 81% in 2035, with each fossil fuel accounting for approximately a third of that total (Figure 7.6).

Figure 7.6 Past and projected world energy consumption by fuel (Mtoe), 1965–2035



Note: BP (2014a, 2014b) and EEA calculations (interpolation of five-yearly projections).

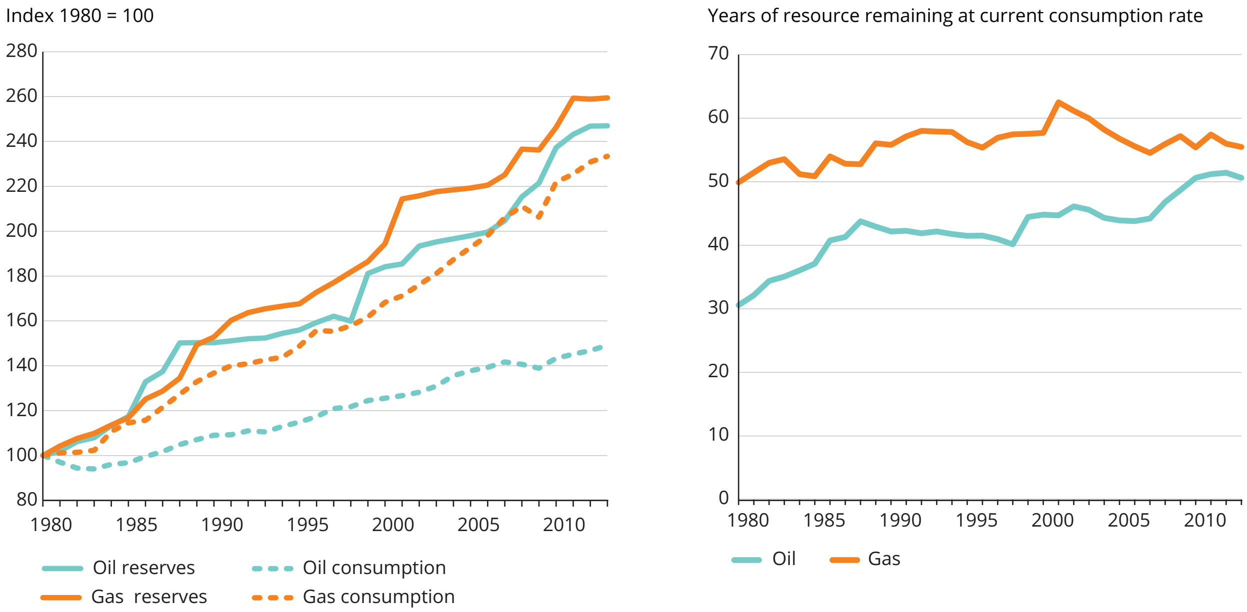
As well as facilitating a move towards alternative energy sources, technological advances have also boosted access to fossil fuels. Estimates of reserves evolve rapidly as new deposits are discovered and innovation allows previously unreachable or unusable sources to be exploited with potentially greater environmental risks (e.g. deep water drilling and mining of tar sands). These factors mean that proved global reserves of oil and gas have increased substantially since 1980 — faster, indeed, than consumption of either resource (Figure 7.7, left). As a result, the number of years that proved reserves would last at current consumption rates has increased in the last three decades (Figure 7.7, right). In the case of oil, the increase was considerable: from approximately 30 years to more than 50.

In the last decade, technological advances and high oil prices have facilitated a huge growth in extraction of shale gas and oil. The boom initiated in the US, where shale oil and gas production shifted from minimal quantities at the start of the 2000s to account for approximately 40% of US production of both crude oil and natural gas by the close of 2013 (EIA, 2014, 2015). A US government report estimates that proved and unproved shale oil and gas could augment total world technically recoverable resource significantly, with total crude oil resources increasing by 10% and natural gas resources by 47% (EIA, 2013). The same study estimates that Russia may have the largest technically recoverable shale oil resources, while China may hold the most shale gas.

These recent developments may have wide-ranging impacts on the global energy market, thereby affecting economic development. In 2012, the International Energy Agency (IEA) projected that the USA will become the largest oil producer by around 2020 and a net oil exporter by 2030 (IEA, 2012). However, the IEA also identified a range of potential constraints to developing fracking, including adverse fiscal and regulatory frameworks, limited access to pipelines and markets, and shortages of expertise, technology and water, which is used in large quantities for extracting gas (IEA, 2012). Several European countries are scrutinising the environmental impacts of hydraulic fracturing ('fracking'), which include air and water pollution, and such concerns prompted France to ban the practice in 2011.

The outlook for future shale gas and oil production is also strongly dependent upon volatile global energy prices. Although there is much uncertainty about the price level at which US production is commercially viable (Reuters, 2014) — and that price level is likely to shift as extraction technologies develop — the sharp

Figure 7.7 Oil and gas: proved reserves and consumption, 1980–2013 (left) and implied years of reserves remaining at current consumption rates (right)



Note: BP estimates of proved oil reserves are compiled using a combination of primary official sources, third-party data from the OPEC Secretariat, World Oil, Oil & Gas Journal and an independent estimate of Russian and Chinese reserves based on information in the public domain. Canadian oil sands 'under active development' are an official estimate. Venezuelan Orinoco Belt reserves are based on the OPEC Secretariat and government announcements. BP estimates of proved natural gas reserves are compiled using a combination of primary official sources and third party data from Cedigaz and the OPEC Secretariat.

Source: BP, 2014b.

decline in world oil prices during the second half of 2014 has caused clear reductions in projections of US shale oil production (IEA, 2015).

Commodity price developments

Commodity markets provide further insights into the interaction of global resource demand and supply. The prices of major resources categories (energy, minerals and metals, food) followed contrasting paths until about 2000 (Figure 7.8). Price indices for food and other agricultural commodities such as timber, cotton and tobacco peaked in the mid-1970s, when a combination of bad harvests, currency adjustments and a surge in energy prices induced by major oil producers brought about the 'world food crisis' (FAO, 2000). Since 2000, however, the price trends have been more similar. Prices more than doubled in real terms in the period 2000–2012, as growing global resource demand outpaced increases in supply.

Looking ahead, the UNEP International Resource Panel notes that commodity prices are hard to anticipate (UNEP, 2011). Uncertainties regarding future resource demand and supply are reflected in diverging commodity price projections from different sources. Whereas the World Bank foresees a slight reduction in commodity prices in real terms up to 2025, recent OECD and FAO projections suggest that real prices for agricultural products will remain relatively stable in the period 2013–2022 (OECD, 2013). In contrast, the European Commission expects that resource prices will increase in coming decades (EC, 2011).

Figure 7.8 Global commodity prices 1960–2012 and projections 2013–2025 (2010 USD)

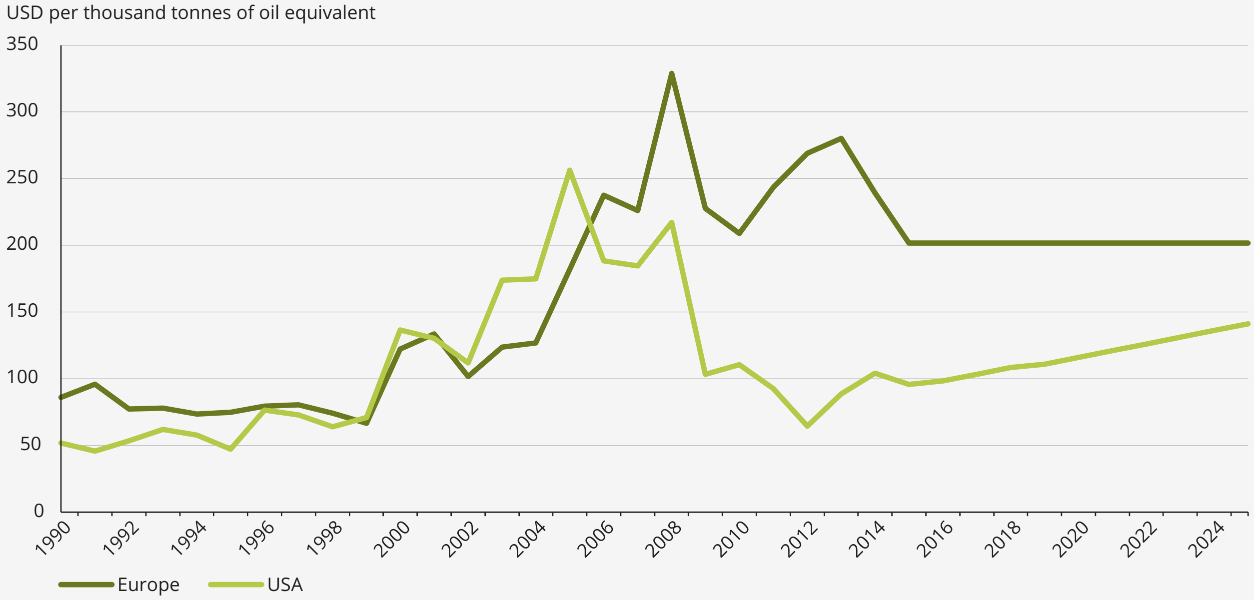
Source: World Bank, 2015a, 2015b.

Box 7.1 Uncertainties around demand and supply: the case of shale gas

Recent price developments provide an illustration of the capacity for technological change to alter the equilibrium in markets very quickly, with implications for the competitiveness of alternative resources. The development of shale gas in the US is apparent in the recent divergence of natural gas prices in the USA and Europe (Figure 7.9). Since 2005 price developments have followed contrasting courses, with US prices standing at less than a quarter of European prices in 2012.

European industries have voiced significant concern about how the disparity in energy prices will affect their competitiveness in global markets. In some instances they have elected to relocate production to the US (e.g. FT, 2013; NY Times, 2012). World Bank projections anticipate a reduction in the price gap in coming years, although European prices are still expected to exceed those in the USA by more than 40% in 2025.

Figure 7.9 US and EU natural gas prices 1990–2014 and projections 2015–2025



Source: World Bank, 2015a, 2015b.

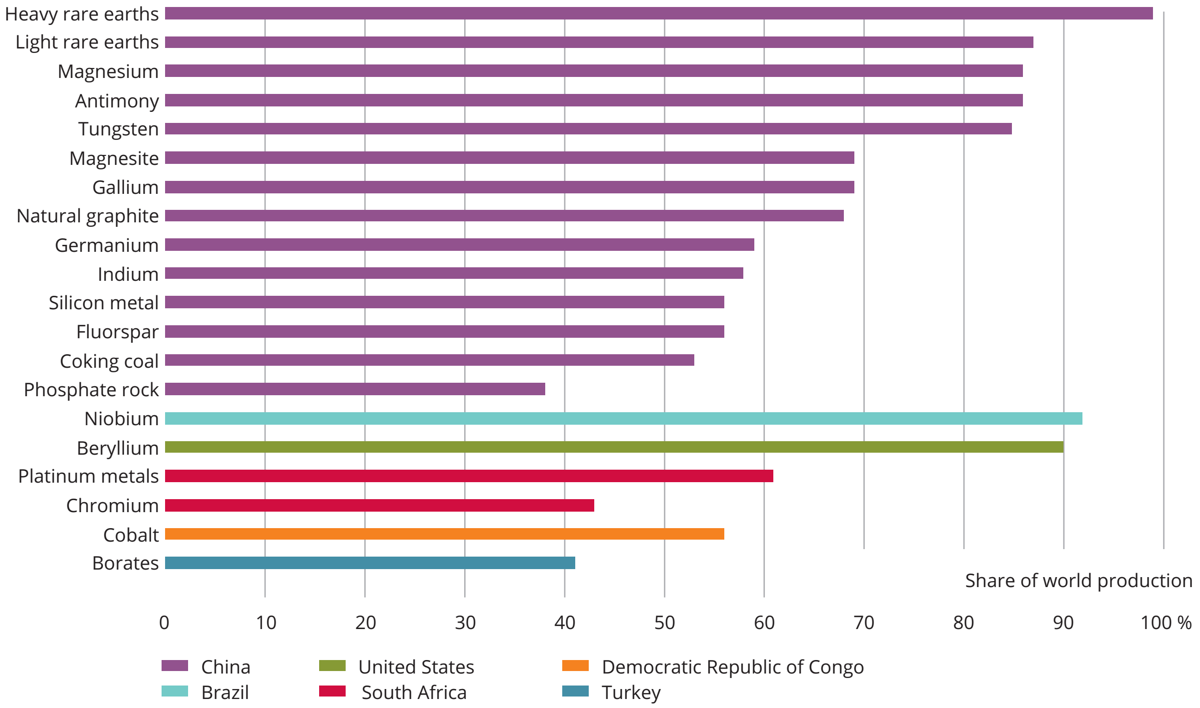
Uncertain access to critical resources

Certain non-renewable resources deserve particular attention because of their economic relevance, including their role in green-energy technologies. In 2014, the European Commission identified 20 critical raw materials — resources associated with a high risk of supply shortage over the next ten years and of key importance for the European value chain (EC, 2014). The EU's selection of critical raw materials was based on three core criteria (EC, 2010):

- 'economic importance', which is measured by identifying the main uses of the material and quantifying the value added by those sectors;
- 'supply risk', which is measured in terms of the degree of corporate concentration of worldwide production, the political and economic stability of the producing countries, the potential to use substitute raw materials, and recycling rates;
- 'environmental country risk', i.e. the risk that a country might implement environmental measures that restrain access to raw materials, which is quantified by combining data on national environmental performance and on the full life-cycle impacts of raw materials on the environment.

As shown in Figure 7.10, global production of some of the 20 critical raw materials is monopolistic in character, conferring a great deal of market power to a limited number of price-setting suppliers. China emerges as a key player as it holds more than 50% of the known global reserves of 13 of the 20 materials

Figure 7.10 **Proportion of global production of EU critical raw materials within a single country, 2010–2012**



Note: The figure shows the 20 raw materials identified by the European Commission as being critical because of risks of supply shortages and their impact on the economy.

Source: EC, 2014.

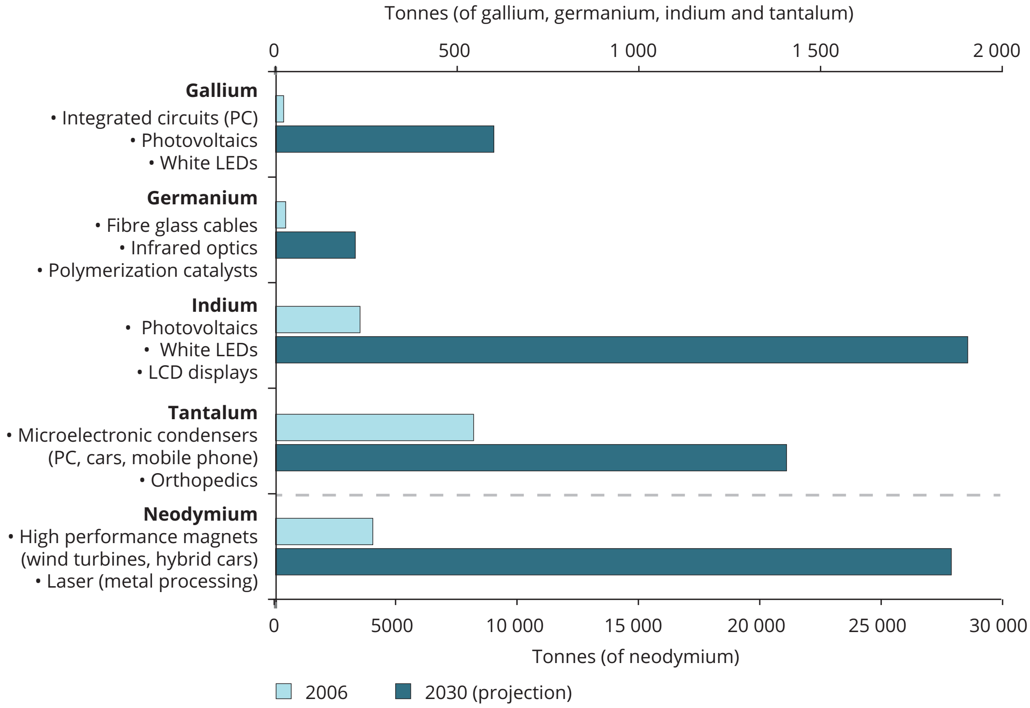
and shows a particular dominance in the area of heavy rare earth metals.

While the direction of future innovation is very hard to anticipate, projections suggest that demand for some of these critical raw materials is likely to expand substantially. Since resource extraction often cannot easily respond to changes in demand (EC, 2012), this implies potential risks in terms of security of supply and price volatility.

Figure 7.11 shows the potential increases in global demand for five out of the 20 key materials, which are crucial because of their importance in fast growing technologies (IZT and Fraunhofer, 2009; EC, 2010). For example, strategic low-carbon energy technologies such as the high performance magnets used in wind turbines or electric vehicles rely on neodymium (included among the rare earths group). Photovoltaic systems depend on gallium and indium, and tantalum is used in computers and mobile phones. The potential growth in global demand for these resources up to 2030 represents a concern for the EU, which has limited reserves (if any) of most of these materials and is heavily dependent on imports.

As with fossil fuels, growing awareness of the vulnerability of supply chains for critical raw materials has created strong economic incentives for countries to locate new reserves. There is evidence that these activities are beginning to pay off, potentially bringing a diversification of global supplies (New Scientist, 2013). As with fossil fuels, however, the rush to identify new deposits of resources presents environmental burdens alongside economic opportunities. In the case of rare earth metals, these include the toxic and radioactive waste generated by mines and processing plants (Schüler et al., 2011).

Figure 7.11 World use of selected critical raw materials in emerging technologies, 2006 and 2030



Source: IZT and Fraunhofer, 2009.

Box 7.2 Uncertainties around demand and supply: the case of phosphorous

The finite character of non-renewable resources, combined with supply chain vulnerabilities and technological advances, contribute to continued changes in estimates of remaining resource reserves and their geographical distribution.

Concerns about the longevity of phosphate reserves, which provide most of the phosphorus used in agriculture, have eased in recent years following a four-fold increase in estimated reserves between 2010 and 2011 (Van Kauwenbergh, 2010). Although projections for demand still suggest that phosphate stocks in the USA and China may be exhausted by 2060–2070, it is estimated that global reserves will last more than 300 years at current extraction rates, compared to previous estimates of less than 100 years.

Nevertheless, the heavy concentration of newly identified deposits in one country, Morocco, implies that concerns persist about security of access to supplies. According to one estimate, Morocco's share in world phosphorous production might increase from 15% today to about 80% in 2100 (Cooper et al., 2011).

7.3 Implications

Insecure access to essential resources and price volatility are threats to economic development and living standards. As illustrated in Figure 7.8, global commodity prices have spiked repeatedly in recent years, reversing long-term downward trends (World Bank, 2015b). Such uncertainty represents a clear risk to the European economy, which is dependent on imported resources, particularly metals and fossil fuels (EEA, 2012).

Imports from outside the EU accounted for 51% of EU-27 consumption of metal ores and products in 2013 and 59% of fossil energy materials (Eurostat, 2015b). This dependence, which increased steadily prior to the financial crisis (Figure 7.3), appears as a major vulnerability in the context of accelerating global demand for commodities and resulting price impacts and threats to security of supply.

In addition to economic risks, attempts to secure access to resources can foster insecurity and conflict (Garrett and Piccinni, 2012). Tensions can arise in connection with competing claims over resource stocks or, less directly, as a result of attempts to restrict trade flows. As the World Trade Organization notes, 'in a world where scarce natural resource endowments must be nurtured and managed with care, uncooperative trade outcomes will fuel international tension and have a deleterious effect on global welfare (WTO, 2010).

Escalating resource use also imposes an increasing burden on the environment, through impacts related to resource extraction, use and disposal. Such impacts will increase if higher prices and growing concerns over scarcity induce countries to exploit sources such as tar sands that were previously deemed uneconomic.

Clearly, growing scarcity and rising prices also create strong incentives for private and public investment in research and innovation aimed at exploiting abundant or non-depletable resources, such as wind and solar energy. Governments can augment these incentives through ecological fiscal reform — increasing the tax burden on resource use and pollution.

Innovation can also alleviate resource demands by increasing efficiency or reducing waste, although such improvements can also make products cheaper, incentivising increased consumption. For these reasons, reducing resource demand often requires a mixture of technological improvements and policy measures addressing both production and consumption in an integrated manner.

Moreover, technological innovations can also augment pressures on the environment by increasing access to non-renewable or polluting resources. For example, new sources of fossil fuels could weaken the momentum behind global efforts to boost efficiency and mitigate climate change. According to McGlade and Ekins (2015), achieving the global target of limiting

Figure 7.12 EU-28 direct physical imports and exports by main material categories, 2002–2013

Source: Eurostat, 2015b.

average world temperature increases to 2 ºC above pre-industrial levels will require that a third of current world oil reserves, half of gas reserves and more than 80% of coal reserves must remain unused between 2010 and 2050. Achieving this level of restraint is likely to be difficult if new technologies mean that it remains markedly cheaper to produce energy from fossil fuels than renewable sources.

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Global megatrend 8 — Growing pressures on ecosystems

Driven by global population growth and associated demands for food and energy, as well as evolving consumption patterns, the pressure on the Earth's ecosystems is continuously increasing. Despite some positive developments, such as a recent reduction in the rates of tropical deforestation, global biodiversity loss and ecosystem degradation are projected to increase.

Climate change is expected to exacerbate this trend by altering the environmental conditions to which species are adapted. In addition, the need to shift to alternative energy sources may create challenges for global land and freshwater resources, most notably related to increased bioenergy production.

Poor people in developing countries are expected to be those most strongly affected by the projected degradation of ecosystems and their life-supporting services. Sustainable management of ecosystems and socio-economic development are thus intertwined challenges. Continuing depletion of natural capital globally would not only increase pressure on European ecosystems but also produce significant indirect effects, such as environment-induced migration.

8.1 Drivers

Population, earnings and consumption

During the last century, global population growth, increased earnings and shifting consumption patterns (see GMTs 1, 2 and 5) have resulted in steadily increasing human interventions into the natural environment. Humans harvest biomass to provide for many aspects of their existence, including essentials such as food, fuels, fibres and construction materials. The associated conversion of land has wide-ranging impacts on ecosystems and the services that they provide, including their ability to maintain a healthy, stable environment.

One way to quantify humanity's diverse demands on ecosystems is in terms of 'human appropriation of net primary production' (HANPP). Krausmann et al. (2013) estimate that humans today appropriate 25% of the Earth's primary production of biomass annually, via harvesting or burning, or as a result of land conversion. This is almost twice the rate of appropriation recorded a century ago. Humanity has, however, become more efficient in its exploitation of biomass during this period. Since 1910, the human population has quadrupled and global economic output increased by a factor of 17. Per capita HANPP thus declined from 3.9 tonnes of carbon annually in 1910 to 2.3 tonnes in 2005, due in part to a shift away from wood fuel to fossil fuels (Krausmann et al., 2013).

As illustrated in Map 8.1, human-induced land use changes, such as the conversion of forest to cropland or infrastructure, account for a major part of the annual appropriation of biomass in Africa and the Middle East, and eastern Europe, central Asia and Russia. In contrast, consumption (e.g. of crops or timber) accounts for most of the appropriation in western industrial countries and Asia.

The last 50 years have seen a doubling in global population from 3.5 to around 7 billion people (UN, 2013; GMT 1). Around two percent of the global land area is currently covered by cities and infrastructures already (UNEP, 2014). Continued urbanisation and an increasing middle class — with resource-intensive, developed-world mobility and consumption patterns — (GMT 2) might cause this number to double by 2050 (UNEP, 2014), leading to further landscape fragmentation.

Looking ahead, human pressures on ecosystems are likely to increase. Projections suggest that the global population will expand by 40% in the next 40 years, from around 7 billion today to around 9.6 billion (UN, 2013; GMT 1). Pressures on natural resources are likely to intensify, particularly in regions where high population growth rates coincide with a high and direct dependence on natural capital for economic development (OECD, 2012), such as in sub-Saharan Africa or parts of south-east Asia.

Economic growth is likely to augment demand for natural resources. Per capita economic output is projected to triple by 2050 (OECD, 2013; GMT 5), bringing changes in consumption patterns including a shift to increased meat consumption, which is comparatively resource intensive (UNEP, 2012).

The impacts of such a shift on ecosystems could be considerable. For example, increased global demand for meat has been identified as the main driver of deforestation in the Amazon since the early 1990s (Zaks et al., 2009).

Food and bioenergy

Dietary changes might override population growth as the major driver of global demand for land in the near future (Kastner et al., 2012). Meat-based food requires about five times as much land per unit of nutritional value as its plant-based equivalent (UNEP, 2009), and also has a higher water footprint which is, on average, 20 times higher for beef than for cereals (Mennonen and Hoekstra, 2010).

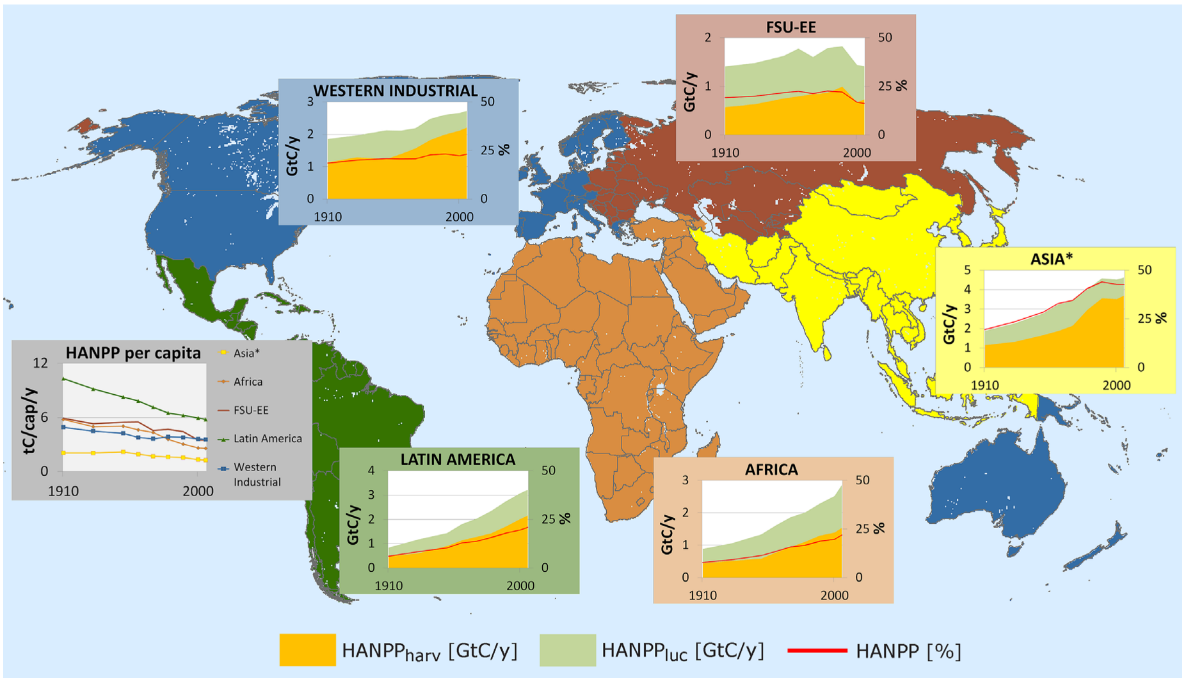
Over the last 50 years, global per capita annual consumption of meat has almost doubled, increasing from around 23 kg per person to some 42 kg (see black line in Figure 8.1). Among the ten most populous world regions or countries, the United States has by far the highest per capita meat consumption, although consumption has declined slightly in recent years.

China and Brazil recorded strong increases in meat consumption in the last 20–30 years, with Brazil recently reaching the European per capita level. In contrast, other populous Asian countries such as India, Bangladesh, Pakistan and Indonesia, as well as the most populous African country, Nigeria, still remain at relatively low meat consumption rates.

The United Nation's Food and Agriculture Organization (FAO) estimates that by 2050 agricultural production (including all crop and livestock products) will grow by about 60%. Increasing wealth is projected to further boost annual demand for meat products by 76% to 455 million tonnes, although a decline in annual growth rates is anticipated over time as more countries attain high per capita levels of meat consumption. The FAO likewise projects that global cereal production will increase by 46% in 2050, relative to output in 2005 (FAO, 2012).

Increases in crop yields due to efficiency gains are unlikely to compensate for the growing demand for both plant- and animal-based food. This could lead to a large-scale expansion of cropland, mostly at the expense of forest and grassland ecosystems, of

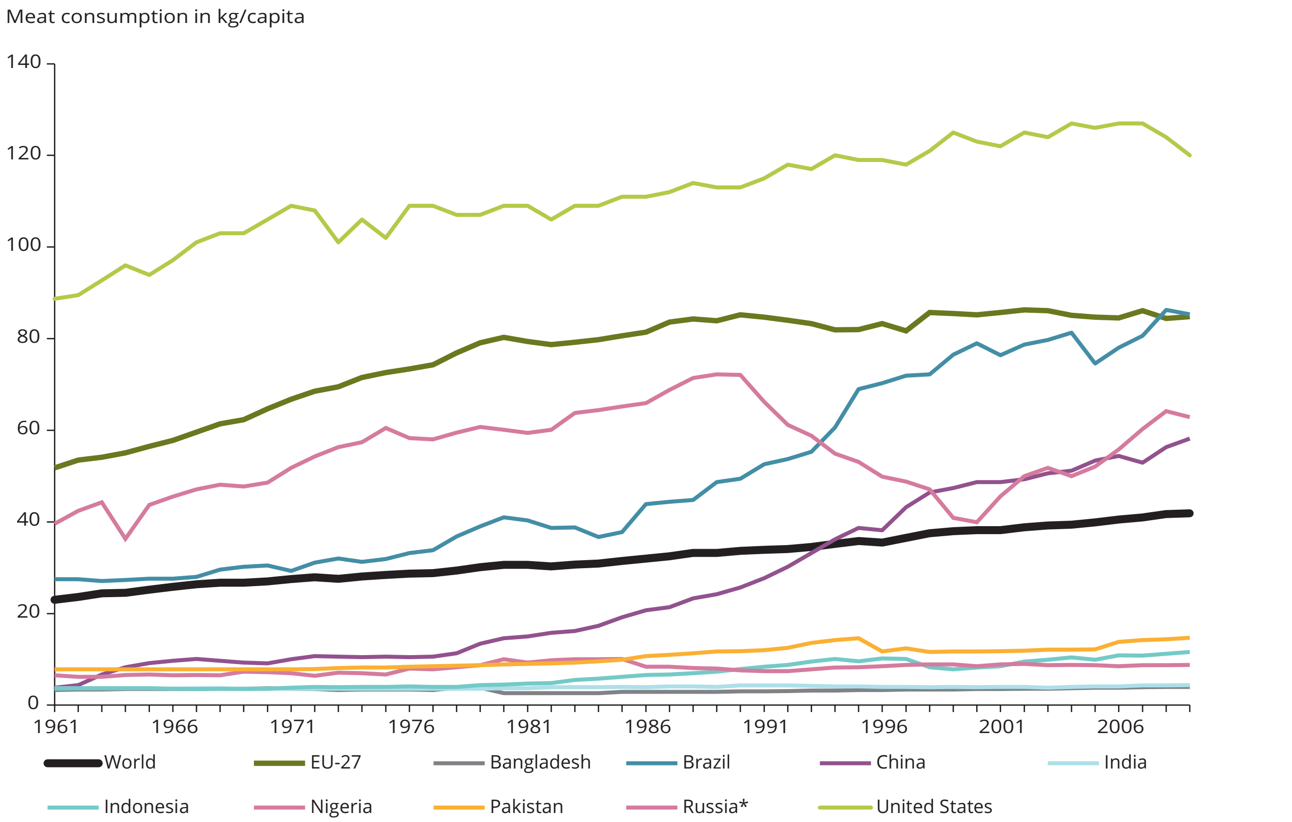
Map 8.1 Human appropriation of net primary production, 1910–2005



Note: HANPP is 'human appropriation of net primary production'. Net primary production is quantified in terms of the total carbon produced annually by plant growth. $HANPP_{harv}$ refers to gigatonnes of carbon in biomass harvested or consumed per year, including e.g. crops/food, timber, forest slash, forages consumed by livestock. $HANPP_{luc}$ refers to losses of carbon stock in biomass (gigatonnes per year) due to human-induced land use change, such as the conversion of forest to cropland or infrastructure.

Source: Krausmann et al., 2013.

Figure 8.1 Meat consumption in the world's most populous regions and countries, 1961–2009



Note: * Data prior to 1992 refer to the Union of Soviet Socialist Republics (USSR).

The figure represents the ten most populous world regions/countries, which account for more than 65% of the total world population (in 2012).

Source: FAO, 2013.

120–500 Mha (million hectares) by 2050 on top of the current 1 500 Mha of global cropland – 10% of the global land area (UNEP, 2014). Furthermore, if loss of productive land to severe soil degradation and conversion to built-up areas is taken into account, cropland expansion could reach 850 Mha by 2050 (UNEP, 2014). In addition, climate change is projected to have a detrimental effect on crop yields, particularly in regions such as sub-Saharan Africa (see Box 8.1).

Pressures on terrestrial ecosystems may be aggravated by a rapid expansion in land allocated to cultivating bioenergy crops, as a means of reducing dependence on fossil fuels (see GMT 7). In addition to potentially increasing food prices, biofuels generated from food crops such as grains, sugar cane and vegetable oils can also have significant ecological impacts. For example, they have been linked to deforestation (Box 8.2) and other land conversions at the expense of natural areas.

Bioenergy crops can also contribute to freshwater scarcity. One study estimates that the global water footprint associated with cultivation of bioenergy crops (i.e. direct and indirect water use across the entire supply chain) will increase ten-fold in the period 2005–2030 (Gerbens-Leenes et al., 2012). Mitigating associated pressures on ecosystems will depend in part on the technological and commercial emergence of bioenergy produced from residues of agriculture and forestry that do not require additional land (UNEP, 2012).

Competition for land and water

Growing global competition for scarce land resources and related concerns about food and energy security are apparent in the number of large-scale transnational acquisitions of land during recent years, mostly in developing countries. This phenomenon, sometimes referred to as 'land grabbing', has increased rapidly. Between 2005 and 2009, global acquisitions totalled some 470 000 km² (Rulli et al., 2013) which approximately equals the size of Sweden. As a consequence, large-scale commercial farming

Box 8.1 Food security in sub-Saharan Africa and potential climate change impacts

In coming decades, rapid population growth is expected to boost demand for food in many of the world's poorest regions, necessitating the allocation of more land to food production. At the same time, agricultural output in some of these regions, notably sub-Saharan Africa, may be severely impacted by increased temperatures and changing precipitation patterns. Assuming an increase in the global average temperature of 4 °C or more by the end of the 21st century, results from 14 different global climate models suggest substantial decreases in yields for some of the most important crops in sub-Saharan Africa. Average maize yields could decline by 24% from the 2000s to the 2090s, bean yields by 71% and forage grass yields by 7% (Thornton et al., 2011). Climate change thus may pose a serious challenge to food security.

Box 8.2 Oilcrops and deforestation

Rapid expansion of oil palm plantations is considered to be a key driver of rain forest destruction in south-east Asia. In that region, the area under oilcrop cultivation increased by almost 70% between 2000 and 2009, rising from 4.2 to 7.1 million hectares.

Globally, demand for oilcrops may rise by 89% in the period to 2050 (FAO, 2012b), with Indonesian production potentially meeting a large share of this increase. The Indonesian government expects to expand the area devoted to palm oil plantations from around 6 million hectares in 2008 to 20 million hectares in 2030, mostly at the expense of forest (UNEP, 2009). The development is triggered by increasing demands for consumer goods in China and India, and growing demand for biofuels in Europe and elsewhere (UNEP, 2012).

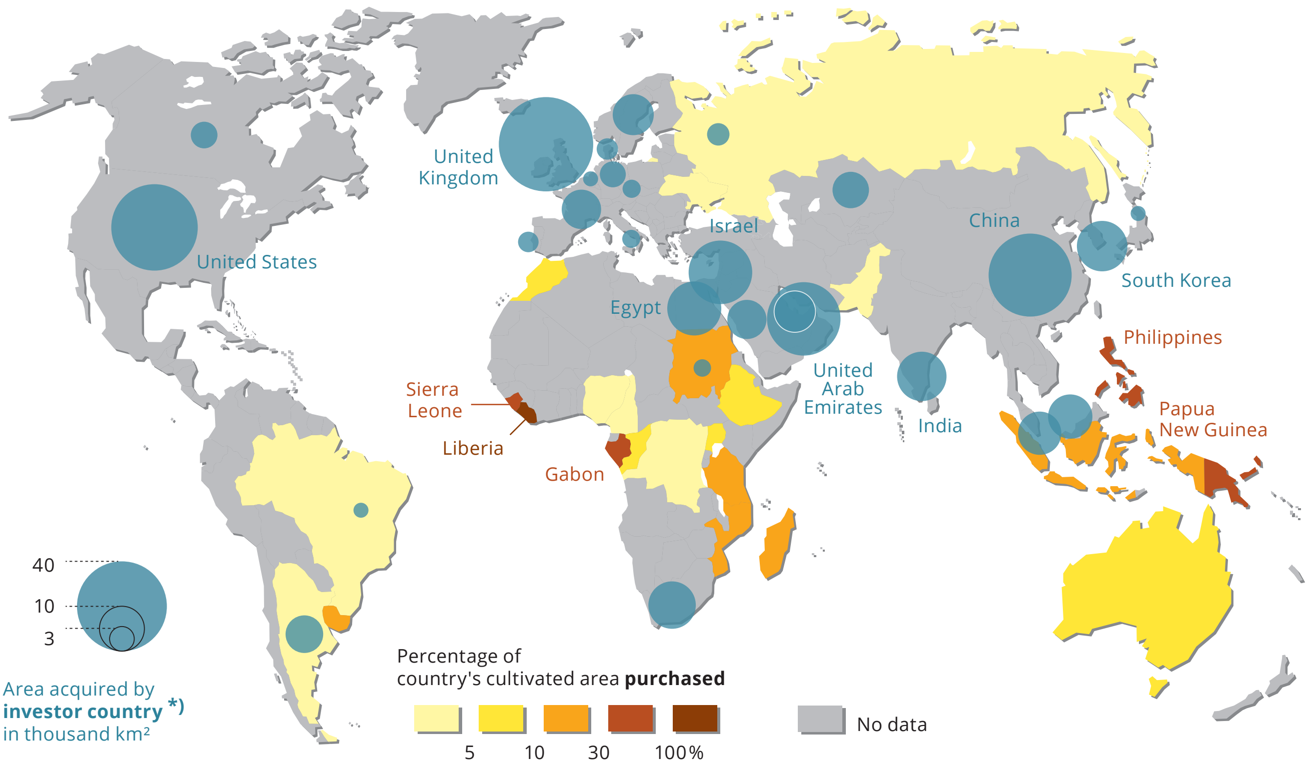
is expanding at the expense of smallholder farmers' access to land and water.

Africa and Asia account for 47% and 33% of the land area 'grabbed' globally. In some African countries, such as Liberia and Gabon, close to 100% of the cultivated land has been acquired through such transactions. Many of the corporations and governments responsible for 'grabbing' the land are from Europe and the Middle East, as well as North America and south-east Asia (Map 8.2).

A key motive for land grabbing, particularly for countries in arid regions, is the goal of securing access to the freshwater resources available there (Rulli et al., 2013). Like land grabbing, this process (sometimes termed 'water grabbing') reflects growing concerns about access to essential resources. In coming decades, the combined effects of population growth, associated food demand and climate change are expected to create significant threats to the availability of freshwater (Murray et al., 2012). A review of 405 of the world's major river basins found that 201 (containing 2.7 billion people) currently face water scarcity in at least one month per year (Hoekstra et al., 2012). Moreover, the arid regions in north Africa and the Middle East that were not part of that analysis.

Scenarios on how to meet the world's food demand in 2050 suggest that even if water use is made much more efficient, the absolute agricultural intensification needed could lead to severe water stress in many world regions (Pfister et al., 2011). This implies a threat to both human water security and to the functioning of ecosystems, including their capacity to provide essential services. Already today, habitats associated with more than half of the global runoff to the oceans are moderately to highly threatened by water shortages (Vörösmarty et al., 2010).

Map 8.2 Transnational land acquisitions, 2005–2009



*) Acquired areas over one thousand km^2 only

Note: Transnational land acquisitions refer to the procedure of acquiring land (and freshwater) resources in foreign countries. It is often called 'land grabbing'. Most commonly, investors or investing countries are located in the developed world, while the 'grabbed' land is usually in developing countries. The term 'land grabbing' has been used by the critical press (e.g. The Economist, 2009) and non-governmental organisations for the recent unprecedented increases in transnational land acquisitions.

Source: Adapted from Rulli et al., 2013.

8.2 Trends

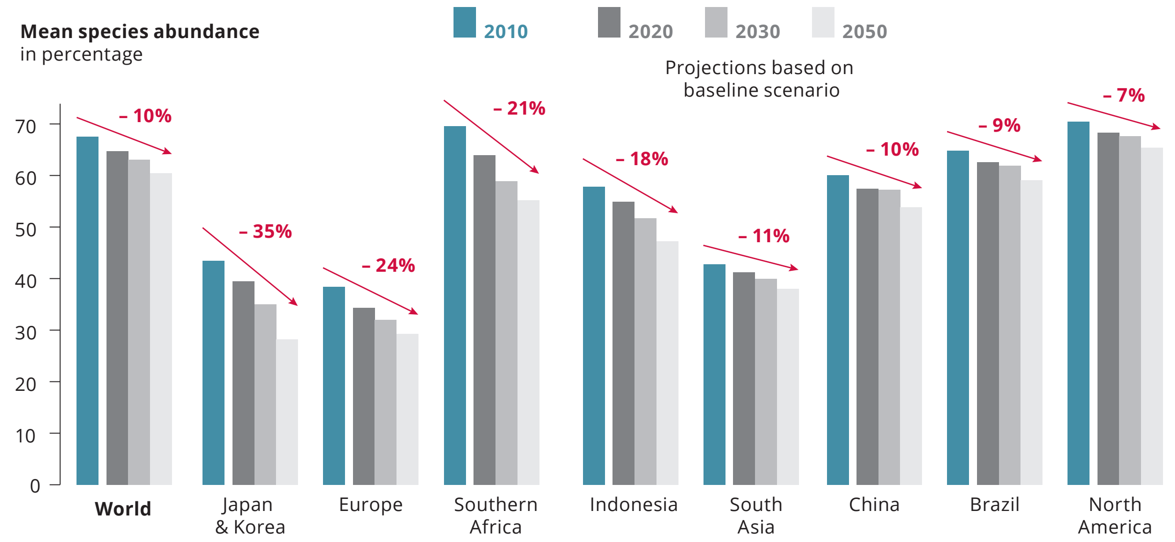
Terrestrial biodiversity

According to OECD projections (2012), human interventions into the natural environment will continue depleting biodiversity in coming decades (Figure 8.2) due to a range of pressures including climate change, forestry, development of infrastructure and agriculture (Figure 8.3). Towards the mid-21st century, climate change, forestry and bioenergy are expected to gain in significance as drivers of biodiversity loss (CBD, 2010; OECD, 2012).

In a business-as-usual scenario, global terrestrial biodiversity measured as mean species abundance (MSA) is projected to decline further to around 60% of the level that potential natural vegetation could support by 2050 (Figure 8.2). Particularly significant losses may occur in Japan and Korea (with a decrease of 36% relative to the 2010 level), Europe (24%), southern Africa (20%), and Indonesia (17%).

These estimates may be conservative, as they exclude two important concerns: risks associated with transgressing possible ecosystem thresholds (see Box 8.3) and the increasing spread of invasive alien species. Whether dispersed intentionally or unintentionally by global travel and trade, invasive alien species pose a serious threat to native biodiversity and can seriously distort ecosystems that they newly inhabit (Butchart et al., 2010). Climate change is expected to further aggravate the spread of invasive species, particularly aquatic and terrestrial invertebrates (Bellard et al., 2013).

Figure 8.2 Terrestrial mean species abundance, globally and for selected world regions, 2010–2050

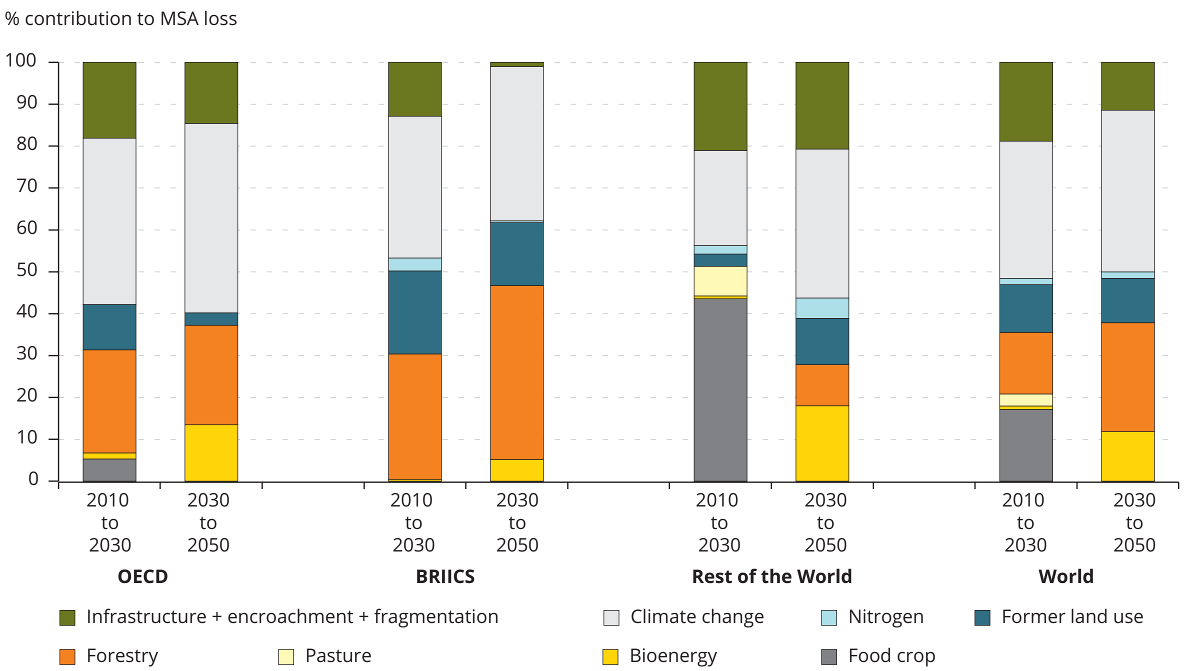


Note: 'Mean species abundance' (MSA) is a measure of how close an ecosystem is to its natural state. It is defined as the mean abundance of original species in an area relative to the abundance in an undisturbed situation. A rating of 100% implies that the biodiversity matches that in the natural situation. An MSA of 0% means that there are no original species remaining in the ecosystem.

Europe refers to the EU-27 plus Iceland, Liechtenstein, Norway, and Switzerland; Southern Africa refers to Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe; South Asia refers to Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka.

Source: OECD, 2012 (output from IMAGE model).

Figure 8.3 Share of different pressures on future global terrestrial biodiversity loss



Note: The numbers represent relative contributions to further (additional) biodiversity loss projected for the two time periods (2010–2030 and 2030–2050). As such, they do not explain losses incurred prior to 2010.
The contribution of 'food crop' (agricultural land) depends on the assumptions regarding future land conversions. The values presented here are based on an assumption of no further increase in agricultural land after 2030. Some other studies (e.g. PBL, 2012) assume that agricultural expansion will continue after 2030. As a result, they project 'food crop' continuing to make a significant contribution to biodiversity loss in the period 2030–2050. 'BRIICS' denotes Brazil, Russia, India, Indonesia, China and South Africa.

Source: OECD, 2012 (output from IMAGE model).

Box 8.3 Environmental thresholds and tipping points

There is evidence that ecosystems may need to maintain a minimum quality (e.g. in terms of the abundance and diversity of species) in order to functioning effectively and deliver many important ecosystem services. Below critical thresholds, ecosystems may reach a tipping point and may suddenly switch in character, no longer providing the same kind, or level, of ecosystem service (Barnosky et al., 2012).

Thresholds, amplifying feedbacks and time-lag effects leading to 'tipping points' are considered widespread and make the impacts of global change on biodiversity hard to predict and difficult to control once they begin. Some studies even suggest that a planetary-scale tipping point (i.e. radical changes in the global ecosystem as a whole) might be approaching (Barnosky et al., 2012).

Amazonian forest dieback

Research shows that complex interactions between deforestation, fire and climate change in the Amazon basin could push ecosystems to tipping points. This could result in widespread Amazonian forest dieback over coming decades, through a self-perpetuating cycle of more frequent fires and intense droughts leading to a shift to savannah-like vegetation (Leadley et al., 2010). The probability associated with such scenarios varies from moderate to high depending on whether the projected temperature increase is less or greater than 3 °C.

The potential implications of widespread dieback would be enormous. Regional effects would include significant reductions in rainfall over large areas of Latin America and beyond. Mass extinctions and reductions in species abundance would have large cultural impacts and greatly reduce many ecosystem services. Global scale impacts would include a reduced carbon sink, increased carbon emissions, and the massive loss of biodiversity due to the exceptionally high species diversity in the Amazon (Leadley et al., 2010).

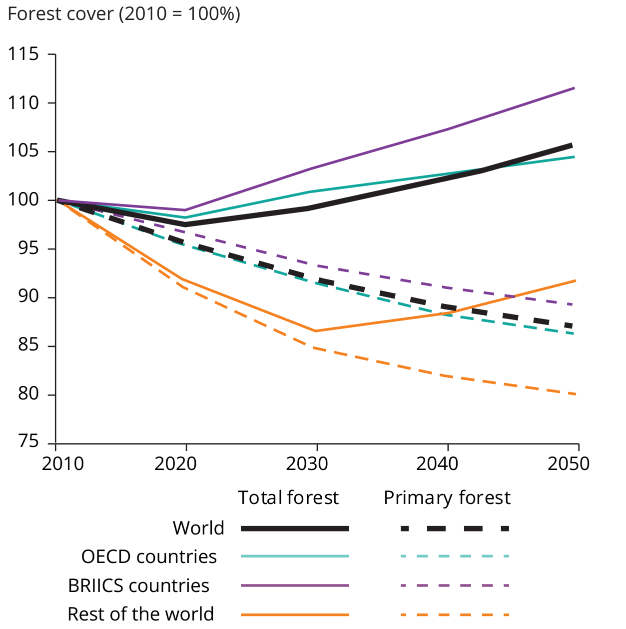
Forests

The multiple competing demands for land have led to alarming rates of (tropical) deforestation during recent decades. While aggregate tropical deforestation remains high, some regions or countries, such as Brazil, have slowed their rates of forest loss. Mainly due to reforestation and afforestation in developed countries in temperate areas or in emerging economies, some models project global net forest loss to halt after 2020 and begin to recover thereafter (Figure 8.4).

The projected recovery largely reflects increases in the area of plantation forest. While plantations can provide ecosystem services such as provisioning timber, carbon sequestration and soil stabilisation, they fall short of primary forests in delivering other essential services such as supporting global biodiversity and genetic resources, and plant pollination. In contrast to plantations, primary forests are projected to decrease steadily up to 2050. The regions of most concern are Africa, Latin America and the Caribbean (which makes up part of the 'rest of the world' in Figure 8.4), and South East Asia (Miettinen et al., 2011; UNEP, 2012)

In addition to human encroachments, climate change may also be altering the remaining tropical forests. For example, Scholz and Vergara (2010) calculate that, even without direct human clearance of forest areas, climate change could reduce the extent of the Amazon biome by one third.

Figure 8.4 Projected change in global forest area, 2010–2050



Note: 'BRIICS' denotes Brazil, Russia, India, Indonesia, China and South Africa.

Source: OECD, 2012 (output from IMAGE model).

Drylands and wetlands

In addition to forests, two types of ecosystems have been identified as particularly threatened by depletion and loss of biodiversity: drylands and wetlands. Drylands cover about 40% of the Earth's surface and host about 2 billion people, mostly in developing countries. Their destruction is continuing at an alarming rate, driven by the transformation of rangeland into cultivated cropland, resulting in problems such as water stress and soil degradation. The irreversible conversion of peatland and coastal wetlands (e.g. mangroves) for agriculture, aquaculture and human infrastructure is also likely to continue at very high rates (UNEP, 2012).

Marine ecosystems

In recent decades global marine ecosystems have become increasingly threatened, which is a major concern in view of their importance to societies across the world. The estimated value of the global catch in wild fisheries in 2008 was more than USD 80 billion. The industry directly employs some 35 million people worldwide, supports the livelihoods of more than 300 million people, and provides food security for millions of coastal communities (ten Brink et al., 2012).

In 2011, some 29% of marine fish stocks were estimated as fished at a biologically unsustainable level and, therefore, overfished. In the same year, 61% were fully exploited and only 10% held potential for increased harvests (FAO, 2014). Modelling of alternative marine fisheries strategies until 2050 indicates that marine catches and stocks will decline in the world's main fishing regions unless fishing efforts are reduced (Figure 8.5). Unsustainable fishing strategies are likely to result in reduced wild catches, increasing demands for farmed fish. Such aquacultures are likely to put pressure on terrestrial ecosystems given the associated need for crop-based feed (Kram et al., 2012).

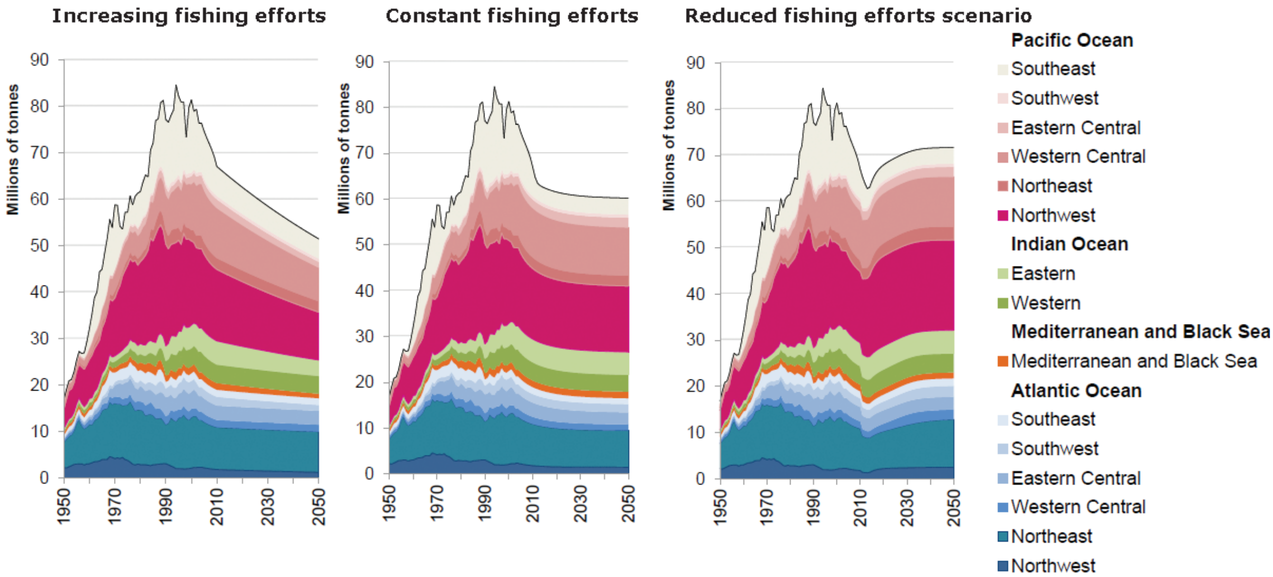
8.3 Implications

Models and scenarios in both global and regional environmental assessments indicate that biodiversity loss and ecosystem degradation will continue or accelerate under all the policy scenarios considered (Leadley et al., 2010; IEEP et al., 2009). Drivers such as population growth and increasing per capita resource use have a dominant role in shaping biodiversity outcomes, greatly outweighing the impacts of measures to protect biodiversity (IEEP et al., 2009).

Loss of ecosystem services

Ecosystem degradation not only diminishes the diversity of living organisms on Earth, but also erodes nature's ability to support human societies (TEEB, 2010). The diversity of living organisms and ecosystems

Figure 8.5 Observed and projected fish catch, 1950–2050 (three different scenarios)



Source: Kram et al., 2012.

provide people with a wide range of valuable ecosystem services, including:

- provisioning food, raw materials, medicines and genetic resources;
- regulating the environment, for example via carbon storage and sequestration, mitigating hazards from flooding and other disasters, pollinating crops and preventing erosion;
- cultural services such as providing opportunities for recreation and ecotourism, and delivering spiritual and educational values (MEA, 2005; TEEB, 2010).

The benefits of protecting ecosystems and their associated services often far outweigh the costs (Balmford et al., 2002; TEEB, 2010; Box 8.4). However, market systems seldom convey the full social and economic values of ecosystem services. As a result, market prices often incentivise unsustainable and socially undesirable decision-making about resource use and ecosystem management.

Costs of climate change mitigation and adaptation

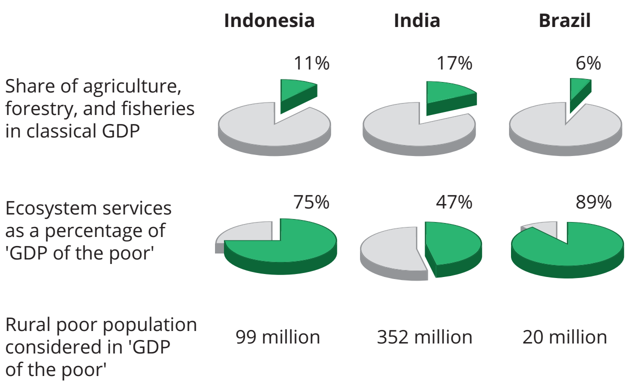
The issue of climate change provides a clear example of the potential costs of ecosystem service loss. Substantial reductions in greenhouse gas emissions are needed in the decades ahead to mitigate climate change (see GMT 9). Here, the vast amounts of carbon stored in natural ecosystems are of global importance. Currently global deforestation and forest degradation account for about 12% of global CO_2 emissions annually (van der Werf et al., 2009). Protecting natural habitats can ensure continued carbon storage if the ecosystems are managed effectively to prevent degradation. Consequently elements of an international financial mechanism to reduce greenhouse gas emissions from deforestation and forest degradation (REDD+) has been adopted by parties to the United Nations Framework Convention on Climate Change (UNFCCC, 2010).

In addition to supporting climate change mitigation by serving as stores for carbon, natural ecosystems play an important role in climate change adaptation. Ecosystem-based adaptation approaches rely on the capacity of ecosystems to buffer human communities against the adverse impacts of climate change through 'adaptation services' (IPCC, 2014; Jones et al., 2012; World Bank, 2010). Mangrove forests and coastal marshes, for example, can reduce disaster risk as they are natural buffers that protect against erosion and wave damage along exposed coastlines. As the climate is changing and temperatures increase (see GMT 9), society's need for adaptation measures, including ecosystem-based approaches, will increase (EC, 2013).

Unequal distribution of impacts across society

The projected degradation of ecosystems and their services will create many challenges for poor people across the world. Lower income groups in developing countries rely disproportionately on the sustainability of local ecosystem services to provide for their basic needs and afford health and security. It is estimated, for example, that non-market ecosystem goods and services account for 89% of the total income of the rural poor in Brazil, 75% in Indonesia and 47% in India (Figure 8.6). Sustainable management of ecosystems and socio-economic development are thus intertwined challenges (Sachs et al., 2009; TEEB, 2010; UNDP, 2011).

Figure 8.6 The rural poor's reliance on ecosystem services



Source: Adapted from TEEB, 2010.

Box 8.4 Benefits of the Natura 2000 Network

The EU's Natura 2000 network of nature protection areas currently contains more than 26 000 terrestrial and marine sites of high biodiversity value. Estimates show that the benefits that flow from Natura 2000 are in the order of EUR 200–300 billion per year, while the annual costs associated with managing and protecting the network are approximately EUR 5.8 billion. In addition, the 1.2–2.2 billion visitor days to Natura 2000 sites each year generate recreational benefits worth EUR 5–9 billion per annum (ten Brink et al., 2011).

Box 8.5 Key uncertainties regarding the future state of the global ecosystem

While there is no doubt that land, soil, freshwater, forest and marine resources are under growing pressure, the magnitude and nature of change is subject to significant uncertainty. The global ecosystem is complex and composed of components that interact in non-linear ways. A growing body of literature highlights that critical thresholds are approaching, beyond which abrupt and irreversible failures in life-support functions of the planets' natural resources may occur (see Box 8.4).

A key uncertainty is the degree of socio-economic change over the coming decades. This relates for instance to the extent of global population growth, economic development across world regions, changes in consumption patterns, or technological advances.

While the response of species and ecosystems to human-induced alterations as well as climate change impacts is still not fully understood, it is clear that current policies and strategies are not adequate to facilitate the sustainable management of the Earths' natural capital. Recent assessments suggest that current stocks might be still be sufficient to meet future demands for food, water, energy, and materials, if complex transitions towards changed value patterns and associated changes in consumption are accomplished, along with successful policy innovations.

The importance for Europe

The continuing degradation of ecosystems across the world affects Europe directly and indirectly. Diminishing global natural capital stocks may limit Europe's ability to draw on natural resources elsewhere, thereby increasing pressures on European ecosystems.

As the world's poor are most directly reliant on functioning ecosystem services, widespread ecosystem degradation can negatively influence poverty and inequality, which may fuel conflict and instability in regions with fragile governance structures. Besides the indirect impacts this may also directly lead to increased human migration flows to Europe.

Failing to take advantage of cost-effective ecosystem-based solutions for climate change mitigation in other parts of the world may impose increased costs on Europe. Moreover, if ecological systems reach critical tipping points (for example Amazon forest dieback) it could result in unprecedented global environmental, social and economic implications.

With these concerns in mind, the EU's biodiversity strategy includes a global focus. Specifically, Target 6 provides that: 'By 2020, the EU has stepped up its contribution to averting global biodiversity loss.'

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Global megatrend 9 — Increasingly severe consequences of climate change

In the past 150 years, the atmosphere and the oceans have warmed, snow and ice cover has decreased, sea levels have risen and many extreme weather and climate events have become more frequent. This warming of the global climate is unprecedented over millennia.

The global mean temperature has increased by 0.85 °C since reliable measurements began in 1880 and is projected to increase further by the end of the 21st century — by between 1.0 °C, assuming strong emissions abatement, and 3.7 °C, assuming high emissions. This warming is expected to be accompanied by a global mean sea-level rise of up to 1 m, an increase of up to 2 °C in global upper-ocean temperature, a reduction of glaciers, ice sheets and sea ice, and an increased frequency of extreme weather events, such as droughts and floods, in many regions of the world.

Increasingly severe impacts of climate change are anticipated for the Earth's natural ecosystems, including substantial losses of biodiversity and increased rates of extinction. Of particular concern are such ecosystems as coral reefs, the Amazon forest and the boreal-tundra Arctic. Furthermore, climate change is likely to slow economic growth, erode global food security, increase global inequalities and adversely affect human health. These societal impacts are anticipated to be most severe in low-income countries and low-lying coastal areas.

Projected impacts directly affecting Europe include increased frequency of drought and water restrictions, increased damage due to flooding and increased impacts on human health from extreme temperatures.

9.1 Drivers

Human influence vs. natural climate variability

Both natural and anthropogenic substances and processes can alter the Earth's energy balance and thus act as drivers of changes in the climate system. There is more scientific evidence than ever before, however, that the climatic changes observed since the industrial revolution, and in particular in the past 50 years, are largely caused by human activity. This relates primarily to greenhouse gas (GHG) emissions from fossil fuel burning, but also to other activities including agriculture, deforestation and waste management. Through these activities, atmospheric concentrations of GHGs, namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and various fluorinated gases, have increased, causing the Earth to heat up. The emission of aerosols and other human activities that change Earth's albedo ([1]) can either have a warming or cooling effect, but the magnitude of these effects is considerably less than the warming effect from GHG emissions.

Recent progress in climate science — more detailed and longer term observations in combination with improved climate models — allows for a clear attribution of the human contribution to the observed changes in many components of the climate system. Firstly, there have not been any significant long-term changes in the sun's energy output that could have contributed to the observed climatic changes (NAS and RS, 2014). Secondly, climate model simulations that purely use natural factors in their calculations cannot reproduce the increases in temperature observed in all world regions. Only when models include the substantial human influence on the atmosphere through emissions are the resulting simulations consistent with the observed changes. Therefore, it is extremely likely that most of the observed increase in global mean surface temperature since the mid-20th century has been caused by anthropogenic increases in GHGs. Furthermore, it is very likely that anthropogenic influence has substantially contributed to increases in upper ocean temperatures, Arctic sea-ice loss, global mean sea-level rise and changes in the frequency and intensity of temperature extremes, such as heat waves, since the mid-20th century (IPCC, 2013a).

Greenhouse gas emissions and atmospheric concentrations

Measurements of CO_2 in the atmosphere and from air trapped in ice show that atmospheric concentrations have increased by about 40% since 1800, with most

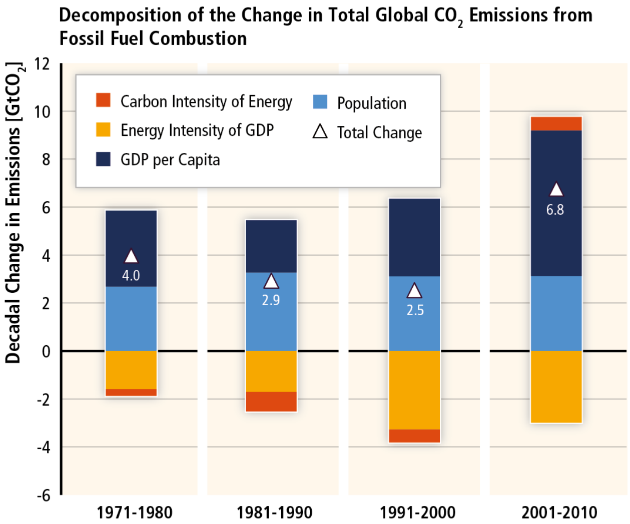
([1]) Reflectivity or reflecting power

of the increase happening since the 1970s when global energy consumption started to rise strongly. Furthermore, measurements from ice cores suggest that current CO_2 concentrations are higher than at any time in the last 800 000 years (NAS and RS, 2014).

Despite a growing number of climate mitigation measures, total global anthropogenic GHG emissions have grown continuously over the period 1970–2010, reaching their highest level in human history in the most recent decade, 2000–2010 (Figure 9.1). Of the total anthropogenic GHG emissions in 2010, CO_2 accounted for 76% (65% related to fossil fuel combustion and industrial processes and 11% related to such land use and land-use change as agriculture and deforestation), while 16% came from CH_4, 6% from N_2O oxide and 2% from fluorinated gases (IPCC, 2014b).

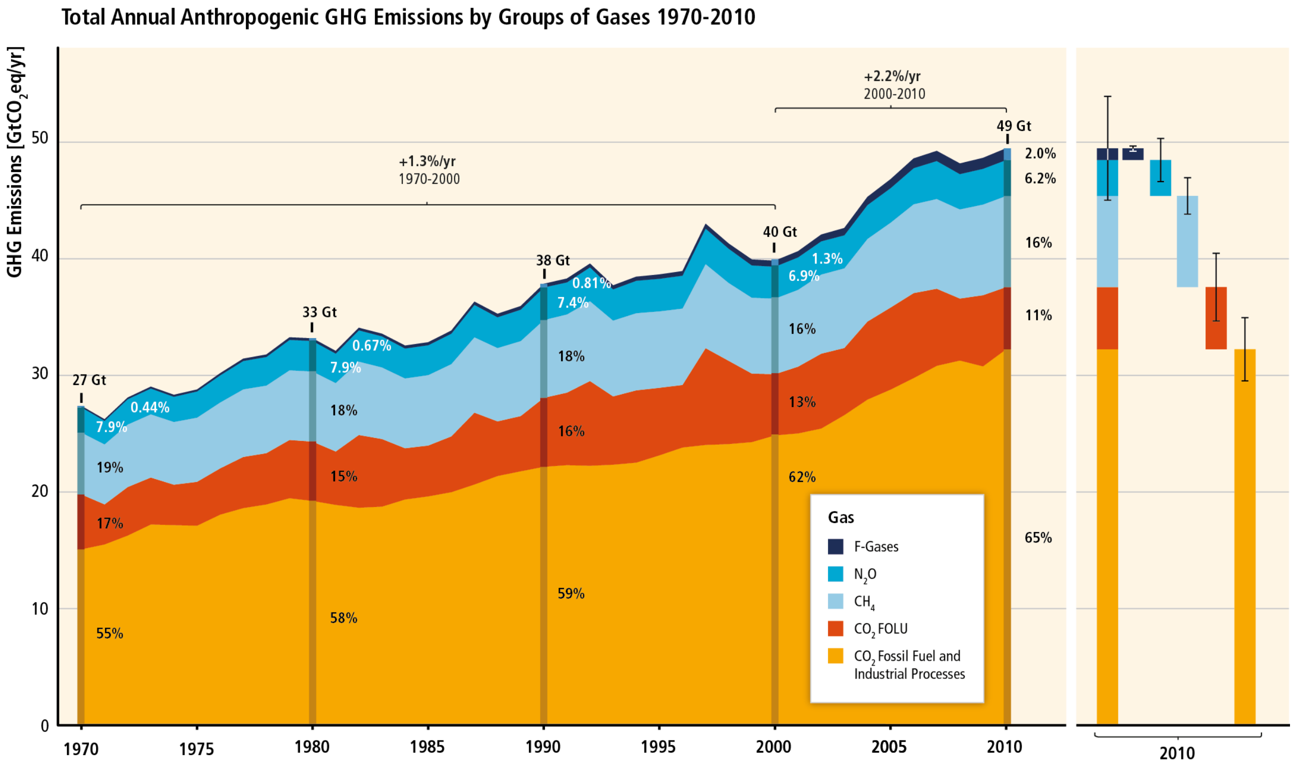
Population growth and current patterns of consumption and production are the most important drivers of increasing global CO_2 emissions, as seen from an analysis of the change in global CO_2 emissions from fossil fuel combustion for 1971–2010 (Figure 9.2). While the contribution of population growth remained at similar levels over the 40-year period, however, the contribution of current patterns of consumption and production (dark blue in Figure 9.2) rose sharply in 2001–2010. A breakdown by country income group reveals that CO_2 emissions from upper-mid-income countries, such as China and South Africa, doubled between 1990 and 2010, and have almost reached the level of high-income countries, US and most EU countries, although per person emissions are still much lower in the former group. Over the same period, lower-mid-income countries, such as India and Indonesia, also experienced substantial increases in national CO_2 emissions (Figure 9.3; IPCC, 2014b).

Figure 9.2 Change in total global CO_2 emissions from fossil fuel combustion



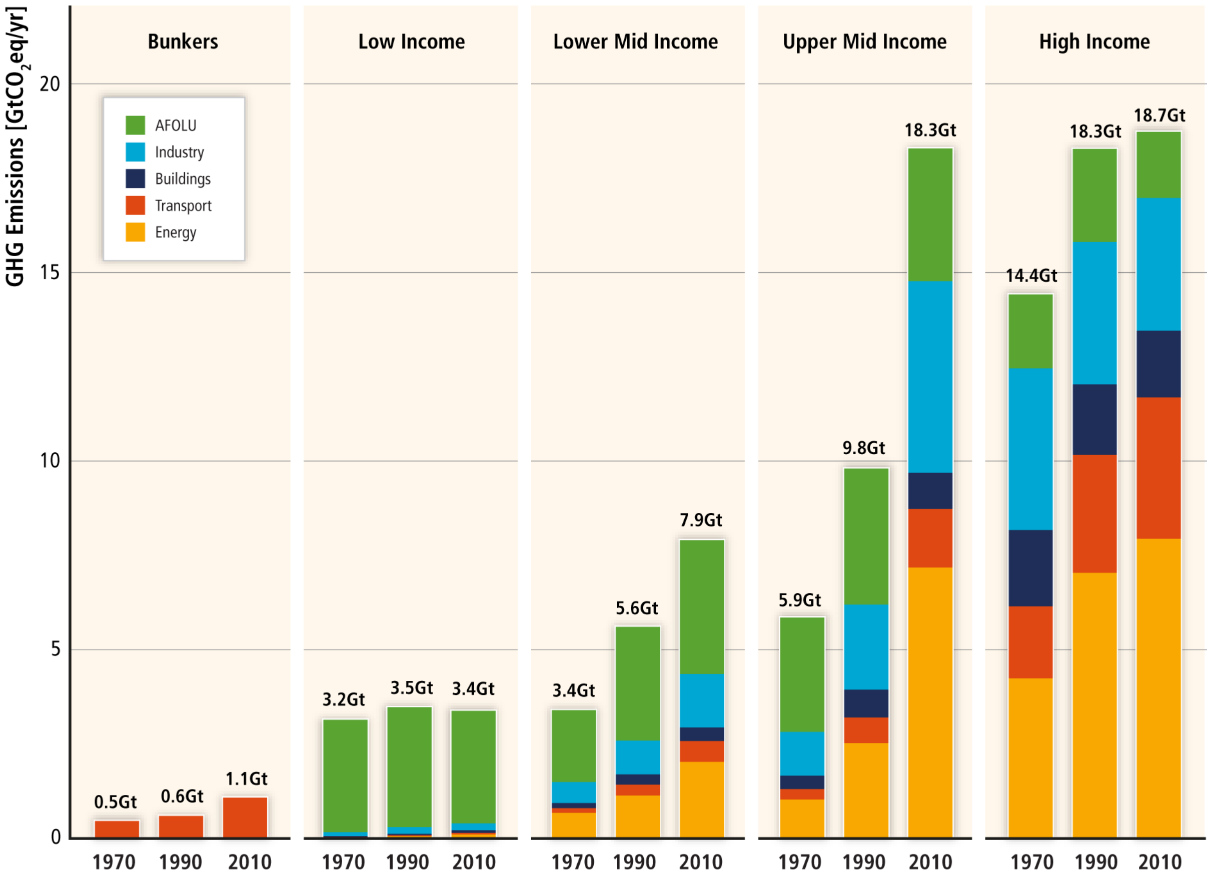
Source: IPCC, 2014b.

Figure 9.1 Total annual anthropogenic greenhouse gas emissions, 1970-2010



Source: IPCC, 2014b.

Figure 9.3 **Total anthropogenic greenhouse gas emissions in 1970, 1990 and 2010 by economic sector and country income groups**



Source: IPCC, 2014d.

9.2 Trends

Observed changes

The Earth's combined land and ocean surface temperature has warmed by 0.85 °C [0.65–1.06 °C] (2) over the period 1880–2012, the period for which reliable measurements are available. In addition, changes in extreme temperatures have been observed since the 1950s. It is very likely that the number of hot days and nights has increased over most land areas, and in Europe, Asia and Australia it is likely that the frequency of heat waves has also increased.

Substantial inter-annual to decadal variability in the rate of warming exists, due to the influence of such natural factors as the *El Niño* effect (Figure 9.4). For instance, since about 2000, global climate datasets suggest a slowdown in the rise of global mean surface temperature, and this has been linked to an intensification of wind-driven heat uptake in the Pacific Ocean (England et al., 2014) Recent research, however, suggests that the slowdown is at least partly an artefact of the exclusion of data-poor regions, in particular in Africa and around the poles, in the calculation of the global mean temperature. Indeed, a re-processed data set, which was interpolated across these data-poor regions, did not show any statistically significant slowdown in global mean surface temperature increase in the last 15 years (Cowtan and Way, 2014). In any case, short-term climate variations lasting a decade or so would not contradict the long-term warming trend (IPCC, 2013a).

The world oceans have also warmed considerably in recent decades. Ocean warming has been observed between 0–2000 m from 1957 to 2013 (Figure 9.4; Levitus et al., 2012; IPCC, 2013a).

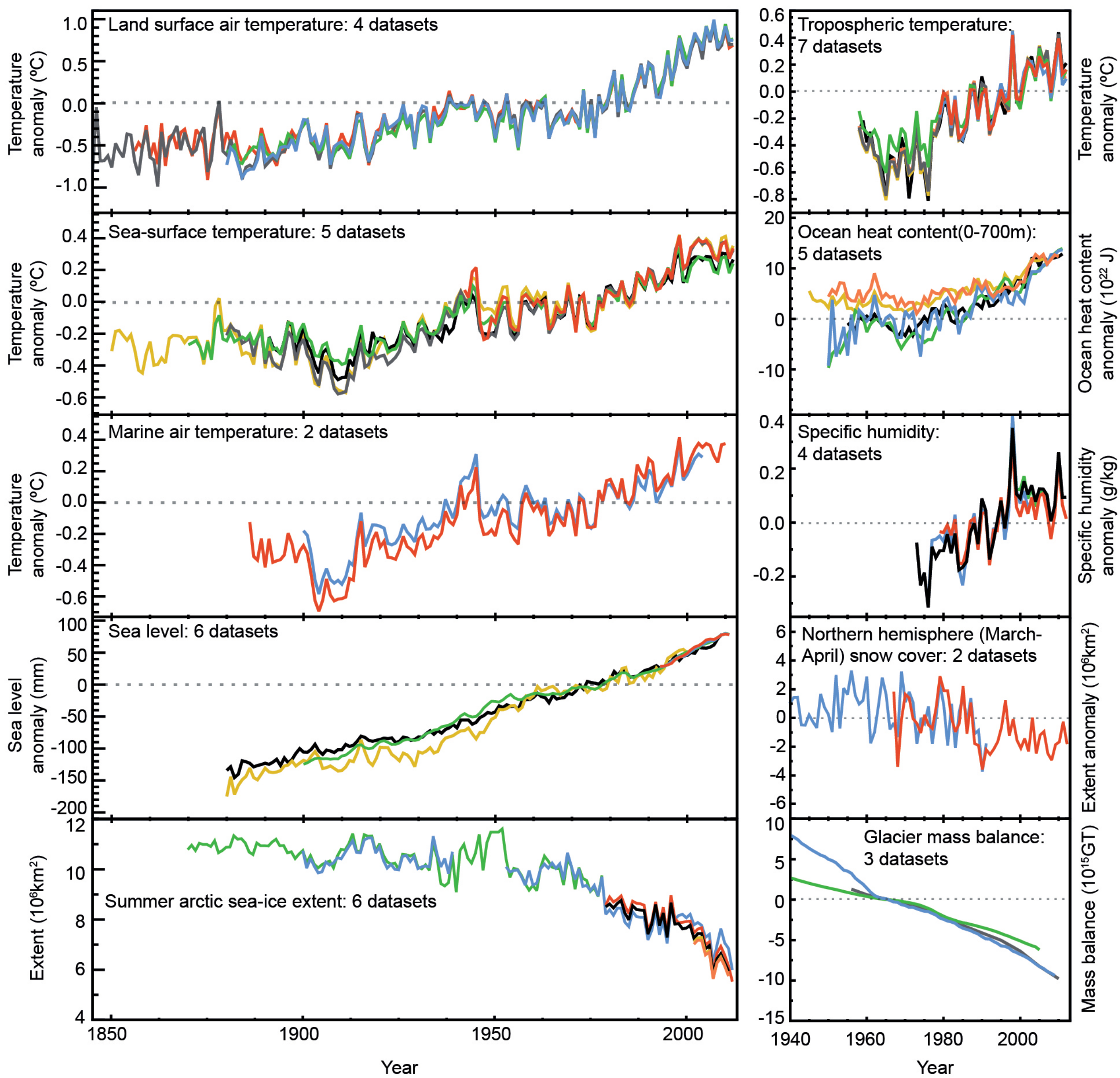
(2) Ranges reported in square brackets express uncertainty about the real value by means of the 90% confidence interval. This means that the estimated value is between the lower and upper value, with 90% likelihood.

Climate change is affecting ice and snow cover across the world. The Arctic sea ice extent at its late-summer minimum has decreased by about 40% since 1979, while northern hemisphere snow-cover extent in June has decreased by 11.7% per decade over the period 1967–2012, with substantial decreases also occurring in other months. Most of the world's glaciers are losing mass, and, indeed, the Greenland ice sheet's loss increased substantially between 2002 and 2011; both processes contributing to global sea-level rise. Furthermore, permafrost temperatures have increased in most regions since the early 1980s, leading to risks of infrastructure damage and CH_4 release (IPCC, 2013a).

Sea levels are rising faster than at any time over the past 2 000 years — they have risen by about 20 cm since 1901 due to thermal expansion of warming ocean water and the melting of glaciers and ice sheets. The rate of increase has almost doubled from 1.7 mm per year between 1901 and 2010 to 3.2 mm per year between 1993 and 2010 (Figure 9.4; IPCC, 2013a).

Observed changes in precipitation show strong regional variations. In many regions, including Europe and North America, increases in either the frequency or intensity of heavy precipitation events have been observed. In contrast, climate records show an increased frequency

Figure 9.4 Indicators of a changing global climate



Source: IPCC, 2013b.

and intensity of drought events in the Mediterranean and parts of Africa (IPCC, 2013a).

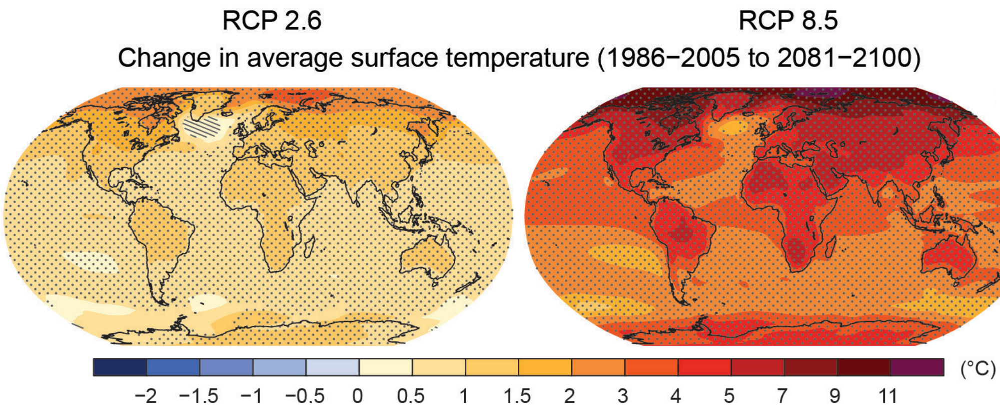
Projected changes: temperature and precipitation (*[3]*)

The warming of the Earth during the 21st century is projected to be significantly greater than during the 20th century, with the magnitude depending on the emissions scenario. Global mean temperature is projected to increase further — between 1.0 °C [0.4–1.6 °C] assuming strong emissions abatement and 2.0 °C [1.4–2.6 °C] assuming high emissions (RCP8.5) — by mid-century (2046–2065), compared to the reference period of 1986–2005. Warming by the late 21st century (2081–2100) is projected to be between 1.0 °C [0.3–1.7 °C] (RCP2.6; Figure 9.5, left) and 3.7 °C [2.6–4.8 °C] (RCP 8.5; Figure 9.5, right). In order to have a two thirds chance of keeping the global mean surface temperature rise below 2 °C compared to the pre-industrial period, the agreed target of the United Nations Framework Convention on Climate Change (UNFCCC), cumulative carbon emissions since 1870 need to be kept below 1 000 gigatonnes (GtC). More than half of this amount, 515 GtC, has already been emitted between 1870 and 2011 (IPCC, 2013a).

As temperature increases, it is very likely that the number and intensity of hot temperature extremes and heat waves will increase globally. Under the RCP8.5 scenario, heat events that currently occur every 20 years are likely to become annual or 2-yearly events in many regions by the end of the 21st century (IPCC, 2013b).

The tropical regions of Africa, South and Central America and Asia are projected to be particularly affected by increases in temperature extremes, because natural temperature variability is lower there than in other world regions. Even under a low emissions scenario, in these tropical regions an average summer at the end of this century is projected to be hotter than any summer experienced there during the 20th century (Figure 9.6, left). Under a high emissions scenario, in most world regions an average summer at the end of this century is projected to be warmer than any summer experienced during the 20th century; in most tropical regions, almost every summer at the end of this century is projected to be hotter than the warmest summer experienced during the 20th century Figure 9.6, right; Coumou and Robinson, 2013) climate models predict more substantial warming. Here we show that the multi-model mean of the CMIP5 (Coupled Model Intercomparison Project.

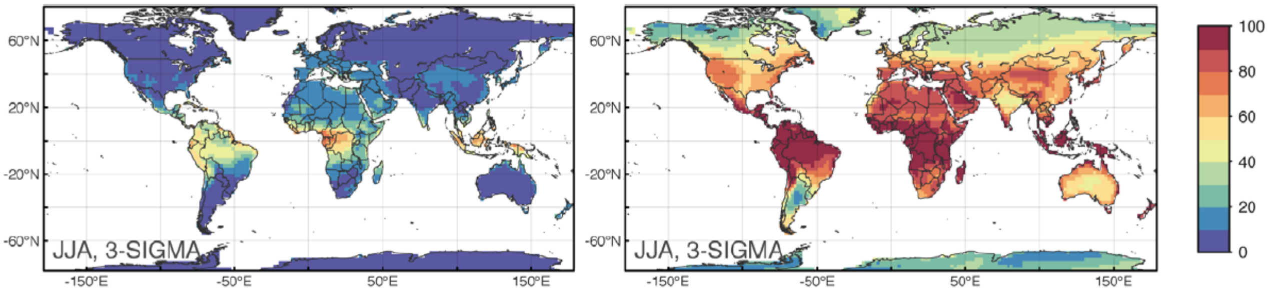
Figure 9.5 Projected changes in average temperature, 2081–2100 relative to 1986–2005 for low-emission (RCP2.6, left) and high-emission (RCP8.5; right) scenarios



Source: IPCC, 2013a.

(3) Projections of changes in the climate systems as given here are based on four so-called Representative Concentration Pathways (RCPs; van Vuuren *et al.*, 2011). The RCPs represent radiative forcing up to 2100 from different levels of emissions and atmospheric concentrations of GHGs. Technically the RCPs are forcing scenarios rather than emissions scenarios. However, this difference is significant for policy-making, as a low RCP can only be achieved by a low emissions scenario and a high RCP is always caused by a high emissions scenario. The RCPs cover a mitigation scenario leading to a very low level of radiative forcing (RCP2.6), two so-called 'stabilisation scenarios' with greater levels of GHG concentrations (RCP 4.5 and RCP 6); and a scenario with very high GHG emissions (RCP 8.5 — the scenario towards which GHG emissions are currently heading if no further abatement measures are taken). The RCPs were developed to aid climate modelling and underpin the IPCC's Fifth Assessment Report. A full description of the comprehensive set of multi-model estimates, as well as further details on the projected trajectories for the various climate components, can be found in the IPCC Fifth Assessment Report (IPCC, 2013b).

Figure 9.6 **Projected changes in hot seasonal temperature extremes over the 21st century under a low emission (RCP2.6, left) and high emission scenario (RCP8.5, right)**



Note: This assessment focusses on the occurrence of seasonal (June, July, August; corresponding to the boreal summer) hot temperate extremes. The maps show how frequent a '3-sigma summer' is projected to occur in the period 2071–2100. A 3-sigma event represents an extremely warm 'summer' that would occur only once in 370 years in the absence of climate change. In most world regions, a 3-sigma 'summer' is warmer than any summer experienced in the 20th century. For example, in regions shown in yellow, orange or red, at least every second summer by the end of the 21st century would be warmer than the warmest summer in the 20th century.

Source: Coumou and Robinson, 2013.

This warming will be accompanied by changes in precipitation, but will vary significantly between regions. Mean precipitation is likely to decrease further in such regions as the Mediterranean and northern Africa, in particular under a high-emission scenario. In contrast, more intense and frequent extreme precipitation events are very likely in most mid-latitude regions, Europe and North America, for example, and wet tropical regions (IPCC, 2013a).

Projected changes: ocean, cryosphere and sea level

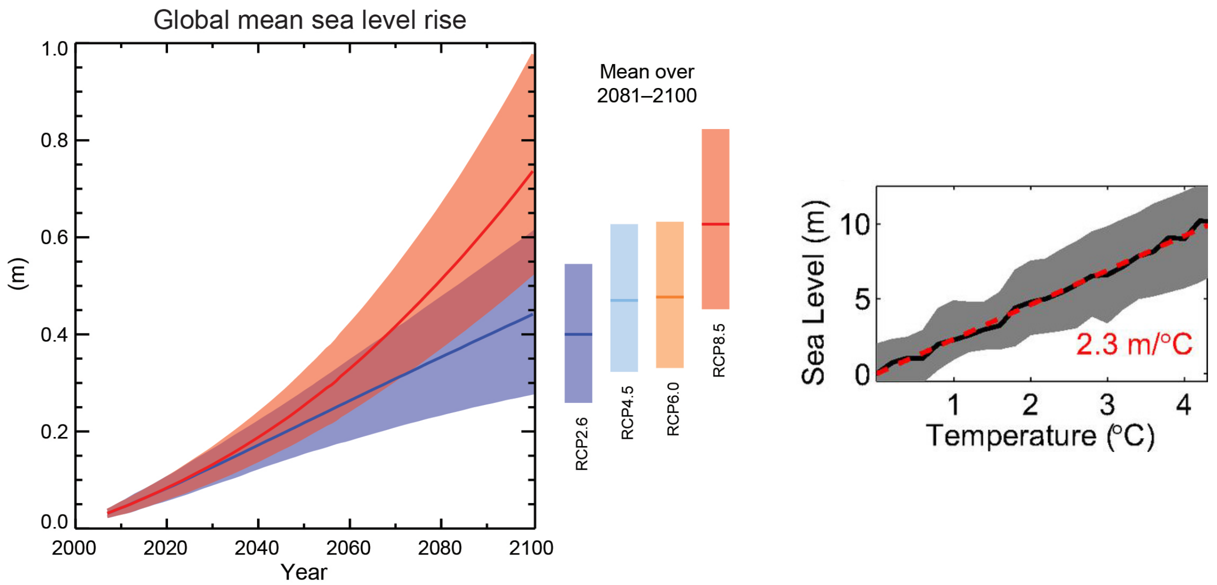
Global ocean temperature in the upper 100 m of the oceans is projected to increase by 0.6–2.0 °C by 2100, depending on the emissions scenario. Moreover, heat will penetrate from the surface to the deep ocean and affect circulation. It is very likely that the Atlantic Meridional Overturning Circulation, which includes the Gulf Stream, will weaken, with reductions of 11–34% projected by 2100 depending on the emissions scenario. However, a collapse, that would significantly alter climatic conditions in north-western Europe, is very unlikely in the 21st century (IPCC, 2013a).

Global warming will lead to further declines in ice, snow and permafrost globally. A nearly ice-free Arctic Ocean in September is likely to be a reality before mid-century under a high-emissions scenario (RCP8.5) while, under all scenarios, there will still be Arctic sea ice in winter throughout the 21st century. Moreover, by 2100 northern hemisphere snow cover is projected to be reduced by 7% (RCP2.6) to 25% (RCP8.5), while the area of near-surface permafrost (upper 3.5 m) is projected to diminish by 37% (RCP2.6) to 81% (RCP8.5; IPCC, 2013a).

Confidence in estimates of global sea-level rise has increased considerably in recent years. Global mean sea-level rise in the 21st century is projected to be greater than in the 20th century, with an additional rise by 2081–2100 of 0.26–0.55 m under a strong emissions-abatement scenario (RCP2.6) and of 0.52–0.98 m under a high emissions scenario (RCP8.5; Figure 9.7, left; IPCC, 2013b).

Sea level will continue to rise for many centuries or even millennia after the climate has stabilized due to the thermal inertia of the deep ocean and a continued melting of glaciers and ice sheets. Even a modest sustained warming of 2 °C above pre-industrial levels is estimated to cause a sea-level rise of at least 4 m over a time horizon of 2 000 years (Figure 9.7, right; Foster and Rohling, 2013; Levermann et al., 2013) global sea level is determined largely by the volume of ice stored on land, which in turn largely reflects the thermal state of the Earth system. Here we use observations from five well-studied time slices covering the last 40 My to identify a well-defined and clearly sigmoidal relationship between atmospheric CO_2 and sea level on geological (near-equilibrium. Very recent research has suggested that a collapse of the West Antarctic ice sheet is inevitable and unstoppable, which alone could cause several metres of sea-level rise over a period of several centuries to a millennium (Joughin et al., 2014; Rignot et al., 2014).

Figure 9.7 **Projected change of global mean sea level, 2000–2100 (left) and committed change in global sea level over 2 000 years per degree of warming (right)**



Sources: IPCC, 2013a; Levermann et al., 2013

9.3 Implications

Drawing on a larger scientific knowledge base than ever before, the Intergovernmental Panel on Climate Change (IPCC) concluded in its *Fifth Assessment Report* (IPCC, 2014a) that continued warming increases the likelihood for severe, pervasive and irreversible consequences in most world regions. Moreover, the IPCC provides five integrated reasons for concern, as a framework for evaluating dangerous anthropogenic interference with the climate system:

1. *Unique and threatened systems*. The number of such systems at risk of severe consequences is expected to increase already with additional warming of 1 °C. Some systems such as Arctic sea ice and coral reefs are expected to face very high risks already with an additional warming of 2 °C.

2. *Extreme weather events*. These include heat waves, extreme precipitation and coastal flooding, and are expected to become more frequent with increasing warming.

3. *Distribution of impacts*. Climate-related risks are unevenly distributed, with higher risks for disadvantaged people in countries at all income levels. The risk of further increases in global inequalities is high with additional warming of 2 °C.

4. *Global aggregate impacts*. The overall risks for the Earth's ecosystems and global economy are moderate with additional warming of 1–2 °C, but accelerate as temperatures rise further, leading to high risks at around 3 °C of additional warming.

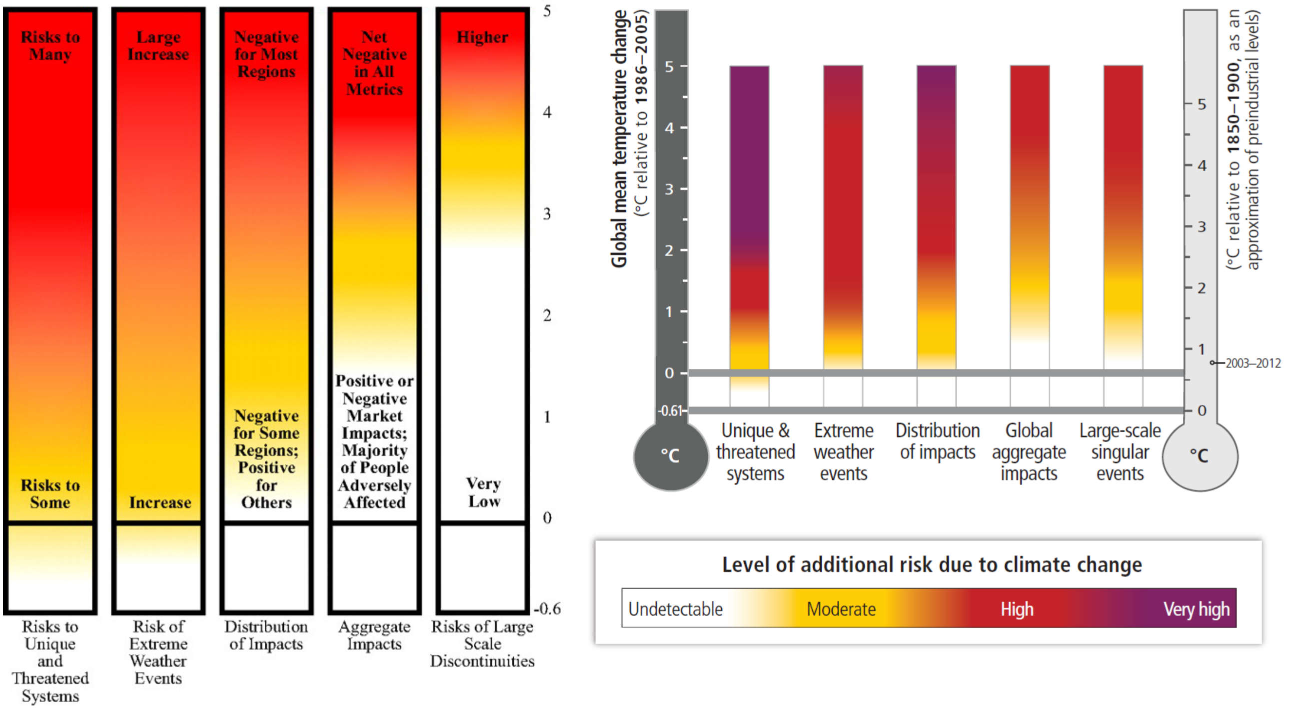
5. *Large-scale singular events.* There are increased risks of abrupt and irreversible changes that increase disproportionally as temperatures increase. These risks become high above 3 °C of additional warming (IPCC, 2014c).

The IPCC has published two assessments of these reasons for concern, its *Third* and *Fifth Assessment Reports* (IPCC, 2001, 2014c), concluding in the *Fifth Assessment* that larger risks occur at lower levels of climate change for all reasons for concern (Figure 9.8). In other words, the risks for a given level of climate change are now assessed to be more severe than previously.

Risk reduction is possible through climate-change mitigation and adaptation. Mitigation is the only way to reduce the risk of large-scale climate change, with action taken now and in the next few decades determining the severity of consequences in the second half of the 21st century and beyond. Side benefits of mitigation, however, such as the reduction of air pollution, could be felt immediately. The benefits of most adaptation actions, such as increasing resilience to reduce the severity of the consequences of climate change, are realized soon after they are taken (EEA, 2013).

Climate change mitigation and adaptation are intertwined with other aspects of sustainable development, in particular biodiversity protection and food and energy security (GMT 8). Examples include

Figure 9.8 **Changes in the 'reasons for concern' from climate change between the IPCC Third (left) and Fifth (right) Assessments**



Sources: IPCC, 2001, 2014c.

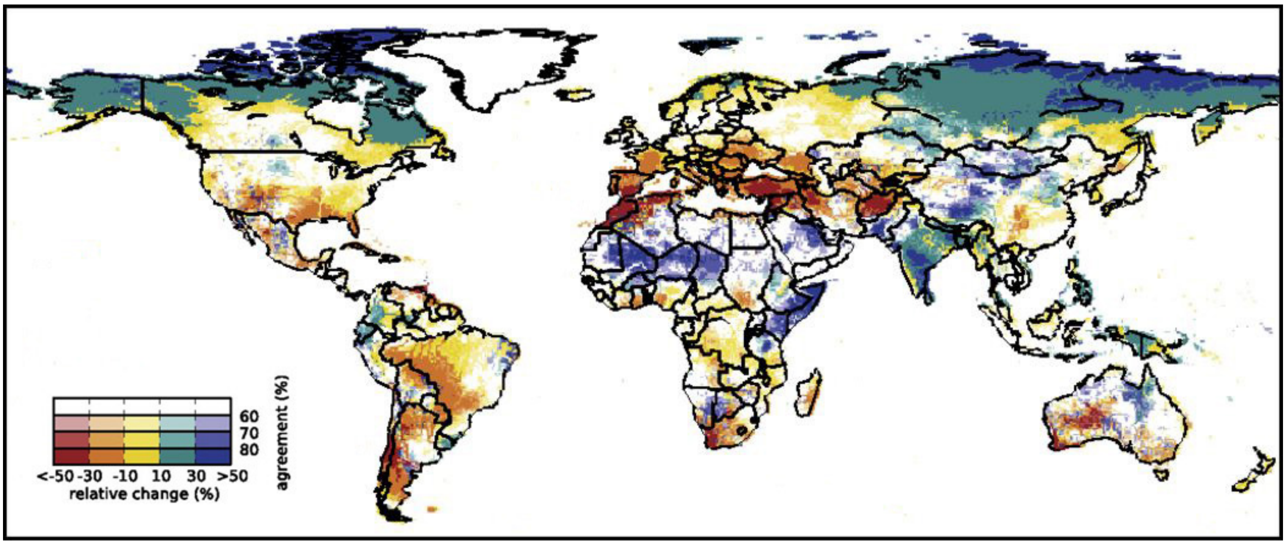
land-use conflicts and ecosystem impacts from the expansion of biofuel and hydropower production, water conflicts from expanding irrigation, and increasing energy demand from further application of sea-water desalination and air-conditioning. The development of climate mitigation and adaptation activities needs to consider these interactions in the context of a broader sustainable development policy. A recent study suggests, for example, that with rising populations (GMT 1) and consumption levels (GMTs 2, 5 & 6), there will not be enough land to simultaneously conserve all remaining natural areas, halt forest loss and switch totally to renewable energy (Kraxner et al., 2013).

Natural ecosystems and their services

Terrestrial and freshwater ecosystems are increasingly threatened under all RCP scenarios. A large share of species is very likely to face an increased risk of extinction, with associated losses of biodiversity and ecosystem services, particularly in areas where climate change acts in conjunction with other stressors such as over-exploitation, habitat destruction (GMT 8) or pollution (GMT 10). Rates of climate change expected under medium- to high-emission scenarios (RCP4.5; RCP6.0; RCP8.5) pose high risks of abrupt and irreversible regional-scale changes in the composition, structure and function of ecosystems, including vital ecosystems such as the Amazon forest and Arctic ecosystems. Climate change will also lead to increased colonization by alien plant species in Europe and other world regions. The risk of forest fires, too, will increase in almost all world regions due to warming. In some regions, including in Europe, reduced precipitation is likely to contribute to increased tree mortality and forest dieback. Furthermore, carbon stored in the terrestrial biosphere, in, for example, peatland and permafrost, will be increasingly susceptible to being lost to the atmosphere. This loss occurs predominantly as CH_4, itself a powerful GHG, thereby further exacerbating global climate change (IPCC, 2014c).

Freshwater-related risks are expected to increase significantly, in particular changes in stream flow, water temperature, and water quality. These risks include droughts and subsequent water scarcity on the one hand, and major flood events on the other. While there is still considerable uncertainty for some regions including China, south Asia and large parts of South America, there is a high degree of agreement that average annual runoff will increase at high latitudes and in the wet tropics, but decrease in most dry tropical and subtropical regions (Figure 9.9). In the latter regions, renewable surface-water and groundwater resources are projected to be reduced significantly. Many currently dry regions, such as the Mediterranean, are likely to face an increased frequency of droughts, in particular under a high-emission scenario (RCP8.5). Consequently, increased competition for water among sectors, as well

Figure 9.9 **Change of mean annual stream flow for a global mean temperature rise of 2 °C above 1980–2010 (2.7 °C above pre-industrial)**

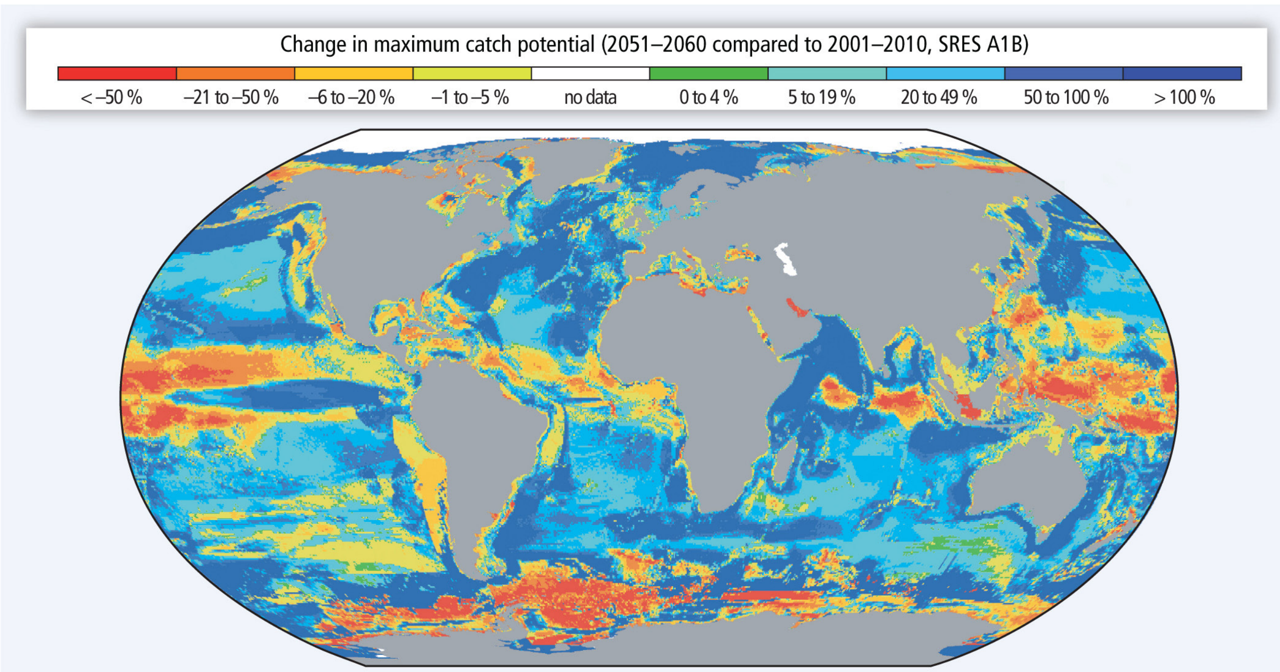


Source: Schewe et al., 2014.

as risks to drinking water quality, are projected even when conventional water treatment is applied (IPCC, 2014c).

About 27% [20–35%] of CO_2 emissions are taken up by the Earth's oceans, thereby turning them sourer (IPCC, 2013a). Marine ecosystems are projected to face substantial risks due to the combined effects of this ocean acidification, ocean warming, changes in salinity and nutrient availability in some regions, and local stressors such as pollution, eutrophication and unsustainable fishing practices (GMT 10). These factors are expected to cause a decline in global marine biodiversity and a global redistribution of marine species that would reduce of the productivity of fisheries and other ecosystem services at tropical latitudes (Figure 9.10), bringing associated adverse

Figure 9.10 **Climate change risks for fisheries: projected global redistribution of maximum catch potential of ~ 1 000 exploited fish and invertebrate species, 2001–2010 to 2051–2060**

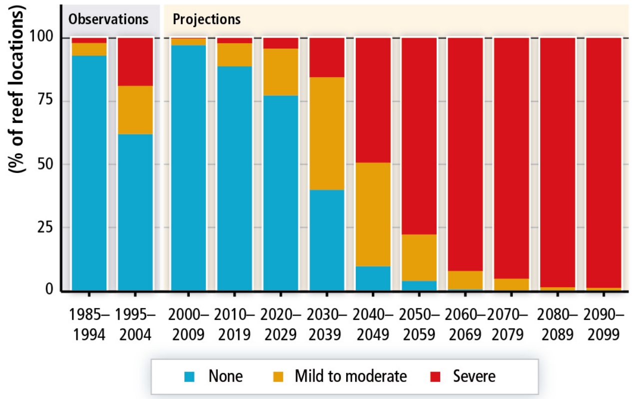


Source: IPCC, 2014c.

implications for human livelihoods. Coral reefs are likely to be particularly affected, and, indeed, the number of coral bleaching events has increased significantly in recent decades. For a medium emissions scenario, almost all coral reefs are projected to experience severe bleaching every decade from 2060 onwards (Figure 9.11), leading to widespread reef mortality, with even stronger impacts expected for high emissions scenarios (IPCC, 2014c).

Coastal ecosystems are very likely to increasingly experience adverse consequences due to the combined effects of sea-level rise, coastal erosion, ocean acidification and human pressures, such as the expansion of settlements and some coastal protection measures (IPCC, 2014c).

Figure 9.11 Observed and projected change in extent of coral bleaching events



Source: IPCC, 2014a.

Economic activities and human well-being

Many economic and leisure activities, food supply, human well-being and health are already affected and these impacts will intensify as climate change continues. Throughout the 21st century, climate change is projected to slow the rate of economic development, erode food security and increase both inequality and the displacement of people. Risks are unevenly distributed and are greater for disadvantaged people in countries regardless of their country's level of development, although the most severe impacts for economic development and livelihoods are expected in low-income developing countries, especially in Africa. In these and other regions, climate change impacts may also indirectly contribute to an increased risk of violence (IPCC, 2014c), and are expected to increasingly influence national security strategies.

Agricultural activities are significantly affected by changes in climate and CO_2 concentrations, which can lead to both adverse and beneficial impacts. Global agricultural production has experienced some regionally limited gains but mostly losses due to climate change since 1960. Yield projections suggest that local temperature increases of 2 °C or more will have negative impacts on yields of wheat, rice and maize in most temperate and tropical regions.

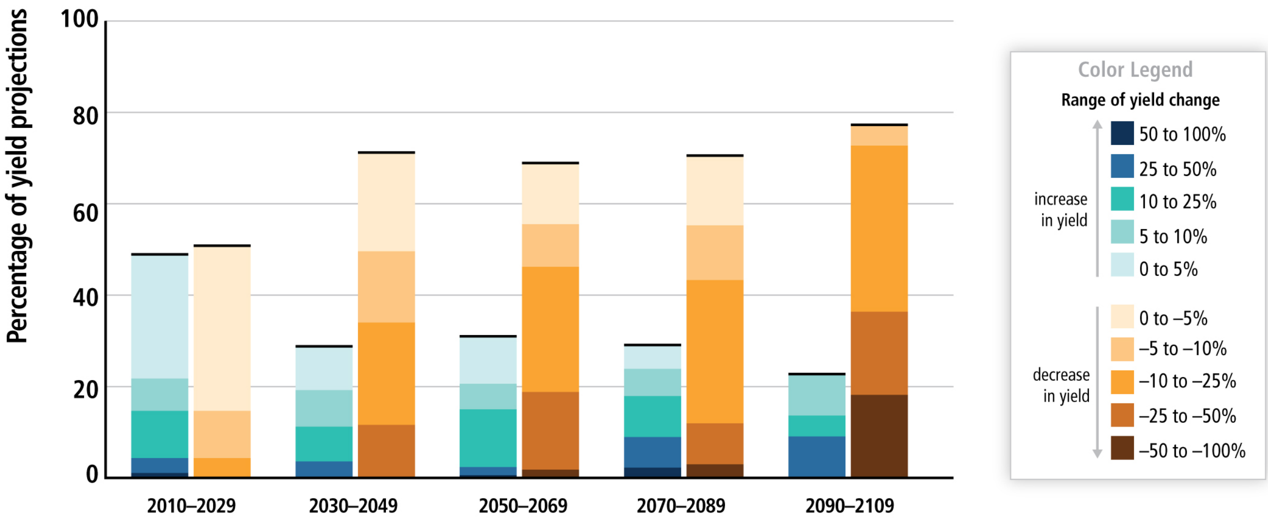
The overall impact on the global food system is expected to be adverse and continue to deteriorate throughout the 21st century (Figure 9.12). Strong global temperature increases of 4 °C or more towards the end of the 21st century, combined with increased food demand due to population growth, would pose significant risks for regional and global food security. Agricultural productivity is particularly threatened in low-latitude areas and in semi-arid regions where currently irrigated areas are projected to face an increased demand for water. Agriculture in the Mediterranean region faces a double stress — from increasing water demand and decreasing water availability (IPCC, 2014c). Increases in atmospheric CO_2 concentrations also directly impact plant growth — elevated levels can increase plant photosynthesis but decrease food quality by inhibiting nitrogen uptake (Bloom et al., 2014).

Human settlements, water supply, industrial facilities and other infrastructure in coastal regions across the world are threatened by sea-level rise. Large coastal cities, settlements in river deltas and on low-lying islands in developing countries are particularly vulnerable — flood losses in 136 major coastal cities around the globe could amount to USD1 trillion or more annually by 2050 unless protection is upgraded (Hallegatte et al., 2013).

Extreme precipitation events are projected to increase further in most regions, including Europe. As a result, more flood damage is considered a key climate-related risk for many cities, also for cities not located in coastal regions. Riverine and urban flooding is of particular concern in many parts of Europe, Australia, North and South America, and Asia. At the other extreme, increased drought stress, associated water restrictions and wildfires are expected in southern Europe, Australia, and parts of Africa, North America and Asia. Recent research suggests that many countries are highly vulnerable financially to extreme weather events and would be unable to cope with their costs without international assistance (Box 9.1).

Human health is expected to be increasingly affected by climate change. There is clear evidence of increased heat-related mortality in many regions over the past decades. Heat stress and related human mortality are of particular concern for urban populations; they have been identified as key climate risks for large parts of Europe as well as parts of Asia and North America. The combination of high temperatures and humidity is expected to compromise

Figure 9.12 **Change in global aggregate crop yields due to climate change considering both low-emission and high-emission scenarios**



Source: IPCC, 2014c.

normal human activity during some months in many parts of the world by the end of the 21st century under a high emission scenario (RCP8.5). Climate change throughout the 21st century is also expected to increase ill health through greater risks of food- and water-borne diseases and the spread of such vector-borne diseases as tick-borne encephalitis and dengue fever. Developing countries are the most vulnerable but Europe is also likely to be increasingly affected (EEA, 2012; IPCC, 2014c; Bouzid et al., 2014).

Box 9.1 **Can vulnerable countries cope with extreme weather event damage?**

The first comprehensive global assessment of public sector costs for dealing with climate-related disaster risk investigated the ability of countries to respond to extreme weather events (Hochrainer-Stigler et al., 2014). The study considered storms, flood and drought events with different likelihoods of occurrence and potential associated costs of recovery in 161 countries around the world. Extreme events that occur relatively often tend to be less destructive, and therefore less costly to recover from, compared with less frequent ones.

The study first calculated the direct risks and public-sector liability for losses. It also calculated the financial vulnerability of the 161 countries and identified the resource gap — between their available funding and the amount required for recovery from events with different recurrence intervals.

The study found that many countries appear fiscally vulnerable and require financial assistance from the donor community to bolster their resilience. According to the estimates, developed countries are generally able to cope with the costs of less destructive events but experience resource gaps for more destructive, less frequent ones. However, 70 out of the 161 countries have resource gaps already for events occurring every 50 years. Fifty-seven of these would be in need of financial assistance already for events occurring every 30 years. The countries with high financial vulnerability are mainly in Africa, the Middle East, and in South and Latin America.

These results are based on current extreme events and assume no further adaptation measures other than those currently in place. However, considering the projected increase in frequency and severity of extreme events throughout the 21st century, costs are expected to rise.

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Global megatrend 10 — Increasing environmental pollution

Across the world, ecosystems are today exposed to critical levels of pollution in increasingly complex mixtures. Human activities (such as energy generation and agriculture), global population growth and changing consumption patterns are the key drivers behind this growing environmental burden.

Historic trends and business-as-usual projections suggest that in the coming decades pollution may reduce in some regions but could increase markedly in others. For example, emissions to air of nitrogen oxides, sulphur and tropospheric ozone are projected to decrease in Europe and North America but may increase significantly in Asia. The trends in Asia could, however, impact other world regions — including Europe — via long-range transport of pollutants.

Nutrient effluents from agriculture and wastewater into the soil and oceans are projected to increase in most world regions, driven in part by the demand for increased agricultural production. The increasing complexity of chemical mixtures released into the environment is also a concern globally.

There is clear evidence of the detrimental effects of pollution on the natural environment, ecosystem services and biodiversity, for example through processes such as eutrophication and acidification. The number of marine dead zones due to eutrophication has increased markedly in recent years. Modelling suggests that, depending on crop type, between 3% and 12% of annual crop production is lost due to elevated ozone levels. Moreover, these rates may increase, particularly in Asia.

Humanity's social and economic systems exert a wide variety of pressures on the natural environment; including growing demand for non-renewable resources and ecosystem depletion (see GMTs 7 and 8). This chapter addresses another type of pressure: the increasing global pollution burden.

Section 10.1 reviews the drivers of environmental pollution. Section 10.2 describes past, current and projected trends of selected pollutants that warrant global attention. Section 10.3 reviews potential impacts of these trends on the environment and related ecosystem services. The impacts of pollution on human health and climate are addressed in GMTs 3 and 9.

10.1 Drivers

Throughout much of human history, environmental pollution has been a local phenomenon linked to activities such as subsistence farming and burning vegetation. In more recent times, pollution has turned into a global problem. Technological advances, for example in the automobile and chemicals industries, have hugely increased emissions, creating an increasingly complex mix of critical pollutants with interrelated environmental effects (see Box 10.1 and Box 10.2).

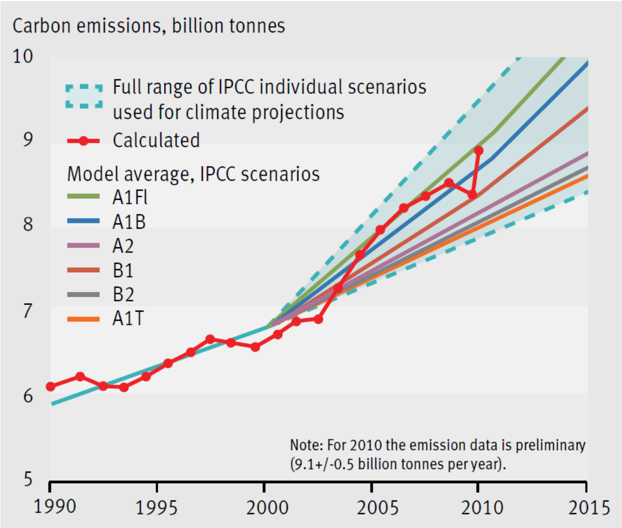
Population growth has also played a role. The world population reached 1 billion in 1804, and surpassed 2 billion in 1927. After that, it took just 84 more years to reach 7 billion (see GMT 1). Although the rate of growth has eased in recent decades, the global population is projected to be between 8.3 billion and 10.9 billion in 2050, with a medium variant of 9.6 billion (UN, 2013).

These technological and demographic trends have driven rapid economic growth (GMT 5) and increased earnings, increasing demand for energy (GMT 7) and food (GMT 8). They have also manifested in a huge expansion of the global middle class, bringing associated shifts in consumption patterns. Collectively, the impact of these changes has been a substantial increase in environmental pollution loads.

Sources and types of pollution

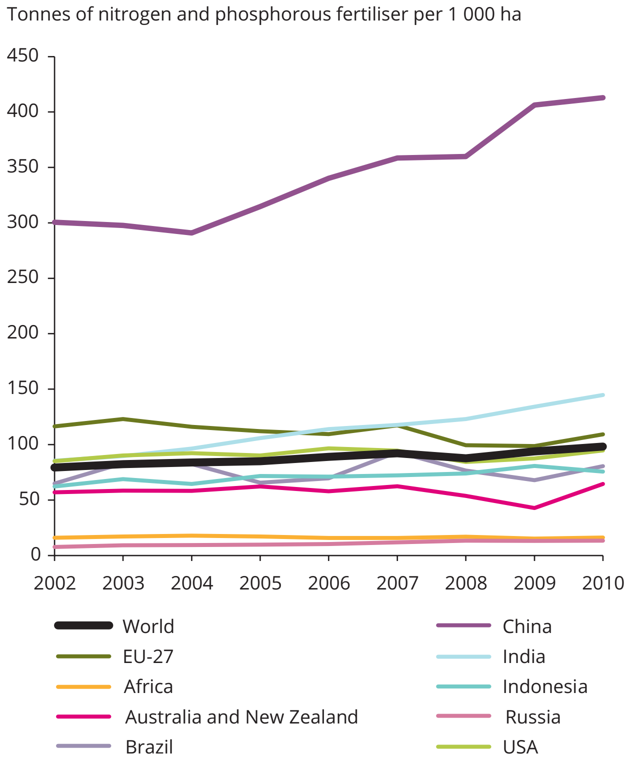
Fossil fuel combustion (related to industrial production and transport) is a key source of pollutant emissions, in particular for air pollution. As shown in Figure 10.1, annual global greenhouse gas emissions from fossil fuels have risen by 50% from around 6 billion tonnes in 1990 to almost 9 billion tonnes in 2010, in accordance with the most pessimistic Intergovernmental Panel on Climate Change (IPCC) scenario (A1FI) in that year (IPCC, 2000).

Figure 10.1 **Global carbon emissions form combustion of fossil fuels (1990–2011) and IPCC projected emission scenarios (2000–2015)**



Source: UNEP, 2012a.

Figure 10.2 **Intensity of fertiliser use on arable land in selected world regions and countries, 2002–2010**

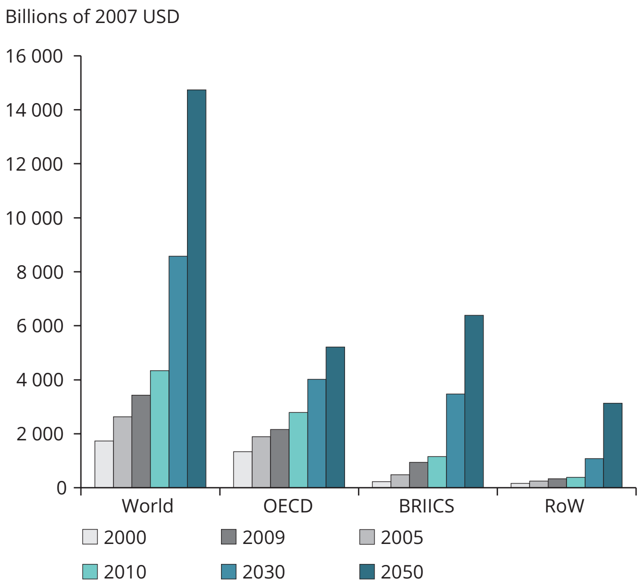


Source: FAO, 2013.

Fertiliser use varies across countries and world regions, with particularly intensive use in China (Figure 10.2). India and China have sharply increased synthetic fertiliser input per unit of agricultural land over the last decade, whereas the rate has remained stable in other world regions such as the USA and the EU-27. Countries within Europe show mixed trends, however. Many eastern European countries have increased their fertiliser use markedly over the last decade, while most southern European countries have considerably reduced fertiliser inputs (EEA, 2013c).

Chemicals released into the environment are another concern. In Europe alone, more than 100 000 commercially available chemical substances are registered in the European Inventory of Existing Commercial Chemical Substances (EINECS), and the number of new substances introduced to the global market is increasing rapidly. Annual global sales from the chemical industry sector doubled between 2000 and 2009, with increases in all world regions (OECD, 2012). Chemicals production is projected to continue growing. Particularly large increases are anticipated in BRIICS countries and output there may surpass aggregate OECD chemicals production by 2050 (Figure 10.3). Of particular concern are persistent, bioaccumulative and toxic substances that remain in the environment for a long time (Box 10.1).

Figure 10.3 **Chemicals production by world region (in sales), 2000–2050**



Source: OECD, 2012 (data for 2010, 2030 & 2050: projections from ENV-Linkages model).

Box 10.1 Persistent, bioaccumulative and toxic substances

Persistent, bioaccumulative and toxic chemicals (PBTs) have emerged as an important environmental and health concern. Such substances can remain in soil and sediment for a long time, being absorbed by microorganisms and plants. Ultimately they accumulate in wildlife, increasing in concentration as they move up the food chain. PBTs are associated with toxic effects in animals, such as cancer, immune system dysfunction and reproductive disorders.

A range of activities emit PBTs, including agriculture, cement production, mining, waste management and ship dismantling. Although these activities occur throughout the world, many are specifically associated with developing countries and countries in economic transition (UNEP, 2009). PBTs can travel long distances via wind and ocean currents, and can move readily between water, soil and air. As such, local emissions contribute to a global burden of pollution. PBTs tend to concentrate in cold regions through a process known as 'global distillation'. Monitoring data confirm bioaccumulation and biomagnification of PBTs in the tissue of Arctic wildlife and fish (Swackhamer et al., 2009).

Recognising the global character of PBT pollution, governments have agreed measures to reduce PBT releases and emissions, notably the Stockholm Convention on Persistent Organic Pollutants. Global monitoring under the Convention indicates that persistent organic pollutant concentrations in air have declined in the past 10–15 years (UNEP, 2009). However, concentrations of PBTs in wildlife show more mixed trends, and there is growing scientific evidence of their toxicity to mammals, birds and reptiles (UNEP, 2012b).

10.2 Trends

Pollutants enter the environment via various means, such as particulate emissions to air or as effluents to soils or aquatic environments. Some pollutants interact in air, water or soil, triggering the formation of new pollutants, such as tropospheric (ground-level) ozone (O_3) ([1]). Table 10.1 provides an overview of key pollutants of natural ecosystems and their effects. The remainder of this section presents historical trends and future projections for some of these pollutants. Their impacts and implications are addressed in Section 10.3.

Emissions to the air

Atmospheric nitrogen pollution

Atmospheric nitrogen pollution primarily consists of emissions of nitrogen oxides (NO_X) from the industry and transport sectors, and emissions of ammonia (NH_3) and nitrous oxide (N_2O) from agriculture (UNEP, 2012a). Nitrogen oxides are precursors of tropospheric ozone and cause multiple effects in the atmosphere that contribute to climate change (see GMT 9). In addition, nitrogen deposited in terrestrial and aquatic ecosystems can harm biodiversity through processes such as eutrophication and acidification (see Section 10.3 for details).

Global emissions of NO_X increased rapidly until approximately 1990 in Europe, North America, east Asia and south Asia (Figure 10.4) ([2]). They then fell significantly in Europe and stabilised in North America but continued to grow in Asia. According to projections based on the concepts of the representative concentration pathway (RCP) scenarios ([3]) (van Vuuren et al., 2011), emissions will continue to decrease in Europe and North America up to 2050. In Asia, decreases may only commence following another two or three decades of increased emissions (HTAP, 2010; Figure 10.4).

Global ammonia (NH_3) emissions have also increased significantly since the 1950s in all four regions shown (Figure 10.4). The strongest increase was in east Asia, where China is the largest agricultural producer. In contrast to nitrogen oxides, ammonia emissions are projected to increase further in coming decades in all the four regions, with the possible exception of Europe.

(1) 'Tropospheric ozone' or 'ground-level ozone' comprises the ozone concentrations in the lowest part of the atmosphere, which directly affect humans, crops and ecosystems. The troposphere stretches from ground level to around 15–20 kilometres.

(2) The analysis in this section focuses on four regions addressed by the Task Force on Hemispheric Transport of Air Pollution (HTAP) organised under the auspices of the UNECE Convention on Long-range Transboundary Air Pollution (LRTAP Convention). These regions were selected because of their dominant share in global emissions.

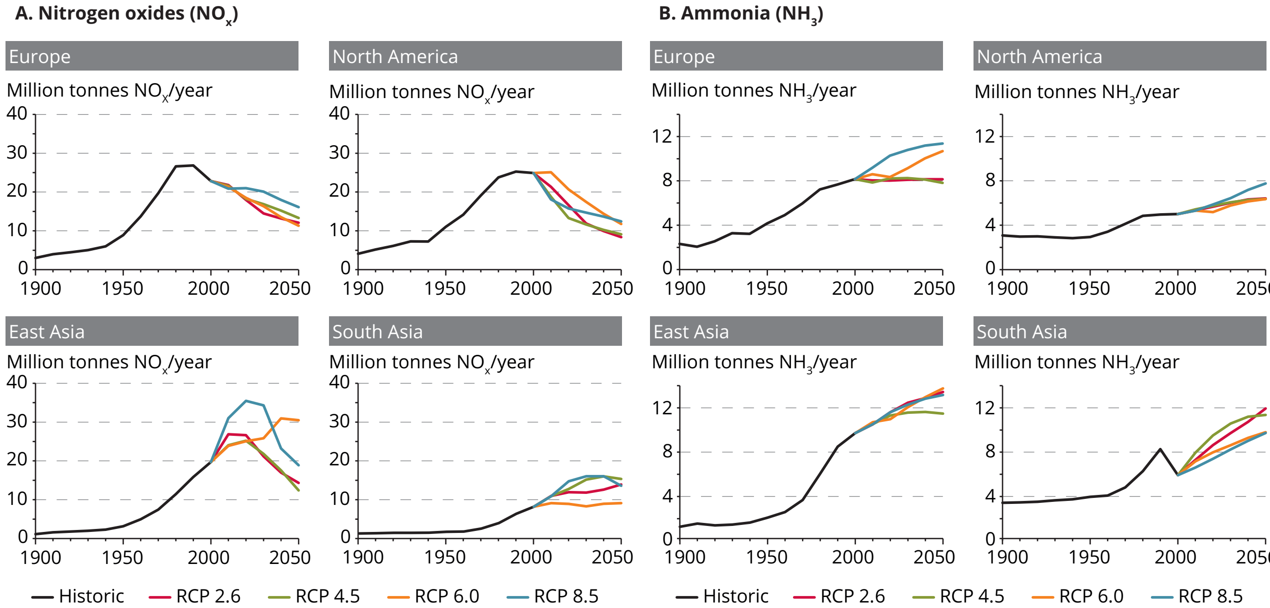
(3) The representative concentration pathways (RCPs) were developed to aid climate modelling, and will underpin the forthcoming fifth assessment report of the IPCC. They do not necessarily represent probable future socio-economic pathways.

Table 10.1 Matrix of pollutants and their effects on natural ecosystems

	Sulphur dioxide (SO_2)	Nitrogen oxides (NO_x)	NMVOCs	Ammonia (NH_3)	Carbon monoxide (CO)	Carbon dioxide (CO_2)	Methane (CH_4)	Nitrogen fertiliser	Phosphorus fertiliser
Ground-level ozone (O_3)		X	X		X		X	X	
Acidification	X	X		X		X		X	
Eutrophication		X		X				X	X

Note: NMVOCs are 'non-methane volatile organic compounds'.
Particulate matter (PM) is not included here as it is addressed in more detail in GMT 3 on human health.

Figure 10.4 Historical and projected trends in nitrogen oxides and ammonia emissions for Europe, North America, east Asia and south Asia, 1900–2050



Source: HTAP, 2010.

Tropospheric ozone
Formation of tropospheric ozone (O_3) is mainly driven by anthropogenic emissions of atmospheric precursors, namely NO_x, volatile organic compounds (VOCs), CO and methane (NH_4). O_3 causes significant damage to vegetation, for example diminishing forest growth and crop yields (e.g. Mills et al., 2011). Ozone is a relatively short-lived pollutant, with an average tropospheric lifetime of approximately 22 days (Stevenson et al., 2006). Despite this characteristic, hemispheric (intercontinental) transport of O_3 is a growing concern (HTAP, 2010). This phenomenon is a result of complex atmospheric chemistry, which enables precursors to form O_3 long after they are emitted (Stevenson et al., 2006).

According to global modelling for the period 1960 to 2000, annual mean ozone concentrations in Europe and North America increased until about 1990; in east Asia and south Asia, concentrations continued to increase during the 1990s, although less rapidly than previously (Figure 10.5).

Projections of future ozone concentrations are heavily dependent on global and regional emission pathways (UNEP, 2012a), as well as on changes in the climate system. As illustrated in Figure 10.5, projections up to 2050 vary greatly depending on the RCP assumption employed. Ozone concentrations in Europe and North America are projected to decline based on three of the four RCPs. At the other extreme, increases are projected in south Asia according to all four scenarios.

Sulphur dioxide
Sulphur dioxide (SO_2) contributes to acidification of terrestrial and freshwater ecosystems, thereby affecting

biodiversity. Volcanic eruptions and human activities are the major sources of sulphur dioxide emissions. The latter includes burning of sulphur-containing fossil fuels, combusting biomass for domestic heating, and biofuel use in the transport sector (EEA, 2013b).

SO_2 emissions have increased significantly since 1850 (Figure 10.6). They grew fastest in Europe and North America before peaking in the late 1970s. Implementation of legislation such as the EU's National Emission Ceiling (NEC) Directive resulted in strong emission reductions in both regions (around 50% in Europe). Global emissions have only dropped by around 20%, however, due to increasing emissions in Asia. Projections based on the IPCC's RCP scenarios suggest that SO_2 emissions will continue to decline in Europe and North America but the patterns will be more varied in Asia. Again, future emissions largely depend on the development and implementation of emission mitigation measures.

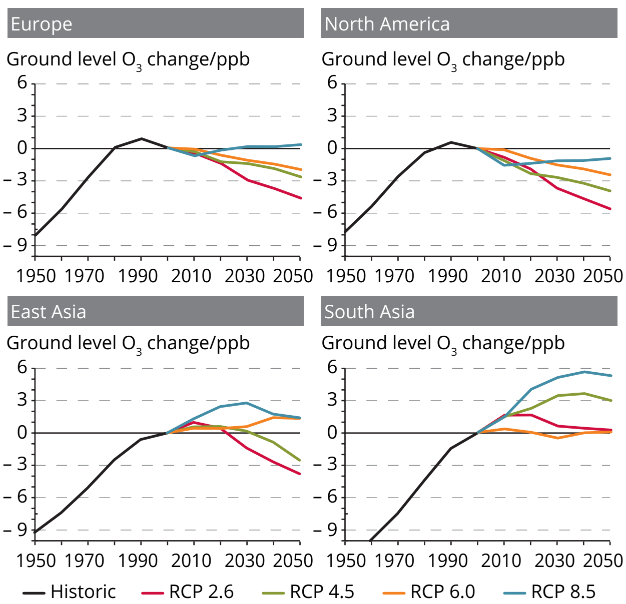
Particulate matter

Particulate matter (PM) consists of a variety of airborne particles, of varying size and chemical composition. PM is emitted either directly through human activities such as energy generation, industrial production or transport, or can be formed in the atmosphere from precursor gases such as sulphur dioxide, nitrogen oxides and ammonia. Recent studies show that PM can be transported across continents, for example via atmospheric brown clouds. Although local emissions of PM are considered to account for the majority of PM-related harm, long-distant sources can contribute significantly (HTAP, 2010). While PM affects plant growth and animals, it is primarily a concern due to its harmful effects on human health (WHO, 2006). It is therefore addressed in more detail in GMT 3.

Releases to aquatic systems and soils

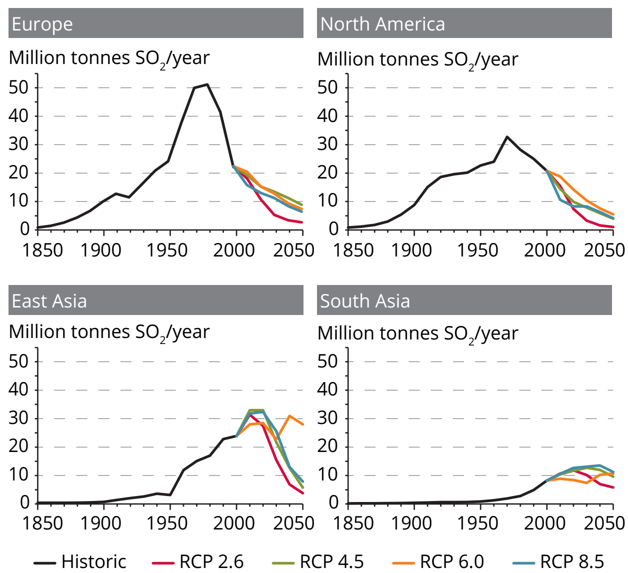
Apart from deposition of airborne sources, pollution of water and soils also results more directly from releases from diffuse agricultural or urban sources, or from point sources such as industrial plants. In some cases, for example nitrogen pollution of marine ecosystems (OSPAR, 2010), direct releases create a much greater environmental burden than deposits from the air. These direct releases are often more local but can have far-reaching effects when transported over long distances, for example via rivers. Increasingly complex cocktails of chemicals and heavy metals (Box 10.2) released from industrial plants are also a growing concern.

Figure 10.5 Historical and projected trends in ozone concentrations for Europe, North America, east Asia and south Asia, 1950–2050



Source: Wild et al., 2012.

Figure 10.6 Historical and projected trends in emissions of sulphur dioxide for Europe, North America, east Asia and south Asia, 1850–2050



Source: HTAP, 2010.

Box 10.2 Potential risks from mixtures of chemicals

Assessments of the environmental risks of chemical pollution have traditionally focused on individual chemicals and sought to establish a 'concentration threshold' or 'dose', below which negative effects are not seen. In reality, however, multiple chemicals interact in the environment, producing combined effects that exceed the sum of individual impacts (Kortenkamp et al., 2009). As a result, a substance present in concentrations below the threshold level may still contribute to combined and possibly synergistic effects. The combined ecotoxicity of a chemical mixture is always higher than the individual toxic effect of even the most potent compound present (KEMI, 2012). In particular, robust evidence exists of combination effects for endocrine disrupting chemicals (EEA, 2012b).

Since the number of chemical combinations is enormous, there is a need to develop methods for prioritising mixtures most likely to occur in the environment and assessing the associated risks. Continued research is needed into priority mixtures, synergistic effects and likely exposure scenarios. Kortenkamp et al. (2009) found that available methods are sufficiently advanced to enable risk assessment of the combination effects of chemicals in a wide range of settings. But there is currently no systematic, comprehensive and integrated regulatory approach to managing mixture effects globally.

Many EU Member States have experience applying mixture testing approaches to emissions and environmental monitoring. However, EU legislation only requires Member States to assess the risks of intentionally produced chemical mixtures, such as in pesticides, cosmetics, or medicinal products. Some Member States have therefore called for a coherent approach to managing chemical mixtures (NCM, 2012). In May 2012, the European Commission launched a process to identify priority mixtures for assessment, ensure consistent risk assessment requirements across EU legislation and address data and knowledge gaps regarding mixture toxicity (EC, 2012).

At the global scale, the World Health Organization (WHO) promotes the development of Toxic Equivalence Factors (TEF) for assessing mixtures of dioxin-like chemicals (IPCS, 2001, 2009). In addition, the UN Globally Harmonised System for Classification and Labelling of Chemicals (GHS) provides detailed guidance on the classification of commercial mixtures for human health and the environment.

Nitrogen and phosphorus

At the global scale, increasing nitrogen and phosphorus pollution has become a major concern because of direct negative impacts on natural ecosystems and biodiversity (see Section 10.3). Triggered by agricultural intensification and global population growth, the total production of nitrogen reactive in the environment (see Box 10.3 for details on its formation) has more than doubled since the 1970s (Galloway et al., 2008).

Synthetic nitrogen fertilisers have enabled a significant increase in global food production. But if global loads of nitrogen (and phosphorus) continue to increase then it may at some point significantly perturb the natural nitrogen and phosphorus cycles. According to Rockström et al. (2009), current levels may already exceed globally sustainable limits.

The role of agriculture

Nutrient effluents from agriculture occur if there is surplus nitrogen or phosphorus in the soil. For example, if synthetic fertiliser is applied but not fully taken up by crops then it may leach into groundwater or surface waters. Thus, effluent quantities depend on the intensity of fertiliser use and the efficiency in fertiliser application.

Several recent studies have suggested that global fertiliser use will increase markedly during the 21st century from the 90 million tonnes consumed in 2000 (Winiwarter et al., 2013). The projections in the studies vary greatly, depending on assumptions regarding population, consumption, biofuels and efficiency. Most estimate that annual nitrogen fertiliser use will be in the range of 100–150 million tonnes in 2050. The FAO (2012) argues, however, that if developing countries shift their models of agricultural production to those already used in developed regions then global nitrogen fertiliser use could well exceed 150 million tonnes in 2050.

The projections of nitrogen fertiliser demand based on IPCC RCP scenarios suggest that there may be trade-offs between greenhouse gas mitigation and pollution abatement. In the two lower global warming scenarios (RCP 2.6 and RCP 4.5), intensified biofuel production could lead to high nitrogen fertiliser consumption (Winiwarter et al., 2013; Figure 10.7). It could also increase concentrations of tropospheric ozone, since certain plant species used for biofuel production (e.g. poplars) emit more isoprene (a biogenic ozone precursor) than the crops they are replacing (Beltman et al., 2013).

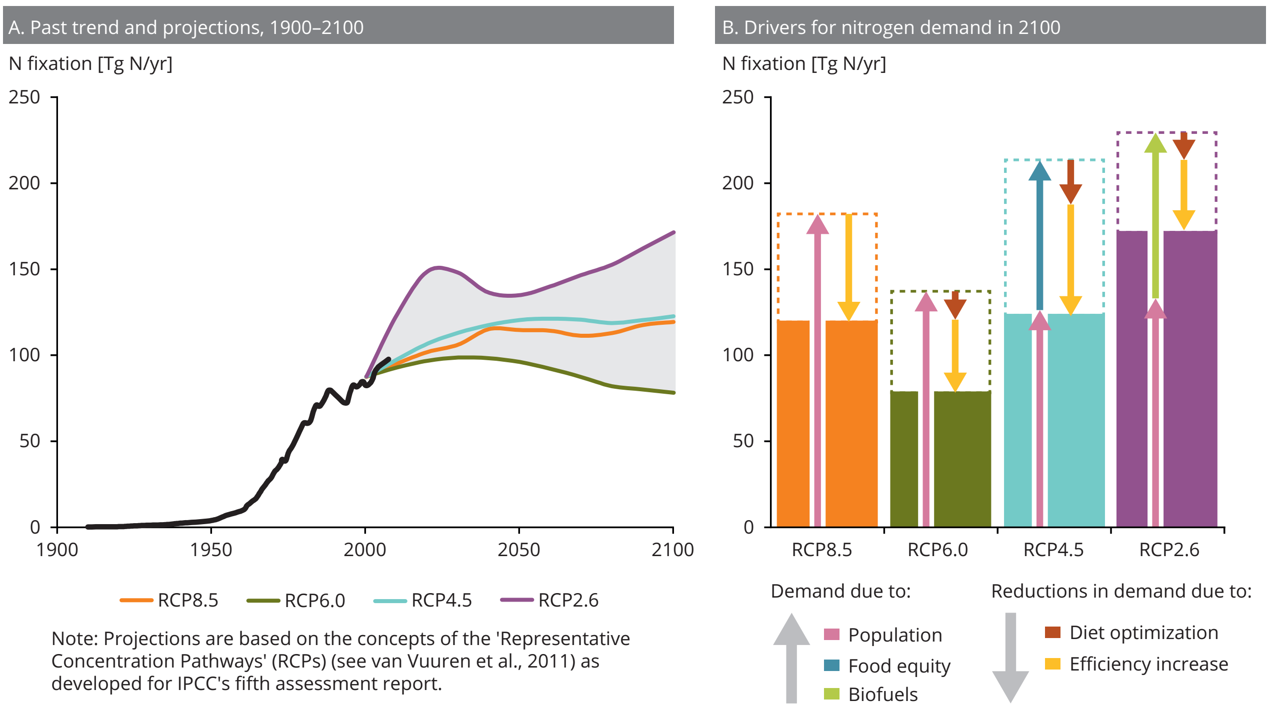
Box 10.3 Formation of reactive nitrogen

Nitrogen makes up almost 80% of the atmosphere in the form of N_2 gases but can only be used by plants and animals if converted into another chemical form: reactive nitrogen. This process of 'nitrogen fixation' can occur in three main ways:

- by lightning or high-temperature combustion (e.g. car exhausts and power stations);
- by nitrogen-fixing plants (e.g. legumes);
- by the industrial creation of synthetic nitrogen fertiliser.

Reactive nitrogen is also released from animal manure. For a more detailed explanation of the nitrogen cycle and the role of agriculture see, for example, Mosier et al. (2004).

Figure 10.7 Historical trend in global agricultural demand for industrial nitrogen fertiliser, 1910–2008, projections to 2100 based on RCP scenarios, and drivers of the projected changes in demand in 2100



Note: 'Diet optimisation' refers to a shift in consumption towards foods produced with more effective nitrogen uptake. 'Efficiency increase' refers to the ratio of nutrients taken up by crops to the total amount of nutrients applied to soil.

Source: Winiwarter et al., 2013.

Scenarios indicate a mixed picture for the efficiency of future fertiliser use. In most OECD countries, agricultural output is expected to grow more rapidly than nutrient inputs, implying increased efficiency of fertiliser use. This could lead to reduced nutrient effluents from agriculture. In contrast, in China, India and most developing countries, effluent rates may increase strongly as growth in agricultural production is likely to outpace increases in efficiency of fertiliser use (OECD, 2012).

The role of wastewater

Nitrogen and phosphorus effluents from wastewater are projected to increase in developed and developing regions (OECD, 2012). Key drivers include global population growth, rapid urbanisation and the high cost of removing nutrients in wastewater treatment systems. Globally, OECD scenarios suggest that nitrogen effluents will increase by 180% between 2000 and 2050, reaching 17 million tonnes per year. Phosphorus effluents might rise by more than 150%

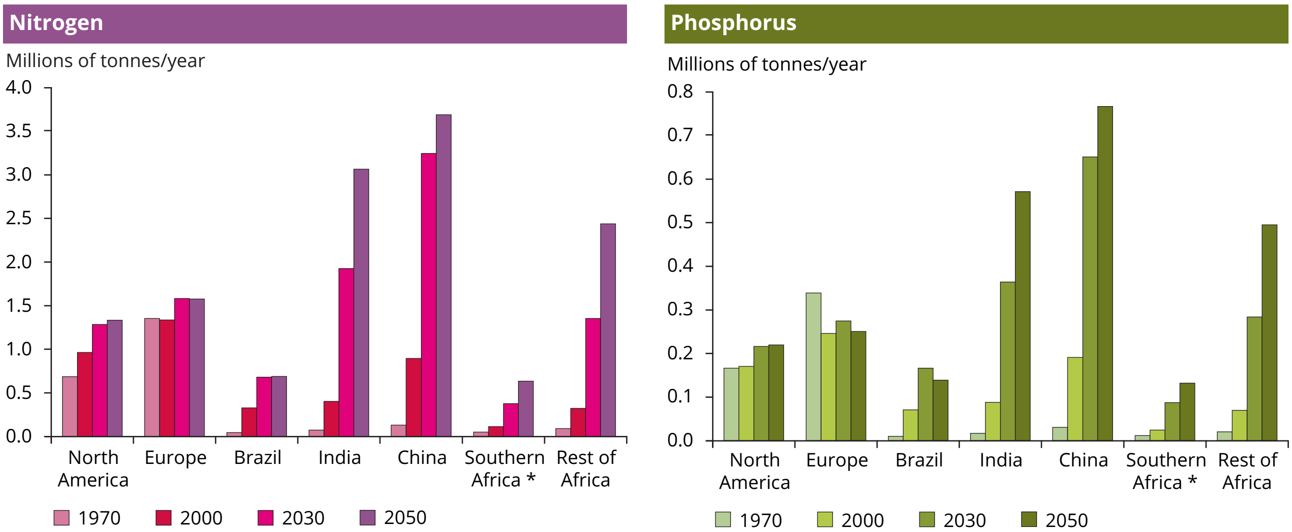
to 3.3 million tonnes per year. In each case, the largest increases are projected in China and India (Figure 10.8).

Under current global policy settings, projected discharges of nutrients via rivers into the sea vary considerably across the world's main seas (OECD, 2012). While nutrient discharges into the Mediterranean and the Black Sea are projected to increase only slightly, the Indian Ocean and the Pacific Ocean may face strong increases. The amount of phosphorus discharged annually into the Pacific Ocean may almost double from 2000 to 2050 (Figure 10.9).

10.3 Implications

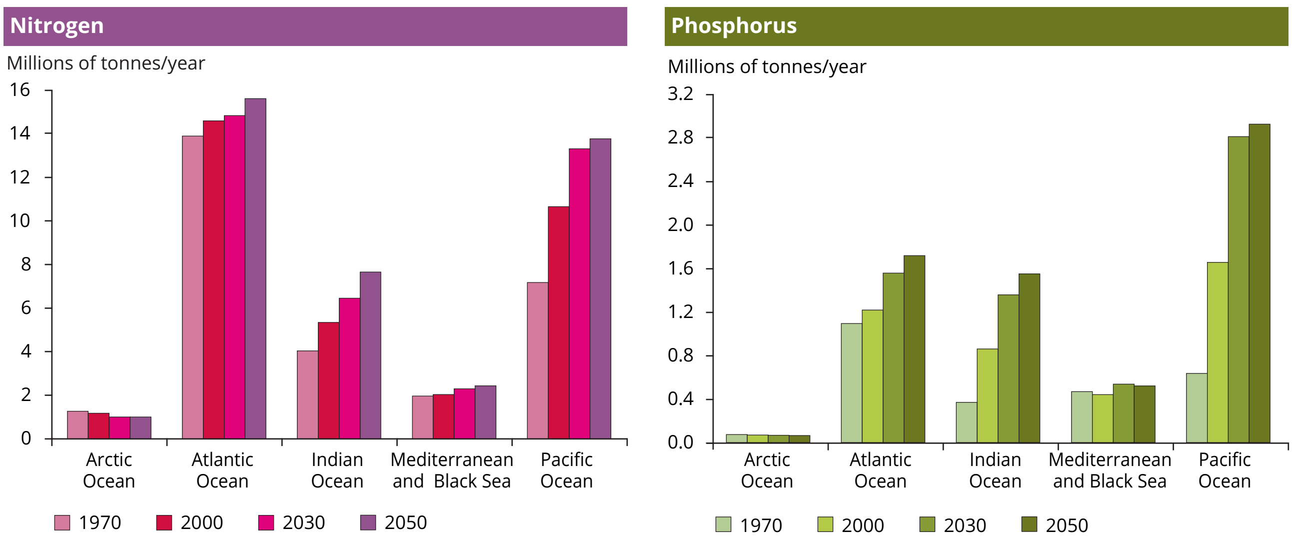
Environmental pollution often triggers harmful processes in the environment. For example, atmospheric deposition of sulphur and nitrogen compounds causes acidification of soils and freshwater resources; elevated nitrate and phosphate levels lead to eutrophication of terrestrial and aquatic ecosystems; and high concentrations of ground-level ozone and ammonia damage vegetation. Synthetic pesticides used in agricultural production can have significant effects on freshwater quality,

Figure 10.8 Effluents of nitrogen and phosphorus from wastewater, 1970–2050



Source: OECD, 2012 (output from IMAGE model).

Figure 10.9 River discharges of nitrogen and phosphorus into the sea, 1970–2050



Source: OECD, 2012 (output from IMAGE model).

marine ecosystems and soil biodiversity (OECD, 2012). In addition, various pollutants are emerging whose effects are not yet well studied. These include chemical substances that may interfere with the hormonal system of humans and animals (see Box 10.1).

This section highlights two related sets of potential pollution impacts that are of particular concern in the context of global population growth and resource scarcity: impacts on biodiversity and ecosystem services; and impacts on agriculture and food provision.

Biodiversity and ecosystem services

Terrestrial ecosystems
The capacity of ecosystems to provide valuable services, such as regulating the environment, provisioning resources and delivering non-material cultural benefits (see GMT 8) can be reduced by chronically elevated reactive nitrogen deposition, thus causing widespread harm. In such conditions, species well adapted to nitrogenous or acidic environments are likely to thrive, displacing other plants. Susceptibility to stress such as frost damage or disease may also be enhanced (Dise et al., 2011). Over time, these factors could alter species composition and reduce diversity. In many European ecosystems, exceeding critical loads of reactive nitrogen has been linked to reduced plant species richness (Bobbink et al., 2010; Dise et al., 2011). An annual deposition of 5–10 kg N per ha has been estimated as a general threshold value for adverse effects (Bobbink et al., 2010), although such effects may also occur over the long term at even lower levels (Clark and Tilman, 2008).

Acidic deposition trends differ markedly across the world's regions. In Europe, they have declined significantly since the 1980s (Vestreng et al., 2007). Although reduced atmospheric emissions do not result in immediate recovery of impacted ecosystems, there is clear evidence of recovery in European ecosystems (e.g. Vanguelova et al., 2010).

In contrast to Europe, Asian and African ecosystems may face increased risk of acidification in the coming 50 years, depending on individual site management practices and policies from regional to international levels. Areas at particular risk are south, south-east and east Asia, where little of the emitted substances are neutralised by alkaline desert dust in the atmosphere (Hicks et al., 2008). At the global scale, Bleeker et al. (2011) find that 40% of the current protected areas designated under the Convention on Biological Diversity (CBD) received annual nitrogen deposition exceeding the threshold of 10 kg N per ha in 2000. In 950 protected areas, primarily in south Asia or south-east Asia and Africa, the nitrogen load is projected to double by 2030.

Ground-level ozone may also have significant effects on biodiversity (Wedlich et al., 2012). This might, for example, take the form of changes in species composition of semi-natural vegetation communities (e.g. Ashmore, 2005) or reductions in forest biomass (Matyssek and Sandermann, 2003), the latter potentially compromising some of the ecosystem services delivered by forests (see GMT 8 for details).

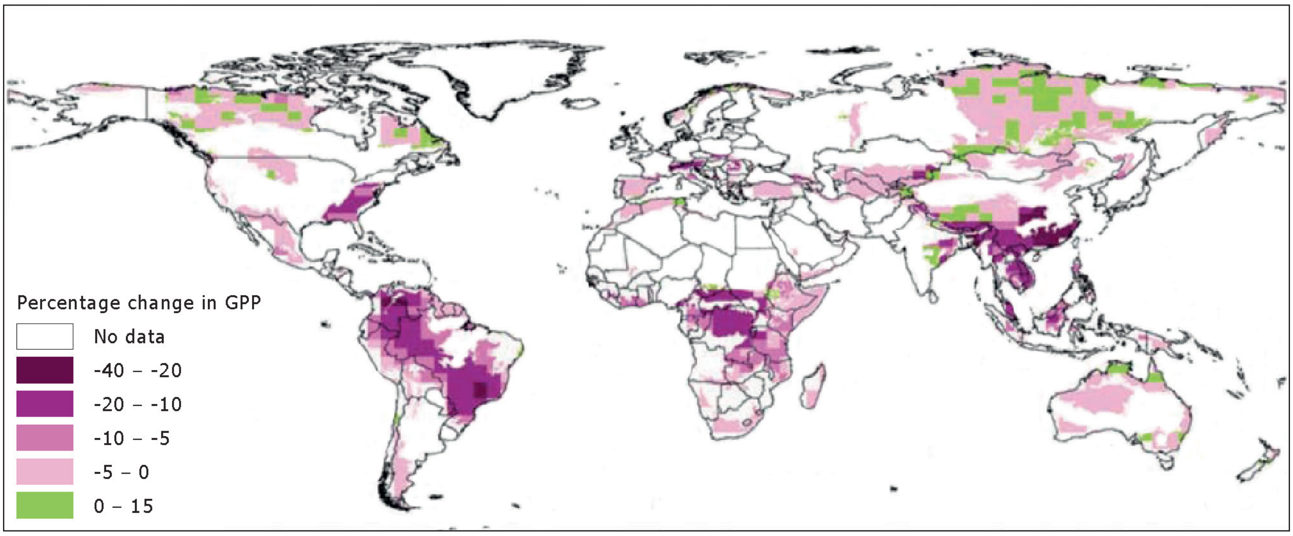
Studies of ozone impacts on ecosystems have so far focused mainly on North America and Europe. As a result, global effects are subject to substantial uncertainty. A global study based on the SRES high emission A2 scenario (IPCC, 2000) suggests that the risk of reduced plant productivity are greatest in eastern North America, central Europe, large parts of South America, central Africa and south-east Asia (see Figure 10.10, top).

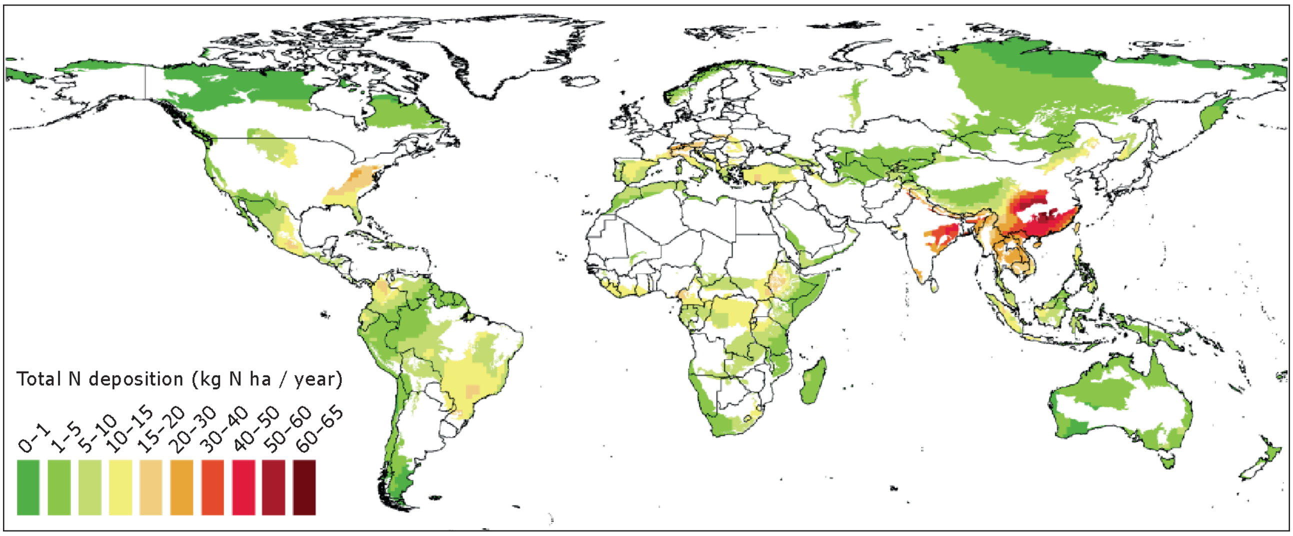
Bobbink et al. (2010) show that some locations at high risk of ozone effects also face substantial risks from nitrogen deposition (Figure 10.10, bottom). Examples include the forests of south-east Asia and south-west China. These findings also need to be considered in the context of additional major threats to biodiversity such as habitat destruction and climate change (see GMTs 8 and 9).

Aquatic ecosystems
Many aquatic ecosystems are threatened or affected by eutrophication. Here, eutrophication refers to the process by which water bodies acquire high nutrient concentrations (in particular phosphates and nitrates) typically followed by excessive growth and decay of plants (algae) in the surface water. It may occur naturally (e.g. in deep waters) but is most often the result of pollution related to human activity, such as fertiliser runoff and sewage discharge and the atmospheric deposition of nitrogen compounds. This process has been linked to serious losses of fish stocks and other aquatic life (e.g. Jenkins et al., 2013).

Eutrophication may cause hypoxia, a state whereby aquatic ecosystems lack sufficient oxygen to support most forms of life, producing 'dead zones' (Rabalais et al., 2010). In marine ecosystems, most dead zones have developed along coasts since the 1960s due to environmental pollution associated with human activities. Just over 400 cases were reported globally in 2008 (Diaz and Rosenberg, 2008). By 2011 the number of documented cases increased to 762 coastal areas, with 479 sites identified as experiencing

Figure 10.10 **Comparison of modelled changes in risks to biodiversity from ground-level ozone for the period 1900–2100 (top) and projected nitrogen deposition rates in 2030 (bottom)**





Note: GPP refers to global plant productivity and is here used as a proxy for the impacts of ground-level ozone on biodiversity

Source: Royal Society, 2008 (upper map); Bobbink et al., 2010 (lower map).

hypoxia, 55 sites improving after experiencing hypoxia, and 228 sites experiencing other symptoms of eutrophication (Figure 10.11). 'Dead zones' are particularly common along the coasts of Europe, North America and east Asia. Many are concentrated near the estuaries of major rivers, and result from the build-up of nutrients carried from inland agricultural areas.

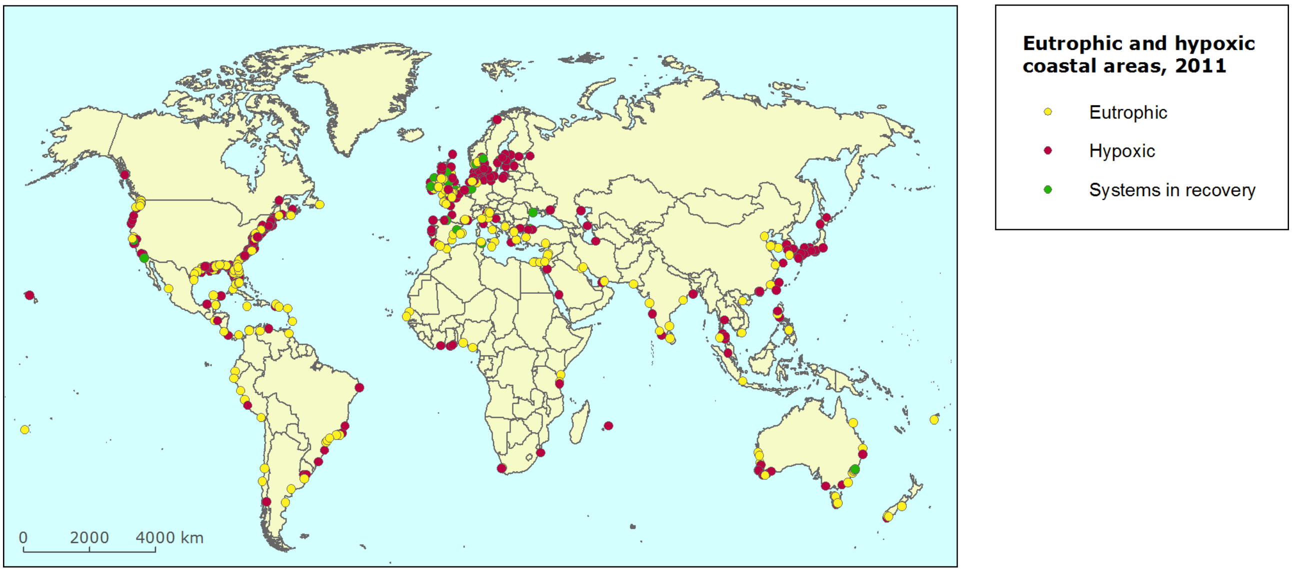
Eutrophication of freshwater ecosystems such as rivers and lakes also remains a key challenge (UNEP, 2012a). Estimates suggest that the number of lakes with hypoxia may increase globally by 20% up to 2050 if existing legislative frameworks remain unchanged. Most of the projected increase may occur in Asia, Africa and Brazil (OECD, 2012).

Agriculture and food provision

Like biodiversity, global agricultural production is mainly affected by the same two types of pollution and related processes: high concentrations of ground-level ozone and acidification primarily caused by sulphur and nitrogen deposition. Ground-level ozone is considered the most important air pollutant to vegetation (UNEP, 2012), on average causing larger economic damages than acidification (van Goethem et al., 2013).

Concentrations of ground-level ozone are unevenly distributed. In urban areas, periods of high 0_3 levels tend to be brief because O_3 reacts with other chemical pollutants, such as nitrogen oxides emitted by

Figure 10.11 Eutrophic and hypoxic coastal areas, 2011



Note: Eutrophic areas are those with excessive nutrients (orange dots), putting them at risk of adverse effects. Hypoxic areas are those where oxygen levels in the water are already depleted and adverse effects expected due to nutrient and or organic pollution (red dots). Blue dots are systems that were hypoxic at one time but are recovering.

Source: WRI, 2013.

vehicles. In rural areas, elevated O_3 levels tend to last longer because substances that destroy O_3 are less prevalent. Furthermore, ozone is strongly phytotoxic, potentially causing a wide variety of damage to various ecosystems, most notably decreasing crop yields.

Global scale estimates based on concentration-response functions derived from chamber experiments suggest that relative yield losses (RYL) range between 7% and 12% for wheat, between 6% and 16% for soybean, between 3% and 4% for rice, and between 3% and 5% for maize, depending on the calculation approach (Van Dingenen et al., 2009). In terms of regional variations, Figure 10.12 highlights that high-production areas are associated with substantial production losses due to O_3. Depending on the crop, such areas are particularly situated in Europe, India, the mid-west United States, and eastern China. Assuming that current legislation remains unchanged, yield losses are projected to increase, particularly in Asia, and particularly for soybean and corn (Figure 10.13). In Europe and North America, yield loss is projected to fall, reflecting current emission reduction legislation (UNEP and WMO, 2011).

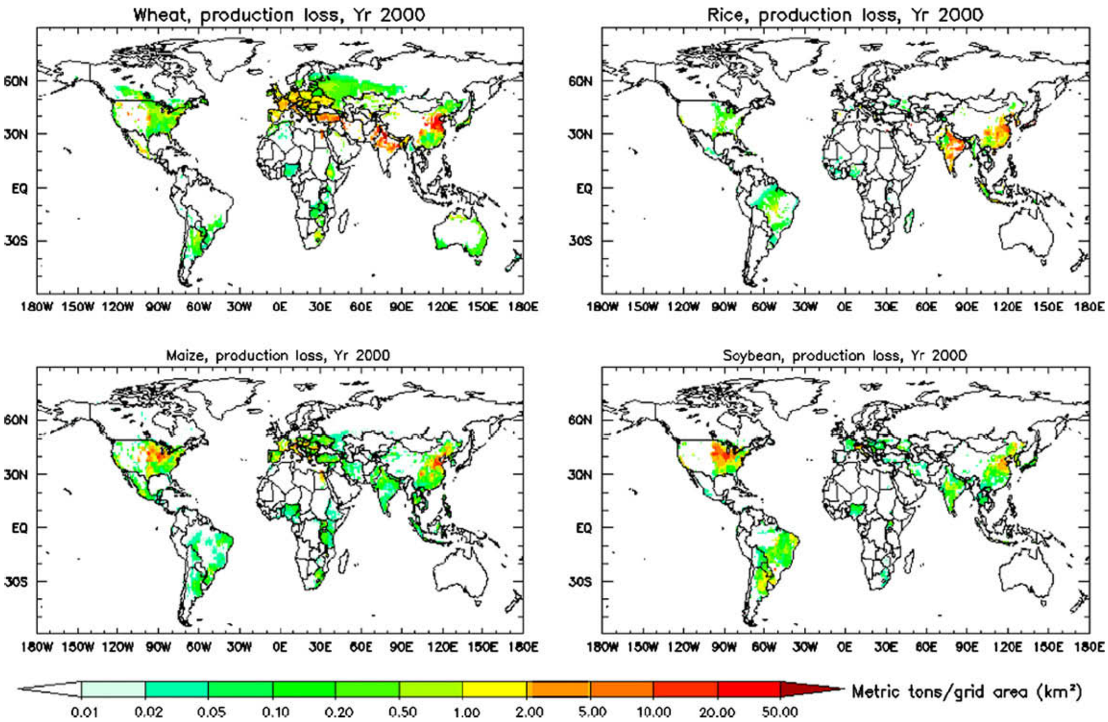
Challenges for Europe

The increasing scale of environmental pollution has created new governance challenges. Although policies aimed at reducing pollutant emissions on European territory have become increasingly effective, other world regions are likely to become more important in driving the absolute pollution burden in Europe and worldwide (UNEP, 2012a).

Trends in ambient concentrations of ground-level ozone and PM in Europe illustrate this challenge. European countries have significantly reduced anthropogenic emissions of ozone precursor gases since 1990. In general, however, ambient air measurements in urban and rural areas of Europe do not show any downward trends in ground-level ozone (EEA, 2013a). Similarly, sharp falls in emissions have not led to equally sharp falls in concentrations of PM in Europe (EEA, 2013b). These contrasting trends are at least partly explained by ample evidence of intercontinental transport of PM and ozone precursor gases (EEA, 2012a). Indeed, for many European countries, less than 50% of the observed fine particulate matter ($PM_{2.5}$) concentrations derive from their own emissions (EC, 2013).

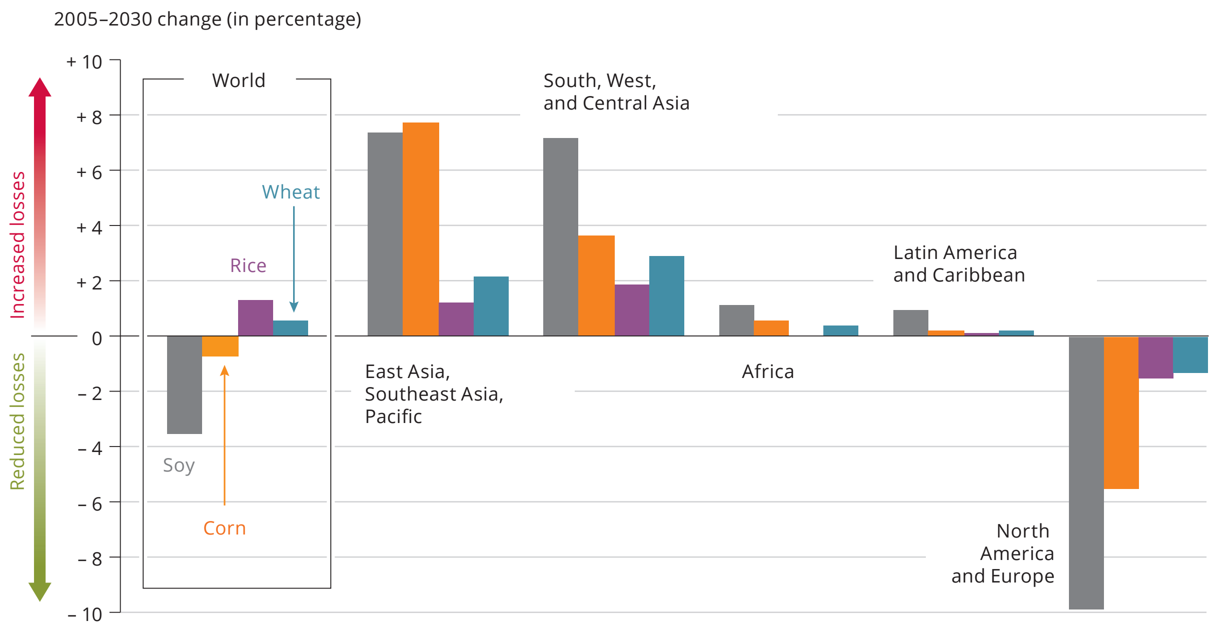
The transboundary character of environmental pollution is also illustrated by the accumulation of persistent, bioaccumulative and toxic chemicals in the Arctic. Collectively, these trends suggest that Europe's capacity to manage environmental pollution and related impacts is constrained — and that the need for a global response to environmental pollution is likely to increase.

Figure 10.12 Modelled crop production loss due to O_3 for wheat, rice, maize and soybeans, 2000



Source: van Dingenen et al., 2009.

Figure 10.13 Projected differences in relative yield losses for wheat, rice, maize and soy beans due to high ozone concentrations, major world regions, 2005–2030



Note: The 2030 scenario assumes the implementation of current legislation for the major world regions. Positive relative yield loss values signify increased yield losses in 2030 compared with 2005.

Source: NEP and WMO, 2011.

Box 10.4 Key uncertainties regarding future loads of environmental pollution

As detailed in other GMTs, the key drivers of environmental pollution — population trends, economic growth, consumption patterns, technological change — are all subject to significant uncertainties. Rapid development of competitive alternative energy technologies, for example, could shift the incentives driving fossil fuel use and related pollution. Equally, a shift towards low meat diets could greatly reduce nitrogen inputs to agricultural production.

Experience suggests that future air pollution levels will depend greatly on the development and implementation of targets and agreements. In contrast to policies in other environmental areas, such as biodiversity, pollution abatement measures at the global and regional scales (e.g. the EU's National Emission Ceiling (NEC) Directive) have produced measurable results within comparatively short time horizons. The development and enforcement of abatement measures is therefore likely to have a major influence on whether or not the projected increases in pollution in Asia and elsewhere will become a reality. Changes in agricultural production systems (in particular in relation to nitrogen and phosphorus pollution) likewise appear to depend heavily on adequate policy development.

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Global megatrend 11 — Diversifying approaches to governance

In the context of rapid globalisation, governments are facing a mismatch between the increasingly long-term, global, systemic challenges facing society and their more national and short-term focus and powers.

The need for more coordinated governance at the global scale has been reflected in the proliferation of international environmental agreements, particularly during the 1990s. More recently, businesses and civil society have also taken an increasing role in governance. This broadening of approaches is welcome but it raises concerns about coordination and effectiveness, as well as accountability and transparency.

Contrasting forms of governance

Across the world, the transition from predominantly agricultural, rural societies to modern urbanised economies has had enormously wide-ranging social and environmental impacts. These changes have been accompanied by a steady evolution in systems of governance, i.e. the mechanisms used to steer society away from collectively undesirable outcomes and towards socially desirable ones (Young, 1999). In particular, two contrasting forms of governance — state hierarchies and markets — have incentivised and organised the socio-economic change, as well as managing the social and environmental harms that have accompanied that process.

These two governance approaches differ in numerous respects (Meuleman, 2014). Hierarchies (as exemplified by the Weberian bureaucracy) are characterised by top-down, rigid, authoritative planning and transfer of information; markets are individualistic, flexible, competitive, decentralised and efficiency driven.

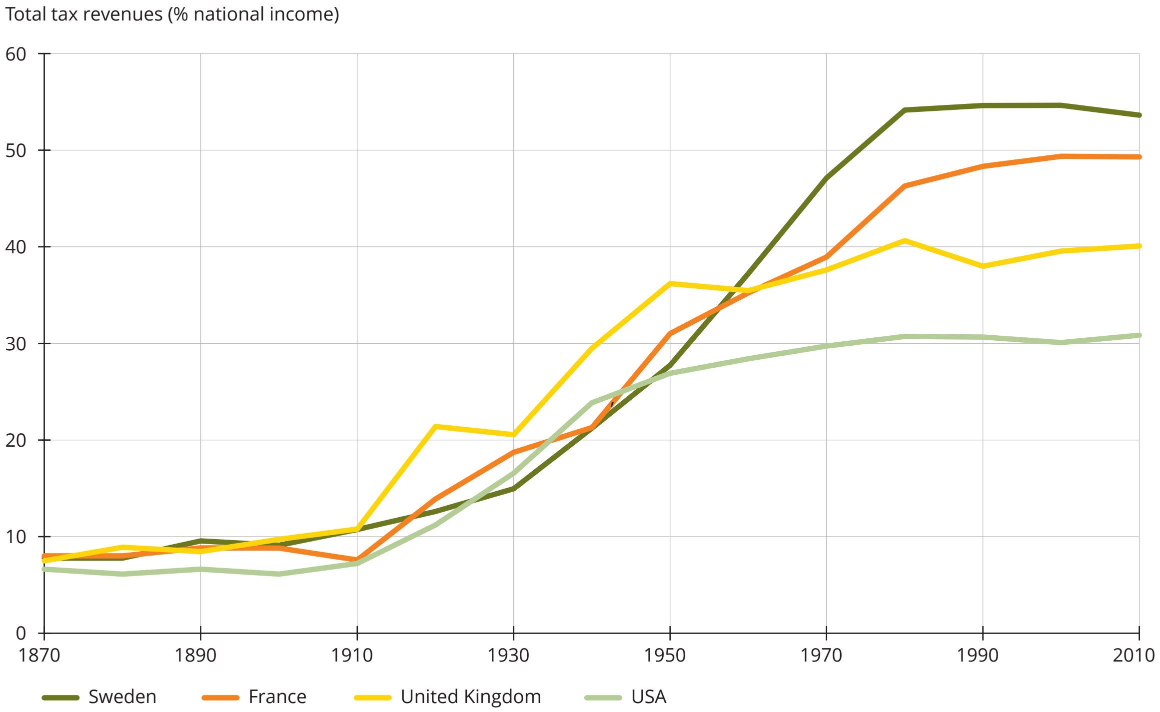
Partly because of these stark contrasts, the two forms of governance are often seen as alternatives. Indeed, this perception has been reinforced in recent decades as a result of neoliberal thinking in the United Kingdom and the US, particularly during the 1980s, which emphasised the advantages of markets in delivering efficiency and innovation, and characterised the state as an obstacle to the operation of the market (Meuleman, 2014). In reality, however, state hierarchies and markets are strongly interdependent. As Rodrik (2011) notes: 'Markets and governments are complements, not substitutes. ... Markets work best not where states are weakest, but where they are strong.'

The importance of governments partly lies in their ability to take collective action in instances where individuals or groups in a society lack the resources or incentives to act. In performing this role, governments have catalysed the emergence of competitive markets, for example by providing the infrastructure (e.g. transport networks), rules (e.g. restrictions on monopolies and cartels), institutions (e.g. well functioning law courts) and information (e.g. product standards) that enable complex systems of commerce to function. In many countries, governments also play a major role in boosting human capital, for example by guaranteeing universal education and health care. Governments are also needed to respond to undesirable outcomes that can result from the operation of the market, such addressing environmental degradation or unfair income inequality.

Beyond the state's role in fixing market failures by supplying public goods and correcting externalities, there is growing recognition that governments play an essential role in driving innovation because they have the willingness and resources to invest in research where the potential gains are hugely uncertain. Government investments have played a dominant role in many of the most important innovations of recent decades, including the computer, nuclear energy, the internet, biotechnology and nanotechnology (Janeway, 2012; Mazzucato, 2013).

The juxtaposition of state hierarchies and markets is therefore misleading, disguising the reality that the two have developed in tandem. Governments have created the conditions for markets to operate; markets, in turn, have helped generate the financial resources to support expanding state competencies. As illustrated in Figure 11.1, the government's role in the economy (expressed as government revenues as a proportion of national income) grew very substantially in France, Sweden, the United Kingdom and the US in the century after 1870 — a period of

Figure 11. 1 Tax revenues as a percentage of national income in selected countries, 1870–2010



Source: Piketty, 2014a.

huge technological change and economic expansion. It has stayed stable in the years since 1980, despite the ideological shifts towards privatisation and liberalisation of markets that have occurred since then.

While recognition of the contrasting competencies and characteristics of state hierarchies and market governance can be traced back to the 1700s, there has been growing recognition in recent decades of a third governance approach. In contrast to the authoritarian or individualistic traits of hierarchies and markets, 'network governance' is characterised by trust, partnership, diplomacy and lack of structure. Meuleman (2014) argues that although network governance has always existed, it emerged as a powerful force in environmental governance the 1990s as an expression of the rising education levels in the general public, and related demands for public participation and consultation in decision-making.

Like hierarchies and markets, the emergence of network governance is a consequence of both changing needs for mechanisms to manage human interactions and new opportunities. The remainder of this chapter will argue that the global demand for new governance approaches is continuing to evolve rapidly, in particular due to the emergence of systemic challenges associated with globalisation and the growing scale of humanity's aggregate burden on the environment. At the same time, new technologies, values and social norms are creating opportunities to coordinate and organise human interactions. The result is a diversification of approaches to governance, bringing together new combinations of hierarchical, market and network governance.

11.1 Drivers

Unmet demand for global governance

Interdependence and demand for governance
As illustrated in GMTs 1–10, humans are increasingly linked as a result of the integration of economic, social and technological systems. Like other regions, Europe is potentially affected by increasing movements of people, infectious diseases, financial resources, materials and pollution, as well as the impacts of global greenhouse gas emissions. This clearly implies a changing need for governance. As Young (2009) notes: 'Ultimately, the demand for governance arises from the existence of interdependencies between human actors. [...] It is therefore important to observe that interdependence is rising rapidly and occurring at a larger scale as a consequence of both global environmental change and global social change in such forms as globalisation.'

In recent decades, the rapid globalisation of economic, social, technical and environmental flows has not been matched by the emergence of effective global governance mechanisms. Held (2006) and Goldin (2013) point to a variety of issues where interconnectivity, complexity and risks have grown and the available governance tools and institutions remain 'weak', 'incomplete' or 'unfit for purpose'. These issues include pandemics, cybersecurity, nuclear proliferation, intellectual property rights, financial markets and taxation of multinational enterprises.

Challenges managing the global environmental commons

The deficiencies of existing governance approaches are particularly clear in the context of global environment management — an area where the scale of humanity's burden on the environmental commons and the impacts of globalised production processes are greatly increasing human interdependencies. The failure of market prices to internalise all the costs of resource use and pollution mean that market forces are unlikely, in themselves, to produce sustainable and socially beneficial outcomes. This is particularly apparent in the area of climate change, which the Stern Review describes as 'market failure on the greatest scale the world has ever seen' (Stern, 2006). Governments face major constraints in correcting the failings of the markets, in part because of the obvious mismatch of scale between the increasingly long-term and transboundary challenges and their more limited focus and powers (Held, 2006).

For example, integration of global markets means that many effects of resource use are felt far from where products are consumed (GMT 6). As a result, governments may have little awareness of the impacts of domestic consumption, and little ability to influence them because of the territorial limits on state authority. Additionally, global trade agreements further limit the ability of individual governments to manage the impacts of their consumption because they prevent states from differentiating between imports based on production methods (WTO, 2014).

Other challenges relate to the incentives for sustainable management of common property resources, such as the global atmosphere, where shared exploitation of the atmosphere's function as a sink for greenhouse gases or pollution results in a 'tragedy of the commons'. Greenhouse gas emissions affect the atmosphere as a whole, with related impacts often falling far from the source of emissions, and potentially falling most heavily on future generations (Cole, 2011). Mitigating climate change requires coordinated action worldwide and individual governments may have little motivation to take unilateral steps to reduce emissions if they suspect that other states will simply 'free-ride' on their efforts.

While climate change is the most serious transboundary environmental challenges, it is not the only one. Long-range transboundary air pollution can travel thousands of kilometres before being deposited. In addition, water resources are often transboundary. Approximately 300 aquifer systems are cross national borders (UN Water, 2008) and 148 states share water basins with their neighbours (UN World Water Assessment Programme, 2012), with actions in one country having potentially devastating effects on another.

Comparable problems arise in the management of global environmental public goods. Individual countries may lack incentives to protect public goods such as rainforests because the benefits that they provide, such as storing carbon and hosting biodiversity, are very widely distributed and long term compared to the short-term financial gains that other land uses could generate.

Electoral incentives and government failure

The shortcomings of government responses to long-term, global environmental challenges may be further undermined by domestic political interests. Behavioural economists have demonstrated the human tendency to disregard the long term when making choices (Ainslie, 1992), and this tendency can be exacerbated by electoral cycles. The result can be short-termism in policymaking, deterring action that delivers benefits in the future and encouraging ones that result in delayed costs.

Electoral cycles tend to be short, fostering policy debate that is often focused on short-term political gains and the satisfaction of the 'median voter' with a concentration on immediate concerns such as jobs and crime (Held and Hervey, 2011). Short electoral cycles are also accompanied by increasingly frequent opinion polls and longer election campaigns, which lead to a general preference of sound bites over detailed analysis (OMCFG, 2013). Due to the spatial and temporal lag of some of the most important environmental challenges, they are rarely considered voters' priorities and are hence less likely to be addressed by politicians (WBGU, 2011).

In some instances, government decisions reflect the interests not of society as a whole but rather those of particular segments. Policy is susceptible to bias resulting from collective action by well-resourced interest groups (Olson, 1965), regulatory capture or corruption. Powerful sectors possess significant economic and informal political power, potentially enabling them to influence regulatory or fiscal regimes in ways that enhance private gains while transferring risk or costs onto society at large.

Economic power here has a twofold meaning. First, lobby groups advocating on behalf of a sector can point to the earnings and employment that a sector generates as a basis for arguing against policy constraints. Second, these groups are often well resourced and can spend considerable amounts of money on their lobbying activities. Many lobby groups have good access to governments, meaning that they are likely to directly influence policy (WBGU, 2011).

New opportunities for governance

The shortcomings of markets and governments in addressing today's global challenges have created increasing demand for new responses. At the same time, a variety of social and technological changes may be facilitating the emergence of innovations in governance.

As noted in GMT 4, the three central functions of information and communication technologies (ICTs) — processing, storing, and transferring information — have all shown exponential increases in performance during recent decades and these trends are expected to continue. By 2030, it is estimated that computer memory costs will reduce by 95%, raw data storage costs will fall to just 1 % of the price today, and network efficiency will increase more than 200-fold (NIC, 2013).

By facilitating the collection, storage and sharing of data, these advances can potentially support established government processes: informing policymaking, promoting successful and efficient implementation and building trust between governments and citizens (OECD, 2003). But ICTs also offer new ways to establish international communities and networks, encouraging collaboration and information sharing. For example, at a time when political party membership has declined sharply, online platforms such as Change.org and Avaaz have been highly successful in engaging the public in campaigning on specific issues (OMCFG, 2013).

Technological changes have also contributed to shifting expectations and values. Better-connected and informed people have become more active and discriminating citizens and consumers. Citizens increasingly demand transparency and accountability from governments (Bertot et al., 2010), as well as business. Media coverage of the social and environmental harm associated with globalised supply chains has grown. Negative news can reach an audience of millions within a very short amount of time, potentially causing long-lasting reputation damage (KPMG, 2012).

Recent decades have likewise witnessed a shift in attitudes towards humanity's relationship with nature, and the responsibility owed to vulnerable populations and future generations (WBGU, 2011). The environment is increasingly prioritised both in developed and developing regions. The fifth World Values Survey (2005–2008) found that 89% of respondents in 49 countries consider global warming to be a serious or very serious problem. Moreover, 55% of respondents stated that they would give priority to protecting the environment even if that slowed down economic growth or caused job losses. Many developing and newly industrialised countries, such as Argentina, China and Colombia also ranked environmental protection over economic interests (WBGU, 2011).

11.2 Trends

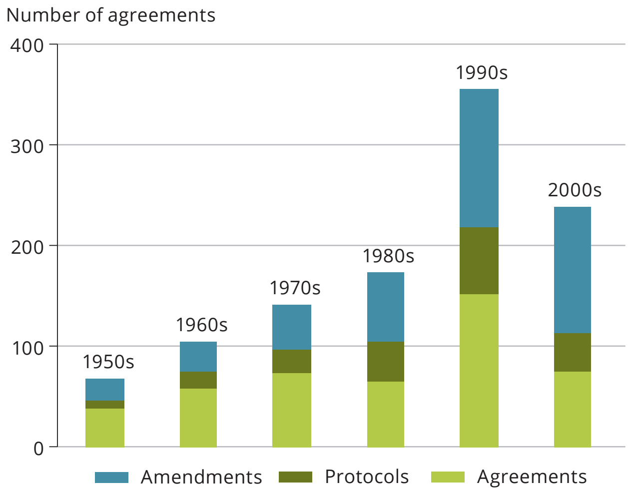
While governments are likely to remain the primary mechanism for coordinating human activity, more diverse governance approaches are emerging. Some can be seen as extensions of hierarchical state authority, while others involve non-state and government actors in 'network governance', based on informal institutions and instruments.

Intergovernmental processes

International agreements
An obvious starting point for overcoming the territorial constraints on government authority is via international agreements, which coordinate hierarchical state governance. The number of international agreements has increased enormously in recent decades, particularly in the area of environmental governance. As illustrated in Figure 11.2, activity peaked during the 1990s, when more than 350 environmental agreements were adopted or amended (Mitchell, 2014).

The subsequent decline in new agreements reflects both the increasingly dense network of regimes in place and growing awareness of their limitations. Negotiations are often extremely complex and slow, and the policymakers involved may have strong incentives to defer costly actions that promise only distant benefits. Due to their focus on consensus finding, international agreements tend to reflect the lowest common denominator of all parties involved. The more parties are involved, the lower

Figure 11.2 Number of international environmental agreements adopted, 1950s–2000s



Source: Mitchell, 2014.

this denominator is likely to be (Cole, 2011). A lack of enforcement mechanisms further undermines their effectiveness and many international agreements are yet to be implemented (KPMG, 2012).

There have been some clear successes. The Montreal Protocol, for example, proved to be a highly effective response to the problem of ozone-depleting substances. However, the characteristics of the problem were fairly unique. The problem of chlorofluorocarbons and the technological solutions were clearly defined and broadly supported by the commercial sector. Uncertainties were limited because the ozone hole could be measured and the associated dangers were expected to affect every nation (Evans, 2012).

In contrast, climate change is a very different issue. Both the problem and the solution are less clearly defined, and greenhouse gas emissions are closely tied to our systems of production and consumption, creating diverse social and economic lock-ins. Partly for these reasons, multilateral agreements have so far fallen far short of what is needed.

One approach that has emerged in recent years to facilitate intergovernmental collaboration is the establishment of long-term environmental targets, particularly addressing climate change mitigation. As noted, a significant part of the challenge in agreeing international measures to manage global environmental resources is the need for reciprocal commitments from most or all states and the strong incentives for 'free-riding'.

Countries appear to have responded to this challenge in recent years by adopting emissions-reduction targets stretching to 2050 (Climate Interactive, 2014). By signalling long-term ambitions, such targets potentially provide a way to secure commitments from other states, as well as helping to deter government short-termism by locking domestic policy into a long-term framework.

Supranational hierarchies

A second form of international policymaking is taking place in supranational blocs, with the EU providing by far the most advanced example. Partial pooling of state sovereignty and the establishment of effective enforcement mechanisms has enabled the EU to agree and implement some of the world's highest environmental standards. Despite the failings of global climate change negotiations, the EU and Member State governments have delivered significant reductions in greenhouse gas emissions (EEA, 2014), in the knowledge that their major trading partners are making similar commitments.

In contrast to the increased coordination of state actions at the regional level, governments have been reluctant to cede powers to global supranational hierarchies. The powers of international organisations are thus much more constrained. As the United Nations Environment Programme notes, 'Intergovernmental organisations are inadequately resourced, are not vested with the requisite authority, lack competence and coordination, and display incoherence in their policies and philosophies' (UNEP, 2012).

Non-state actors and mixed governance approaches

NGOs and businesses as actors in environmental governance

The limitations of state and intergovernmental mechanisms in addressing global governance challenges have enabled non-state actors to assume an increasing role. Non-governmental organisations (NGOs) and businesses may lack the state's rule-making and enforcement powers but they enjoy some advantages in their ability to operate informally across state borders, influencing norms and incentives in diverse jurisdictions. In addition, civil society and business often benefits from substantial local knowledge and contacts (Evans, 2012).

The growing importance of network governance approaches can be partially explained by changes in the scale and focus of non-governmental organisations (NGOs). The number of international NGOs has increased from less than 5 000 in 1985 to more than 60 000 today (UIA, 2014).

This proliferation is reflected in NGO engagement in international environmental negotiations. For example, whereas 2 400 civil society representatives were present at the 1992 Rio Earth Summit, there were 9 800 at the Rio+20 Summit in 2012. For comparison, the number of governments represented increased by just 9%, from 172 to 188 (OMCFG, 2013).

At the same time, the goals and activities of NGOs have shifted. Whereas NGOs traditionally focused on influencing governments and intergovernmental processes, they increasingly undertake activities that bypass government (Delmas and Young, 2009). Functions today include informing agenda setting and policy development; collecting, disseminating and analysing information; defining norms and standards; and monitoring and enforcement processes (Biermann, 2012; Cole, 2011; Evans, 2012).

Businesses arguably have even greater potential to influence environmental impacts across borders. The size of some multinational businesses means that their supply chain and production process decisions can have significant environmental impacts. At the same time, multinational businesses have material power and organisational capacity that is not available to most other international stakeholders (Delmas et al., 2009), ensuring access to policymaking processes. Their expertise and the information they possess gives these businesses authority in international standard setting or in designing environmental programmes (Delmas et al., 2009).

Shared incentives for network governance approaches

Businesses become involved in governance processes for numerous reasons, including pressure from customers, investors and the public, the desire to manage environmental impacts on their operations, and the aim of pre-empting or influencing governmental action (Lyon, 2006). Crucially, businesses often have a commercial interest in adopting production standards. Network governance approaches can thereby operate by aligning the interests of different stakeholders — with NGOs proposing standards and business promoting them (Cashore and Stone, 2012), sometimes in collaboration with state bodies.

For example, companies may favour the harmonisation of standards to reduce production costs or achieve level playing fields with competitors. In such cases, business may have a strong incentive to lobby governments to formalise and enforce standards (Levin et al., 2012). The adoption of EU emissions standards for road vehicles across Asia (Figure 11.3) illustrates both the desire for standardisation in global production, and the interplay of state and non-state actors in environmental governance.

In other instances, firms may seek to adopt standards as a means to signal good practice to consumers and differentiate their products from those of competitors. Certification and labelling schemes exemplify this approach and today address some key environmental problems, such as forest degradation, ecosystem fragmentation and pollution (Ecolabel Index, 2014).

The Forest Stewardship Council (FSC) is an important example of a successful certification scheme, in which different stakeholders share common interests for different reasons. Established in 1993, the FSC has certified some 184 million Ha of forests in over 80 countries as sustainable. It certifies the supply chains corporate giants such as Home Depot and IKEA in the absence of any legal regulations.

Certification and auditing schemes are being greatly facilitated by technical innovations such as geographic information systems (GIS) and global positioning systems (GPS), which enable spatial mapping; mobile and smartphones, which render the collection and dissemination of information more efficient; and DNA and chemical testing, which allow for the determination of a product's species and geographic origin. (Auld et al., 2010). The growth of certification and auditing networks make them one of the most dynamic trends in environmental governance and this growth is estimated to continue into the future as the demand for disclosure is regarded as almost exponential (Evans, 2012).

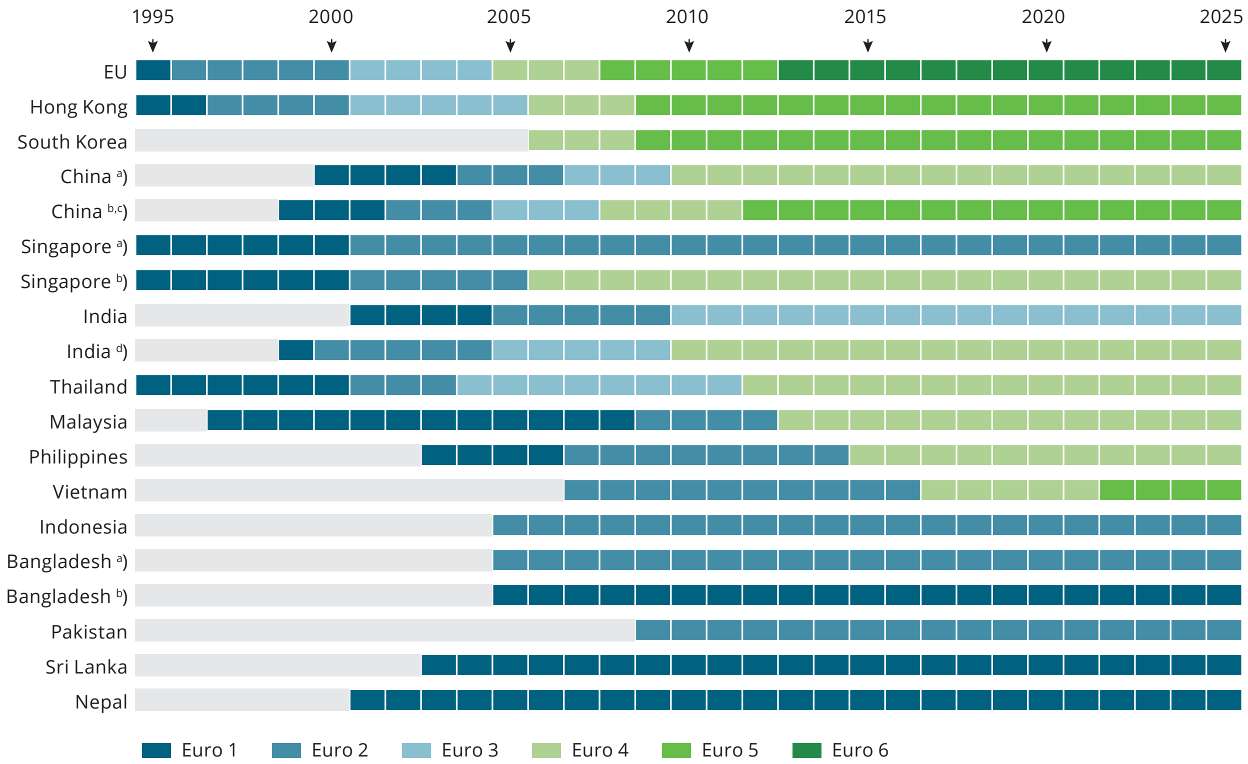
Co-existing with certification and ecolabelling networks are auditing networks that measure sustainability achievements. Environmental and sustainability auditing is dominated by the EU Eco-Management and Audit Scheme (EMAS) and the UN Global Reporting Initiative but there are many other schemes (Evans, 2012).

Cities and networks

The rise of networks is also providing opportunities for state actors at the local level. Cities and networks of cities, for example, are expected to play an increasingly important role in environmental governance (NIC, 2012). Cities concentrate populations, economic activity and innovation of all sorts. This not only creates opportunities for resource-efficient ways of living but also means that changes at local scales can have far-reaching effects.

As noted in GMT 2, the percentage of the global population living in urban areas is projected to reach 67% by 2050 (UN, 2012) and it is estimated that cities around the world account for 60-80% of energy consumption and approximately half of anthropogenic CO_2 emissions (UNEP, 2011; Satterthwaite, 2008).

Figure 11.3 Adoption of the EU's Euro emissions standards for cars and vans in Asian countries, 1995–2025



Note: a) Petrol
b) Diesel
c) Beijing: Euro 1 (Jan 99); Euro 2 (Aug 2002); Euro 3 (2005); Euro 4 (1 March 2008); Euro 5 (2012).
Shanghai: Euro 1 (2000); Euro 2 (Mar 2003); Euro 3 (2007); Euro 4 (2010); Euro 5 (2012).
Guangzhou: Euro 1 (Jan 2000); Euro 2 (July 2004); Euro 3 (Sep-Oct 2006); Euro 4 (2010).
d) Delhi, Mumbai, Kolkata, Chennai, Hyderabad, Bangalore, Lucknow, Kanpur, Agra, Surat, Ahmedabad, Pune and Sholapur.

Source: Clean Air Initiative for Asian Cities, 2011.

Whilst each city has its unique set of environmental challenges, many core problems are shared, such as air quality concerns, noise pollution, traffic congestion and GHG emissions (EC, 2013b). At the EU level, the 7th Environment Action Programme identifies enhancing the sustainability of EU cities as one of its nine priority objectives. It aims to ensure that by 2020 the majority of EU cities are implementing policies for sustainable urban planning and design (EC, 2013b).

Cities have policy options that are tailored towards the local context and potentially very effective. In the area of car use, examples include parking regulations, limiting road space, car-free areas or days, and local taxes and charges. At the same time cities can further the attractiveness of alternative options through, for example, bicycle infrastructure and effective public transport systems (Otto-Zimmermann, 2011). In order to promote and reward efforts made by leading cities to improve the environment, the European Commission launched the European Green Capital Award in 2008. This not only recognises past efforts but also aims to incentivise further efforts and boost awareness (EC, 2014).

Better networking of cities has a crucial role to play in the diffusion and up-scaling of local innovations. For example, the Covenant of Mayors, launched by the European Commission in 2008, has created a network of cities commited to meeting or exceeding the EU's 20% CO_2 reduction targets by 2020 through an increase in energy efficiency and the use of renewable energy sources. Similarly, the C40 Cities Climate Leadership Group is a network of megacities that combined have nearly 300 million inhabitants and represent 10% of global carbon emissions. Member cities share technical expertise and best practice with the goal of reducing GHG emissions and climate risks. The actions they have initiated are being replicated by non-C40 cities (Bouteligier, 2013). As of 2014, fifteen C40 cities have made public commitments to reduce their emissions by 80% by 2050 encouraging other cities to work towards the same goal (Bloomberg and C40 Cities, 2014).

Cities also form hybrid networks with organisations, financial institutions and businesses. The European Innovation Partnership for Smart Cities and Communities, for example, aims to establish partnerships between industry and European cities to develop sustainable urban systems and infrastructure.

11.3 Implications

The growing scale and complexity of humanity's interactions and environmental impacts suggest that the new governance models outlined are both necessary and desirable. It is clear, however, that they bring a variety of uncertainties and risks.

Engagement and representation of interests

The mixture of opportunities and risks is certainly apparent in the increasing involvement of civil society groups in international governance processes. Undoubtedly, such engagement can increase inclusivity, transparency and democratisation, as well as contributing to the development of networks and shared norms. NGO engagement in international negotiations can also ensure representation for perspectives and interests that might otherwise be excluded, and can also foster knowledge exchange (Evans, 2012; UNEP, 2012).

On the other hand, it is also likely that increased participation at these summits can make discussions more complex and make it harder to reach consensus (OMCFG, 2013). Moreover, political equality can be threatened through the over-representation of certain interest groups. The influence of lobbyists representing economic sectors is significantly greater than that of civil society industries or the 'green' industry.

Among environmental NGOs there is also a risk of over-representation of popular subjects. For example, NGOs from developed regions focused heavily on rainforest protection in the 1980s, which strongly contributed to the emphasis on tropical forests in environmental governance. Peatlands, which present larger global carbon sinks than rainforests, were not represented by NGOs and therefore hardly appear on the global agenda (Evans, 2012).

Lack of coordination

The dispersion of authority to numerous actors pursuing varied interests is already producing a profound shortage of coordination in governance. The work of many non-state actors is sector specific, which increases the risk that links between different policy areas will be missed (Grevi et al., 2013).

Worse than a lack of coordination is direct competition between actors, which can result in inaction, wasteful use of funding and complications in national and international policymaking. For the EU, as for other stakeholders, progress in environmental governance will therefore mean striking the right balance between inclusiveness and effectiveness (Grevi et al., 2013).

The increasing number and diversity of actors involved in global governance could also mean that stakeholders are confronted with an ever increasing array of legislation, standards, norms and labels. The Ecolabel Index currently tracks 459 schemes covering 197 countries (Ecolabel Index, 2014). While these have an important role to play in environmental governance, a plethora leads to confusion and loss of trust (EC, 2013a).

Undermining state authority and lack of accountability

The rise of business and civil society in governance can have a mixed impact on democratic processes. At one level, it enables a larger number of stakeholders to shape governance approaches, affording a greater voice to grassroots organisations with a keen appreciation of local realities. At the same time, however, the growing role of non-state actors could well undermine the authority of elected governments, potentially threatening democratic processes.

While changing technologies and rules on access to information mean that government choices are increasingly subject to the scrutiny of empowered and interconnected citizens, a shift to non-state governance may reduce the democratic legitimacy, transparency and accountability of decision-making.

In elected parliamentary systems, decision-making processes and debates take place in the public domain, and the representatives involved are accountable to voters. In contrast, non-state actors are unelected and unaccountable, with their workings not always transparent. The funding and expenditure of non-state actors, for example, cannot necessarily be traced by members of the public and debates on policy and strategy tend to occur behind closed doors. This is a particular challenge where civil society engagement takes the form of short-term coalitions directed at specific issues — a process termed 'bazaar governance' (Demil and Lecocq, 2006). As non-state actors become more important in global governance, they will need to improve their transparency and accountability.

The extent to which the environment is already regulated means that the focus of governance has increasingly turned to how to make existing standards and norms work better. Experience suggests a need for flexibility and the right mix of hierarchical, market-based and network approaches. Risk assessment that addresses the state of the environment, pressures and conduct is likely to point to the need for a range of responses. Openness to different and evolving governance approaches is therefore highly desirable.

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