Cross-cutting Issues

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Chapter 4

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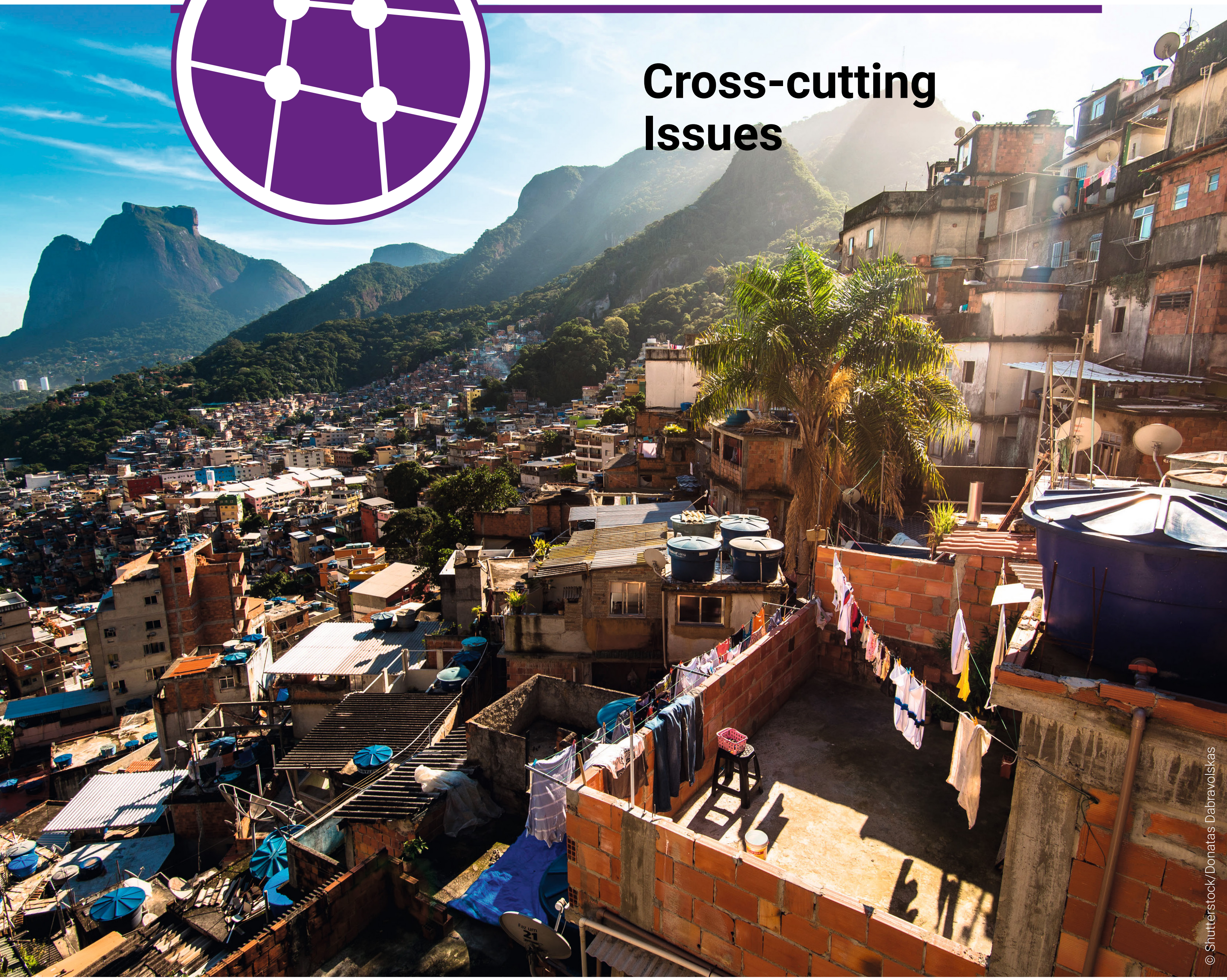

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Executive summary

Environmental pollution is still a major source of damage to the health of the planet (*well established*), **human health** (*well established*), **equity** (*well established*) **and economic sustainability** (*established but incomplete*). The risks, however, are systemic and wide-ranging, including climate change, ecosystem and biodiversity loss, wildlife damage, systemic change and other major issues. Sustainable development is possible if 'Healthy Planet, Healthy People' becomes central to our understanding of genuine progress. Solutions need to be both evidence-based and systemic, tackling sources of pollution, aiming for co-benefits and checking for unintended consequences. {4.2.1}

The number of people affected by both slow and sudden-onset environmental disasters is increasing due to compounding effects of multiple and interacting drivers (*well established*)**.** These drivers include climate change and environmental degradation, poverty and social inequality, demographic change and settlement patterns, increasing population density in urban areas, unplanned urbanization, unsustainable use of natural resources, weak institutional arrangements, and policies which do not consider disaster risk. Disasters undermine human security and well-being, resulting in loss and damage to ecosystems, property, infrastructure, livelihoods, economies and places of cultural significance while forcing millions of people each year to flee their homes. {4.2.2}

Gender equality and women's empowerment are multipliers of sustainability (*well established*). Ensuring gender-equal representation in environmental assessments, resource management and environmental decision-making ensures that diverse experiences and knowledge systems about the environment are integrated and ecosystem conservation and sustainable use of natural resources are enhanced. In this way, increasing gender equality and women's empowerment contribute to achieving the environmental dimension of the Sustainable Development Goals (SDGs). {4.2.3}

Significant progress has been made around the world with implementing education for sustainable development (ESD) in all educational sectors (*well established*). However, upscaling of ESD is still needed in order to include it as a core element in the structures of educational systems globally. In this way, education will contribute to achieving the SDGs. Policies are needed that eliminate economic and gender barriers to accessing education. {4.2.4}

Urban footprints have transboundary ramifications (*well established*). The magnitude, scale and scope of contemporary urbanization is now so large as to be affecting global resource flows and planetary cycles. At the same time, the current urbanization process and its prospects represent not only a challenge, they also represent an opportunity to improve human well-being with potentially decreasing environmental impacts per capita and per unit of production. {4.2.5}

Climate change is one of the most pressing issues affecting natural (*well established*) **and human systems** (*established but incomplete*) **(SDG 13).** The evidence of current global climate change is unequivocal. Worldwide, the average surface temperature has gone up by about 1.0°C since the 1850-1879 period; if the current rate of greenhouse gas emission persists by the 2040s warming will exceed 1.5°C. Eight of the ten warmest years on record have occurred within the past ten years. The impacts of climate change are much wider than temperature increase, affecting water availability, ecosystems, energy demand and production, transportation and other sectors. Shifts in weather patterns, extreme events (e.g. heat waves and droughts) and environmental disruptions (e.g. crop failures) result in greater risks to human health and well-being, and livelihoods, especially among the poorest and most vulnerable groups. {4.3.1}

Current observations and climate model experiments indicate that polar surface temperatures increases exceed twice the mean global temperature rise (*well established*). This amplified warming has cascading effects on other components of the polar-climate system, with sea ice in the Arctic retreating; permafrost thawing; snow cover extent decreasing; ice sheets decaying; and ice sheets, ice shelves and mountain glaciers continuing to lose mass, contributing substantially to sea level rise. {4.3.2}

Modern society is living in the most chemical-intensive era in human history, the pace of production of new chemicals largely surpasses the capacity to fully assess their potential adverse impacts on human health and ecosystems (*well established*). The risks to human health and ecosystem integrity produced by the combined effects of certain currently used chemicals, including in products, given their occurrence in the environment as a complex mixture, even in remote areas, are poorly understood and need further evaluation. Regulations, assessment and monitoring as well as industry and consumer responsibility, in informing and substituting the use of chemicals of global concern with safer alternatives are needed. Sustainable and green chemistry is aiming to achieve the sustainable design, production, use and disposal of chemicals throughout their life cycle, while taking into account the three dimensions of sustainable development. {4.3.3}

The disposal and discharge of waste to receiving environments is negatively impacting ecosystem and human health (*well established*). Issues of global concern include: increasing distribution and impact of marine litter, in particular plastic, in the world's oceans; the loss and wastage of approximately one-third of the food produced for human consumption; and increased trafficking of waste from developed to developing countries. While developed countries transition to reduced waste generation and greater resource efficiency, developing countries grapple with basic waste management challenges, including uncontrolled dumping, open burning, and inadequate access to waste services. {4.3.4}

The use of resources and the environmental impacts of resource extraction and use are growing despite a large potential for resource efficiency through circular economy and sustainable consumption and production approaches (*well established*)**.** Global resource use has accelerated since the year 2000 and reached 90 billion tons in 2017; high-income countries consume ten times the amount of resources that low-income countries consume; resource efficiency has been stagnant and the environmental impacts of resource use have been growing at a rate commensurate with overall resource use; there are many economically attractive opportunities for resource efficiency in the short term; in the medium and long term resource efficiency creates better economic outcomes compared with business as usual; there are considerable co-benefits of resource efficiency for climate mitigation.{4.4.1}

Coupled with efficiency improvements, transition to low-carbon energy sources has been accelerating globally over the last decade but it is still not sufficient to achieve the 2°C target of the Paris Agreement (*well established*), warranting bolder action in terms of technology innovation. Meanwhile the access of billions of poorer people to electricity and other modern energy services remains a challenge. {4.4.2}

The food system is increasing local to global pressures on ecosystems and the climate (*well established*). Farming is the most expansive human activity in the world and the principal user of fresh water. Food production is the main driver of biodiversity loss, a major polluter of air, fresh water and seawater, a leading source of soil degradation, and a significant source of greenhouse gas emissions. Changing consumption patterns are both increasing these pressures and presenting new food security challenges resulting in malnourishment, including overnourishment, as well as undernourishment. Climate change, natural resource constraints, and demographic trends suggest that the challenge of producing and distributing nourishing and sustainable food for all continues to escalate and will necessitate significant changes in food production and consumption. {4.4.3}

4.1 Introduction

As understanding of the interdependence between a healthy planet and healthy people becomes more developed, complex issues that thread through systems and societies gain new importance. Beyond the traditional Global Environment Outlook (GEO) themes addressing air, biodiversity, oceans, land and fresh water, this GEO-6 assessment addresses cross-cutting issues worthy of further examination. Using a systems approach, these cross-cutting issues offer entry points allowing another dimension for analysing GEO-6 themes as well as understanding the network of interconnections throughout earth and human systems. These cross-cutting issues are grouped according to shared characteristics: health, environmental disasters, gender, education and urbanization are grouped as 'people and livelihoods'; climate change, polar and mountain regions, chemicals and waste and wastewater are grouped as 'changing environments'; and resource use, energy and food systems are considered as 'resources and materials'. While each issue provides useful entry points into GEO-6 themes, it is important to discuss the state of the environment and policy context for each one.

As the deficiencies in our traditional issues-based approach to environmental assessment limit our ability to consider truly transformative pathways, cross-cutting and more integrated approaches are essential and must ultimately displace those based on single-issue analyses. Therefore, this chapter initiates a new approach in the GEO assessment process through an analysis of selected cross-cutting issues that illustrate the pressing need for more integrated and transformative policy responses. Given the global scale of the GEO-6 assessment, the chapter can address only a few cross-cutting issues, threads and influences among the myriad possible combinations. The cross-cutting issues selected for this assessment are chosen because of their close alignment with the SDGs and the fact that the scope and influence of these different issues vary dramatically over time, scale and region.

Given the obvious intersections among these cross-cutting issues, a number of emerging issues arose in regard to taking a 'Healthy Planet, Healthy People' perspective. This chapter addresses the health of the environment, the consequences for human health from pollution of all kinds, climate change impacts, environmental disasters and unsustainable consumption of natural resources, as well as the longer-term health effects of rapid and intense changes to lives, livelihoods and the environment, which require a wider focus.

The policy implications of addressing these cross-cutting issues converge on four particular human and economic systems that could accomplish the required transformation into a healthy planet supporting healthy people. Contributions from all 12-issue teams, including insights from at least 50 issue specialists from around the world, developed into system studies on climate change adaptation, sustainable food, clean energy systems and a more circular economy. The products of these collaborative efforts are presented in Chapter 17 (Part B) of this report.

4.2 People and livelihoods

4.2.1 Health

The public health community has two long-established ways of reflecting the complex web of relationships between healthy planet and healthy people that is central to GEO-6. One way is to define human health inclusively as "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (World Health Organization [WHO] 1948), and then use 'well-being' (Glatzer *et al.* 2015; Maggino 2015) together with 'health' to incorporate the psychological, emotional and social dimensions. The second way focuses on the determinants of health: it recognizes that human health is mediated by multiple factors in the natural, social and built environments, including our senses of equity and safety as well as equitable access to environmental resources and human contact with nature (WHO 2008). So, while human health is the direct focus of Sustainable Development Goal (SDG) 3, this complexity links health and well-being directly and indirectly to all the SDGs (e.g. Section 20.3.1) and to issues throughout GEO-6, including the thematic chapters and other cross-cutting topics.

Buse *et al*. (2018) identify six frameworks developed from late 20th century onward to show and deal with this complexity: political ecology of health, environmental justice, Ecohealth, One Health, Ecological Public Health, and Planetary Health. These frameworks represent a shift towards a more sophisticated understanding of the implicit, complex and systemic links between human health and well-being and the natural environment. They build on an older tradition (from the mid-19th century), of 'occupational and environmental health'. This is narrower (e.g. Ayres *et al*. eds. 2010) than the more recent frameworks in two ways. First, health is often interpreted as risk of death and disease or illness, referred to as mortality and morbidity, rather than as the more holistic health and well-being. Second, it focuses on the physical, chemical and biological spheres, rather than on the social as well as determinants of health.

Within this traditional but narrow framework of pollution and disease, this report shows numerous examples of how health is damaged by environmental changes including air, water and land pollution; heat waves, flooding and other weather extremes; toxic chemicals; pathogens; ultraviolet and other radiation; desertification; reduced biodiversity; melting of polar ice; and destruction of coral reefs. Overall, "natural systems are being degraded to an extent unprecedented in human history" (Whitmee *et al*. 2015, p. 1,974) and the damage to human health is already severe. For example, the Lancet Commission on pollution and health (Landrigan *et al.* 2017) estimated that diseases caused by environmental pollution resulted in 9 million premature deaths in 2015. The biggest effects are from exposure to outdoor and indoor air pollution, which together caused 6.4 million deaths in 2015 (Cohen *et al.* 2017). More generally, the incidence of non-communicable diseases is on the rise globally and will continue to be affected by the state of the environment in relation to pollution, diet and physical (in)activity. However, human health depends on much more than a healthy planet.

Similarly, Prüss-Ustün *et al.* (2016) estimated that in 2012 modifiable environmental health risks caused 12.6 million deaths globally, representing 23 per cent (13-34 per cent, 95 per cent confidence interval [CI]) of all deaths. These are big impacts, but nevertheless they show that even if it were desirable and feasible to attain a healthy, sustainable planet without addressing socioeconomic issues and associated determinants of health, it would still leave humanity far short of the goal of 'healthy people' (see also Section 20.3.1).

Environmental pressures and their impacts on health and well-being are not equitably distributed. They fall especially on groups that are already vulnerable or disadvantaged, such as young people and elders, women, poor people, those with chronic health conditions, indigenous peoples and people targeted by racism (Solomon *et al.* 2016; Landrigan *et al*. 2017, pp. 27-31). For example, unsafe food and water can cause diarrhoeal diseases (Mills and Cumming 2016), with children under five in sub-Saharan Africa and South Asia being the most affected (Walker *et al.* 2013; Prüss-Ustün *et al.* 2014) (SDG 3 notes that four out of every five deaths of children under age five occur in these regions).

New challenges (which may be countered by relevant, sound, scientific research) include the growth of resistance of pathogens to antibiotics (antimicrobial resistance) that have been, and are, used heavily in agriculture and aquaculture (Finley *et al.* 2013; Wallinga, Rayner and Lang 2015); the multitude of industrial chemicals (though not all are widely used) that challenges our ability to meaningfully test their potential impacts on environmental and human health, including for future generations (The American Society of Human Genetics *et al.* 2011; Sharma *et al.* 2014; Landrigan *et al*. 2017); the cumulative effect (both social and environmental) of multiple exposures, including those of chemical mixtures (Solomon *et al.* 2016); emergence and re-emergence of infections originating in birds and animals (Ostfeld 2009; Lindahl and Grace 2015; Hassell *et al.* 2017); increased physical inactivity associated with new technology for work and leisure; and others including some whose effects on human health are currently unclear (e.g. the presence of microplastics in fish and marine biological resources).

Solutions to the degradation of natural systems, including the management of environmental pollution at its sources, should take account of the complex interactions between planet and health (Whitmee *et al.* 2015) and consider environment-health as a complex system, seeking co-benefits (Haines 2017), and where practicable avoiding trade-offs or win-lose situations or unintended adverse consequences (von Schneidemesser *et al*. 2015). There are now many examples of health co-benefits, especially of greenhouse gas reductions (Chang *et al.* 2017; Quam *et al.* 2017; Deng *et al.* 2018). For example, the unfolding transition to cleaner energy improves air quality and slows climate change effects, each of which greatly benefits health and well-being (Smith *et al.* 2014a; Haines 2017; see also Section 4.2.1). Active travel, such as walking and bicycling, can have multiple benefits for health and well-being (Saunders *et al.* 2013; Smith *et al.* 2014a); however, benefits will vary with (for example) climate and pollution levels. Reducing red meat intake per capita where there is high consumption, especially of processed meat, will improve human health (McMichael *et al.* 2007; Wolk 2017), while reducing pressure on biodiversity and greenhouse gas emissions, including methane. The benefits to human health and well-being of access to safe and biodiverse natural environments, green and blue spaces, are being recognized (Coutts and Hahn 2015; Wolf and Robbins 2015; Wall, Derham and O'Mahony eds. 2016; Grellier *et al.* 2017).

Rigorous incorporation and integration of human health considerations within health-determining sectoral plans (e.g. agriculture, water, disaster management, urban design) can support responses that address human health impacts, with a focus on prevention activities. Initiatives to reduce environmental risks, focusing on benefits across sectors, are consistent with the World Health Organization's (WHO) call for Health in All Policies (WHO 2014) and the development of tools for integrated environmental and health assessment (Fehr *et al.* 2016). The health sector must rapidly strengthen the way that it articulates messages on human health and emphasize that the majority of environmental pressures will ultimately have human health impacts.

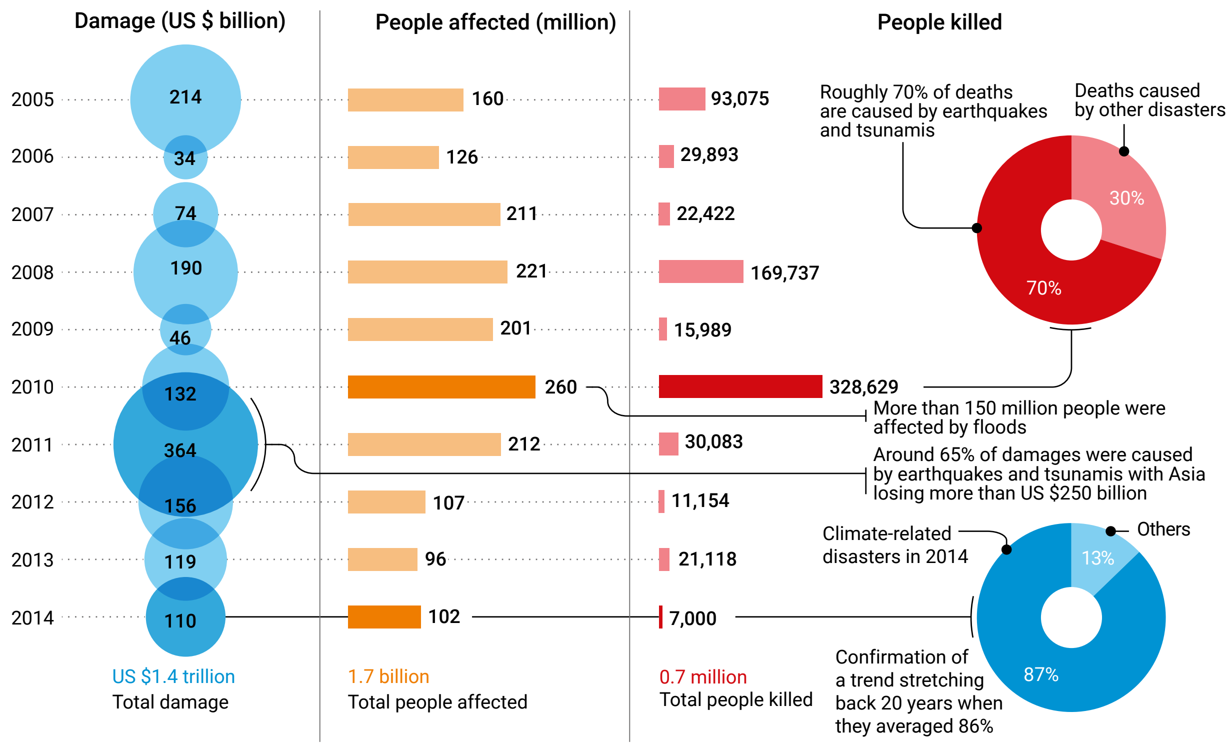
More fundamental changes may be needed, for example "the redefinition of prosperity to focus on the enhancement of quality of life and delivery of improved health for all, together with respect for the integrity of natural systems" (Whitmee *et al.* 2015). This view resonates with intentions to keep the GEO-6 goal of Healthy Planet, Healthy People central to our understanding of genuine progress.

4.2.2 Environmental disasters

Hazards become disasters when they disrupt human communities. Therefore, the consequences of these disasters are as much a part of where and how people live as the presence of the hazard itself (Sun 2016, p. 30). This includes anthropogenic effects on the climate, but also disasters directly caused by human activities such as oil spills, accidents at nuclear power stations or other hazardous installations, and even earthquakes triggered by fracking and the building of large dams (Legere 2016). Sudden-onset disasters, such as earthquakes, tsunamis, landslides, flash floods and severe storms, are distinguished from slow-onset events, experienced as drought, desertification, sea level rise and coastal erosion. Slow-onset events comprise as much as 90 per cent of disasters worldwide and threaten growth, development and livelihoods (Lucard, Jaquemet and Carpentier 2011). Development and disaster risk are closely linked; decisions regarding the management of natural resources and development pathways determine patterns of vulnerability and exposure to a range of environmental hazards. Disasters, in turn, can set back development gains by years or even decades, at immense social and economic cost. Over the long or short term, these decisions and their management can act as drivers of migration and displacement (United Kingdom Government Office for Science 2011). They can also affect peace and security (Schilling *et al.* 2017).

Environmental disasters are affecting an increasing number of people globally and taking an ever-larger toll on societies and economies, particularly in the poorest communities and countries. Between 2005 and 2015, they affected more than 3 billion people (Centre for Research on the Epidemiology of Disasters 2017). This is partly due to an increase in frequency and magnitude of climate and hydrometeorological hazards

Figure 4.1: The economic and human impact of disasters in the last ten years



Source: United Nations Office for Disaster Risk Reduction (UNISDR) 2014

such as tropical cyclones, fires and floods. However, social and economic processes that increase exposure to hazards by placing more people, infrastructure and economic activities in harm's way significantly escalate disaster risk. For example, migration away from rural drought to overcrowded, poorly planned, coastal megacities in flood-prone zones can increase mortality, displacement, health and disaster risks in urban areas.

In some cases, disasters result from the combined effect of several interacting hazard events. The 2011 Tohoku disaster in Japan exemplified such a case when a sequence of cascading events occurred, including an earthquake, a tsunami and a nuclear power plant accident, all contributing to 15,893 casualties. The disaster forced more than 350,000 people into protracted displacement (i.e. displacement of more than one year) and cost an estimated US$ 210 billion in direct damage. Disasters also disproportionately affect some of the most vulnerable populations; 54 per cent of fatalities from the Tohoku disaster were women and girls, and 56 per cent were above age 65 (Leoni 2012). To date, it remains the most expensive environmental disaster in history (Ranghiere and Ishiwatari eds. 2014, pp. 2, 269, 284).

The consequences of disasters are far-reaching and long lasting. In 2016 alone, 24.2 million people in 118 countries became newly internally displaced by sudden-onset disasters (Internal Displacement Monitoring Centre [IDMC] 2017, p. 10). They outnumbered those who were newly displaced by conflict and violence three to one (IDMC 2017). Precipitation shocks, droughts, floods and storms in Philippines, for example, correspond with significant intensifications of conflict (Eastin 2016, p. 12). The Protection Agenda of the Nansen Initiative, endorsed by 109 governments in 2015, is a key instrument to foster the protection of the rights of those displaced across borders by disasters. The Platform on Disaster Displacement, established in 2016, is tasked with supervising implementation of the Agenda and following up on the work carried out by the Nansen Initiative between 2012 and 2015 (Disaster Displacement 2017). In many cases, drivers of displacement are difficult to disentangle from other destabilizing factors. The African Union's Kampala Convention, a legally binding protection instrument shielding those displaced by conflict, violence and human rights abuses alongside disasters, is an important step in recognizing these interactions (African Union 2009).

Learning from past disasters and shifting from a culture of disaster response to one of prevention, preparedness and resilience is imperative. While initiatives such as disaster response and recovery strategies have been formulated in many countries following disaster events, the number of countries that have incorporated prevention, mitigation and preparedness as part of a comprehensive disaster risk reduction strategy remains quite low (Ranghiere and Ishiwatari eds. 2014, p. xv). The Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR 2015) represents a new opportunity to further improve disaster risk reduction efforts. Improvements can be achieved by mobilizing and prioritizing investments, enhancing policy and institutional coherence, promoting innovation and technological development, increasing collaboration and cooperation, and mainstreaming disaster risk reduction in development and climate change adaptation efforts.

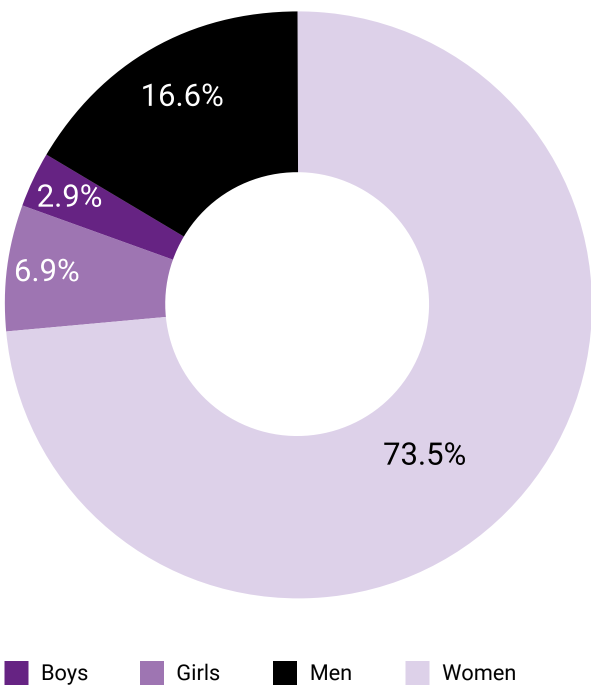
4.2.3 Gender

A gender approach redefines the environmental situation through the lens of social relationships and their reflection in human-environment interactions, instead of defining the state of the environment primarily in its physical or ecological forms. Gender analysis reveals that while systemic environmental problems typically manifest in physical landscapes and ecosystems, the state of the environment can only be explained by examining social, cultural and economic systems and arrangements. Those structures are 'gendered': they are shaped by socially constructed roles and relationships between women and men. For example, in *The State of Food and Agriculture 2010-11* paragraph 4.3.3 on 'Food systems' the role of women in agriculture is underlined (Food and Agriculture Organization of the United Nations [FAO] 2011).

Figure 4.2 shows that women's and girls' responsibilities in collecting water is much larger than that of men and boys (United Nations Entity for Gender Equality and the Empowerment of Women [UN-Women] UN Women 2015; Sagrario and Willoughby 2016; United Nations Environment Programme [UNEP] 2016a; WHO 2017).

Assessments of the economic value of environment-related sectors are often seriously distorted because women's contributions are overlooked (see also Section 4.1.3). For example, the economic work of women in fisheries continues to be undercounted, partly because fishing is often defined only as catching fish at sea with specialized equipment. This type of fishing is highly masculinized (Harper *et al*. 2013; UNEP 2016a; Harper *et al.* 2017). Women's tasks in the fishing sector focus on coastal fishing, fish processing and trade, and are often neglected (Lambeth *et al*. 2014). Throughout this publication, some other examples of the gender-environment relationship are included.

Figure 4.2: Percentage distribution of the water collection burden across 61 countries



Source: UNICEF and WHO (2017, p. 30).

The scholarly and practitioner field of gender and environment has been developing since the 1980s and is now a large and robust domain of analysis and assessment (Skinner 2011; Aguilar, Granat and Owren 2015). Early directions in this field focused on identifying the gender-differentiated impacts of environmental change (Dankelman and Davidson 1988). Now, an emerging focus is examining the ways in which the drivers of environmental change are also gendered, rooted in socially constructed norms of masculinity and femininity, including in our economies, sciences and technologies (Harcourt and Nelson eds. 2015; UNEP 2016a). Revealing the gendered dimensions of environmental dynamics illuminates new aspects of environmental states and trends, as well as pointing out pathways for transformations and policy solutions that are sustainable. The Global Gender and Environment Outlook, which elaborates on the importance of gender in most environmental areas, provides the first comprehensive global assessment of the gender-environment nexus and offers a channel for gender analysis in GEO-6 (UNEP 2016a). Applying a gender lens to environmental assessment also creates awareness of the relevance of additional social dimensions and intersections in environmental use and management, such as differentiation by class, race or ethnicity, caste and age (Harris 2011).

Recent studies recognize the diverse roles of men and women in collecting forest products and their related diverse knowledge systems (Sunderland *et al.* 2014; Chiwona-Karltun *et al.* 2017). Evidence from studies on community forest management point to the understanding that women's participation in environmental assessment and resource management can enhance ecosystem conservation and sustainable use of natural resources (Agarwal 2010; Agarwal 2015).

Other evidence suggests that when women are accorded equal voice in environmental decision-making, public resources are more likely to be directed towards human development priorities and investments (Chattopadhyay and Duflo 2004; UN-Women 2014). Women's enhanced access to and control over productive agricultural resources helps create food security and sustainable livelihoods (FAO 2011; UN-Women 2014). The use of gender budgeting is another important approach to promote gender-responsive financing. The SDG framework reveals that sustainable development will not evolve, nor will environmental policies and initiatives be effective, if gender equality and women's empowerment are not enhanced (United Nations 2015a). Environmental sustainability and justice contribute significantly to SDG 5: achieving gender equality and empowering all women and girls, and to the gender targets of SDGs 1, 4, 8 and 10 (Agarwal 2010; UNEP *et al*. 2013; Agarwal 2015; United Nations 2015b; Dankelman 2016; UNEP 2016a). While gender equality can be tacitly read in all the other SDG goals, there are almost no explicit gender targets and indicators included in the environment-related SDGs.

Bringing gender perspectives to bear on environmental frameworks is not a matter of simply adding 'women' into environmental analyses. Approaching the environment through a gender lens means new and different questions in environmental assessment, emphasizing different dimensions of human-environment relationships and requiring gender-responsive methodological tools and approaches, as well as gender-disaggregated data (Patt, Dazé and Suarez 2009; Doss 2014; Seager 2014; Bradshaw and Fordham 2015; Harcourt and Nelson eds. 2015; Jerneck 2018). Given the difficult state of the environment, the persistence of drivers of environmental change, and the severity of societal and ecological consequences that societies face, a gender-integrative approach is a precondition for more effective and transformative environmental policies and interventions.

4.2.4 Education

Education for Sustainable Development (ESD), a key area of education, reaching gender equality, developing healthier and more sustainable lifestyles, and creating more peaceful societies. However, this requires access to education for all and a high quality of education (United Nations Development Programme[UNDP] 2016; United Nations Educational, Scientific and Cultural Organization [UNESCO] 2017a). Despite all efforts to provide all children worldwide with access to education, this is still not a reality for all children. "Worldwide, 91 per cent of primary-school-age children were enrolled in school in 2015" (UNICEF 2018). "In 2015, there were 264 million primary and secondary age children and youth out of school: 61 million children of primary school age (9% of the age group), 62 million adolescents of lower secondary school age (16%), and 141 million youth of upper secondary school age (37%)" (UNESCO 2017a, p. 118). Also gender equality is still a major challenge: "While there is gender parity in education participation, global averages mask gaps between countries: only 66% have achieved gender parity in primary education, 45% in lower secondary and 25% in upper secondary" (UNESCO 2017a, p. 182). Education for Sustainable Development, a key area of education, aims to enable individuals to contribute to fostering sustainable development. Instead of promoting certain behaviours and ways of thinking (instrumental approach), an emancipatory concept of ESD concentrates in particular on the critical reflection on expert opinions, testing possibilities of sustainable development and exploring the trade-offs of a sustainable lifestyle (Wals 2015; UNESCO 2017b; Rieckmann 2018). It aims to empower individuals to act responsibly in order to contribute to the creation of sustainable societies, and to prepare them for disruptive thinking and the co-creation of new knowledge (Lotz-Sisitka *et al*. 2015; UNESCO 2017b), but also for exploring and using traditional and indigenous knowledge.

With the overall aim to develop cross-cutting sustainability competencies within learners (Wiek, Withycombe and Redman 2011; Rieckmann 2018), ESD is an important contribution to achieving the SDGs: it enables all people to contribute to achieving the SDGs by providing them, not only with the knowledge to understand what the SDGs are all about, but also the competencies to make a difference towards a more sustainable society (UNESCO 2017b).

The emancipatory ESD approach asks which key competencies are needed for learners to be 'sustainability citizens' (Wals and Lenglet 2016). Various key competencies essential to sustainable development have been outlined (e.g. Wiek, Withycombe and Redman 2011; Rieckmann 2012; Glasser and Hirsh 2016; Wiek *et al.* 2016) – describing what individuals need to be able to do to transform their own individual lifestyles to more sustainable ones and to contribute to societal transformation towards sustainability. In the international ESD discourse, there is agreement that the following key competencies are of particular importance for thinking and acting in favour of sustainable development (UNESCO 2017b; Rieckmann 2018):

- Systems thinking competency
- Anticipatory competency
- Normative competency
- Strategic competency
- Collaboration competency
- Critical thinking competency
- Self-awareness competency
- Integrated problem-solving competency

However, while competencies describe the capacity or disposition of acting, they do not necessarily imply that an individual will act in a certain way in a specific situation. Sustainability-oriented performance depends on the interplay of knowledge and skills, values and motivational drivers, and opportunities (Biberhofer *et al.* 2018). The interrelation of these dimensions influences personal behaviour **(Figure 4.3)**.

ESD is directly related to the other cross-cutting issues. It enables people, for example,

- "to act in favour of people threatened by climate change", and "to promote climate protecting public policies" (UNESCO 2017b, p. 36);
- "to develop a vision of a reliable, sustainable energy production, supply and usage in their country", and "to apply and evaluate measures in order to increase energy efficiency and sufficiency in their personal sphere and to increase the share of renewable energy in their local energy mix" (UNESCO 2017b, p. 24);
- "to communicate the need for sustainable practices in production and consumption", and "to challenge cultural and societal orientations" (UNESCO 2017b, p. 34);
- "to reflect on their own gender identity and gender roles", and "to plan, implement, support and evaluate strategies

Figure 4.3: Key competencies and performance of sustainability citizens

Source: Rieckmann (2018).

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for gender equality" (UNESCO 2017b, p. 20); and
- "to encourage others to decide and act in favour of promoting health and well-being for all", and "to include health promoting behaviours in their daily routines" (UNESCO 2017b, p. 16).

ESD is at the heart of teaching and learning and should not be seen as a complement to the existing curriculum. "Mainstreaming ESD requires integrating sustainability topics into the curricula, but also sustainability-related intended learning outcomes" (UNESCO 2017b, p. 49). Since sustainability competencies cannot be taught or conveyed, but can only be developed by the learners themselves, an action-oriented transformative pedagogy is required (Mindt and Rieckmann 2017; UNESCO 2017b; Rieckmann 2018). In addition to the formal education curricula, ESD should also be promoted by non-formal and informal education. Community engagement and local learning can also play an important role, especially for involving traditional and indigenous knowledge into the learning process.

During the United Nations Decade for Education for Sustainable Development (2005-2014) (DESD) significant progress was made around the world with implementing ESD in all educational sectors (e.g. McKeown 2015; Watson 2015). Monitoring and evaluation of the DESD has shown many good examples of integrating ESD in curricula. Reviews of official curriculum documents show that "many countries now include sustainability and/or environmental themes as one of the general goals of education" (UNESCO 2014, p. 30). Most progress has been made in developing curricula towards ESD in primary and secondary education. "Close to 40% of Member States indicate that their greatest achievement over the DESD has been the integration of ESD into formal curricula, with another fifth describing specific school projects as being their most important contributions to ESD" (UNESCO 2014, p. 82). There has also been good progress with the implementation of ESD in higher education (Karatzoglou 2013; Lozano *et al.* 2015). This is particularly the case in Europe, where there has been a stronger interest in the integration of sustainable development in higher education institutions than in other parts of the world (Lozano *et al.* 2015; Barth and Rieckmann 2016).

However, upscaling of ESD is still needed in order to include it as a core element in the structures of educational systems (Singer-Brodowski *et al.* 2018). The Global Action Programme on Education for Sustainable Development, which was launched in 2014 at the UNESCO World Conference on ESD in Aichi-Nagoya, Japan, has five priority areas:

1. advancing policy;
2. transforming learning and training environments;
3. building capacities of educators and trainers;
4. empowering and mobilizing youth; and
5. accelerating sustainable solutions at local level.

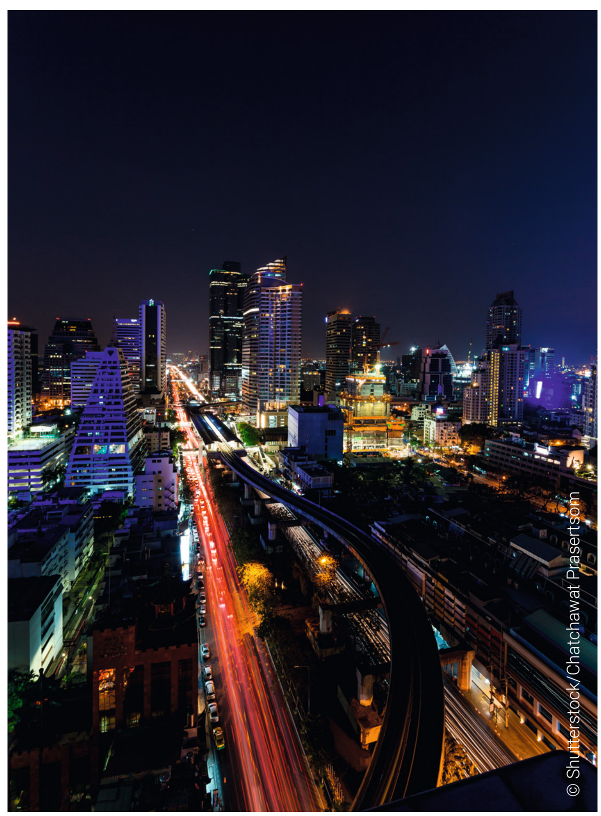
It strives to scale up ESD, building on the DESD (Hopkins 2015; Mickelsson, Kronlid and Lotz-Sisitka 2018). Of particular importance in this context is the increased integration of ESD into (pre-service and in-service) teacher education. "Efforts to prepare teachers to implement ESD have not advanced sufficiently. More work still needs to be done to reorient teacher education to approach ESD in its content and its teaching and learning methods" (UNESCO 2017b, p. 51). For achieving this reorientation of teacher education towards sustainable development, it is necessary to form strategic institutional alliances among national, regional and local governments, non-governmental organizations, universities and other educational institutions involved in teacher education. Further challenges for scaling up ESD are:

- integrating ESD in policies, strategies and programmes;
- integrating ESD in curricula and textbooks;
- delivering ESD in the classroom and other learning settings;
- and changing the ways ESD learning outcomes and the quality of ESD programmes are assessed (UNESCO 2017b).

In order for all learners to benefit from ESD and to develop sustainability competencies, policies are needed that eliminate economic and gender barriers to access to education.

4.2.5 Urbanization

As explained in Section 2.3, urbanization is a major driver shaping the economy, the environment, the planet and human well-being worldwide. About 54 per cent of the world's population lives in urban areas that collectively generate more than 80 per cent of the world's gross domestic product (GDP) (United Nations Human Settlements Programme [UN-Habitat] 2011; UN-Habitat 2016a). By the year 2050, about 6.7 billion people – some 66 per cent of the world total population of 9.7 billion – are expected to be living in cities, adding 3.1 billion to cities' populations over the short span of about 40 years (United Nations 2018). While all world regions (except polar regions) will continue to urbanize, 90 per cent of future urban population growth is expected to occur in Africa and Asia (UN-Habitat 2014).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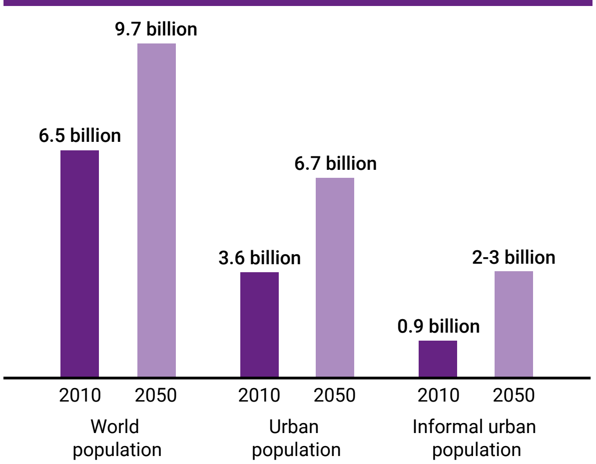
Cities are centres of innovation and historically they experience economies of scale with GDP increasing linearly with city population numbers (Bettencourt 2013). This capacity for innovation and wealth-generation, enabled by proximity and activity-intensity, is one of the features that attracts migrants to cities (International Organization for Migration [IOM] 2015), and will lead to an expansion of urban population by 2050 **(Figure 4.4)**. However, the wealth of cities is not distributed equally across the globe, with only 600 cities contributing more than 62 per cent of the global GDP (UN-Habitat 2011).

There is also significant inequality within cities, with a staggering 2 to 3 billion people –35 to 50 per cent of the urban population in 2050 – expected to be living in informal settlements (UN-Habitat 2014; UN-Habitat-2016a: UN-Habitat 2016b). Urbanization is associated with lower fertility rates, longer life expectancy, and better access to basic physical infrastructure and social amenities such as education and health care. However, inequality, crime and social exclusion are becoming characteristics of many urban areas, where living conditions are deteriorating in relation to the rural origins of many migrants (United Nations 2014).

Cities face huge challenges regarding social inclusion and improved provisioning of basic physical services. Energy, water, buildings, transportation and communication, food, public spaces and waste management emerge as key factors that shape the effect of cities on people, the environment and the planet.

The magnitude, scale and scope of contemporary urbanization is now so large as to be affecting global resource flows and planetary cycles. Urbanization is affecting the entire planet, not solely the areas defined as urban. Through networks of trade, migration and infrastructure, cities are influencing the natural environment well beyond their administrative boundaries (Wiggington *et al.* 2016). For example, although directly occupying only 3 per cent of the world's land area, energy supply to cities contributes more than 70 per cent of the world's energy-related carbon emissions (Seto *et al*. 2014). Direct water supply to cities puts pressure on 42 per cent of the world's watersheds (McDonald *et al.* 2014). In addition, water embodied in food supplied to cities exceeds direct water requirements in urban areas by more than a factor of ten (Ramaswami *et al.* 2017).

Figure 4.4: World urbanization trends



Source: Own elaboration based on (UN-Habitat 2014; UN-Habitat 2016a; UN-Habitat 2016b; United Nations 2018)

Urban footprints that represent both the bounded and transboundary ramifications that cities have on natural resources and the environment are essential to characterize the consequences of different urban activities, such as household consumption, production and community-wide infrastructure provisioning, and to chart pathways towards a sustainable future. In some regions, urban areas are de-densifying: urban population growth at declining densities leads to urban land expansion, which, in ecologically sensitive regions, can cause habitat fragmentation and contribute to large-scale biodiversity loss (Seto, Guneralp and Hutyra 2012).

Cities also face management and technological transformative opportunities. Around 60 per cent of the urban area required to accommodate the urban population of 2050 is yet to be built (Secretariat of the Convention on Biological Diversity [SCBD] 2012). Once built, it will last for at least the next 40 years. The bases of urban structures (e.g. street networks, blocks) "can affect and lock in energy demand for long time periods" (Seto *et al.* 2016).

At the same time, existing cities in advanced economies are repairing or replacing ageing infrastructures. Several infrastructural innovations are on the horizon in cities of both developed and developing countries that can enhance equity, resource efficiency and environmental sustainability. These innovations include new strategies for shared mobility, *in situ* slum rehabilitation, a One-Water approach to urban water management, urban-industrial symbiosis based on sustainable production and consumption through a circular economy, electric and autonomous vehicles for mass transit and private trips, and distributed renewable energy to achieve a decarbonized and resilient grid. Cities around the world are experimenting with infrastructure involving technology, human behaviour, financing and novel governance arrangements. This provides a historic opportunity and the imperative to build inclusive and sustainable infrastructure (UNEP 2013a). Successful urbanization relies on human as well as infrastructural assets.

Urban areas will continue to act as generators of economic growth and, through fertility and migration, they will continue growing in population and size. This can result in increased impacts of cities, but also in potential decreases in impacts per unit of production and per capita. As stated in the Section 2.3 of this report, there are clear challenges and opportunities that urgently need to be understood and addressed. These are related as much to governance as to technology, as is highlighted in Part B of this report (UNEP 2017).

4.3 Changing environments

4.3.1 Climate change

As explained in Section 2.7, climate change is driven by modifications in atmospheric composition due to land-use change, primarily deforestation, and to greenhouse gas (GHG) emissions, such as CO_2 emitted through fossil fuel burning and methane released from agriculture and other sources, as well as the emissions of aerosol particles (Vaughan *et al.* 2013). The evidence of current global climate change is unequivocal (Vaughan *et al.* 2013).

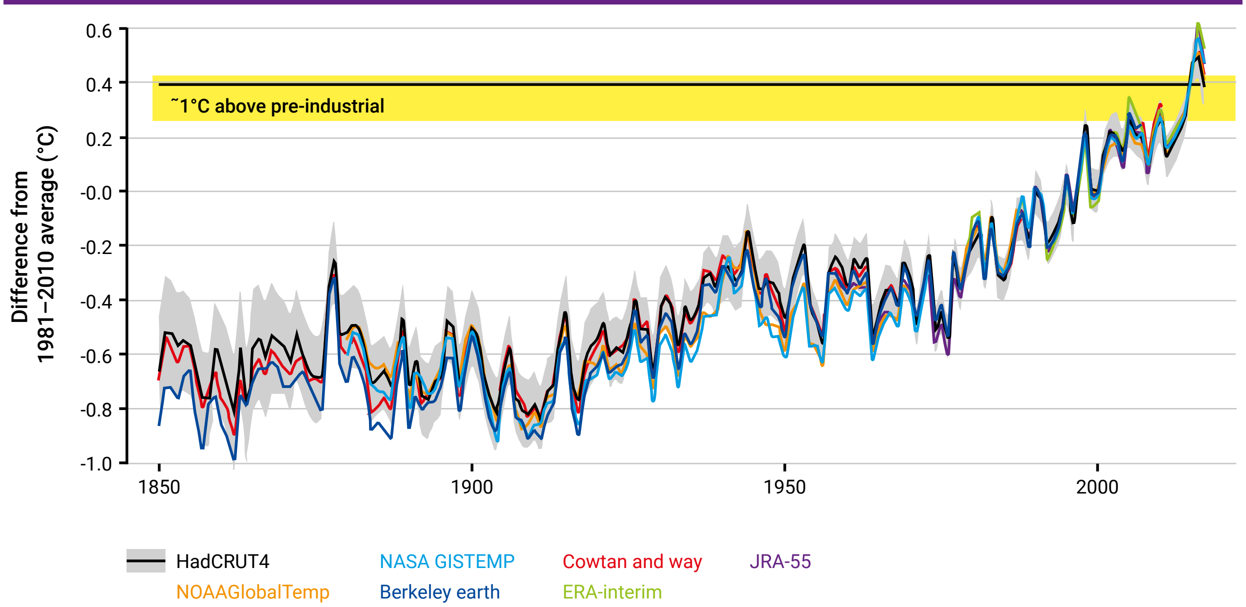
Eight of the ten warmest years on record have occurred within the past decade (United States National Oceanic and Atmospheric Administration [NOAA] 2018). Within this period, 2016 was the warmest year in the history of instrumental observation (NOAA 2017), and 2017 was the warmest year without an El Niño influence (NOAA 2018). As a result, global warming has reached approximately 1.0±0.2°C above the pre-industrial level (**Figure 4.5,** Haustein *et al.* 2017; Yin *et al.* 2017).

The current GHG emission rate, if it persists, will result in continuation of the current rate of global temperature increase of ~0.2°C per decade (e.g. Haustein *et al.* 2017), crossing the 1.5°C Paris Agreement target by the 2040s (Leach *et al.* 2018). While not unattainable, the goal of limiting warming to 1.5°C requires transformational changes leading to radical reduction of GHG emissions and expedited transition to carbon neutrality (Schellnhuber, Rahmstorf and Winkelmann 2016), that requires balancing of remaining anthropogenic CO_2 emissions with anthropogenic CO_2 removals.

Climate change modifies the water cycle by altering precipitation patterns and seasons. In general, dry areas are becoming drier, and wet areas are becoming wetter (Trenberth 2011; Intergovernmental Panel on Climate Change [IPCC] 2014; Feng and Zhang 2015), but numerous exceptions exist. Additionally, the increased water-holding capacity of warmer air leads to more extreme rainstorms that arrive less frequently (Trenberth 2011). Higher temperatures increase evapotranspiration rates and shift precipitation from snow to rain. A warmer atmosphere also governs the growth, melt and discharge of glaciers (Bliss, Hock and Radić 2014). These hydrological modifications determine river flows and the risks of early spring flooding and summer drought (Seneviratne *et al.* 2012; Cook *et al.* 2014; Kundzewicz *et al.* 2014). Changes in flow patterns alter water availability and, at the same time, higher temperatures increase demands from and competition among agricultural, industrial and domestic users (Hanjra and Qureshi 2010; Jiménez-Cisneros *et al.* 2014).

Oceans play an important role in climate regulation, having stored 93 per cent of the additional heat absorbed by the earth system since 1955. During that period, land has taken up 3 per cent of the heat absorbed, ice another 3 per cent, and the atmosphere only 1 per cent (IPCC 2013; Levitus *et al.* 2012). Heat-induced expansion of ocean water contributes to the observed sea level rise that has been accelerating over the past two decades; this trend will continue into the future even if the warming is limited to 1.5°C (Schewe, Levermann and Meinshausen 2011). Higher sea levels increase risks from storm surges for vulnerable small islands, coastal communities and exposed infrastructure. Oceans also absorb CO_2 from the atmosphere. Estimates suggest that, of all the CO_2 released to the atmosphere from human activities since the beginning of the industrial era, approximately 40 per cent has been absorbed by oceans (IPCC 2013; Khatiwala *et al.* 2013), resulting in a reduction of seawater pH (acidification), referred to as 'the other CO_2 problem' (Caldeira and Wickett 2003; Doney *et al.* 2009). This ocean acidification combines with warmer water temperatures and de-oxygenation processes to alter ocean

Figure 4.5: Global annual average temperature anomalies (relative to the long-term average for 1981-2010). Labelling designates different data sets; for explanation refer to the source



Source: United Kingdom Government Met Office (2018) ecosystems (Achterberg 2014), most visibly as coral bleaching (see Chapter 7) when symbiotic algae are expelled from the reefs, reducing or ending their productivity (Fabry *et al.* 2008).

Estimates suggest that approximately 20 per cent of fossil-fuel CO_2 emissions are absorbed by land ecosystems (Arneth *et al.* 2017). Increased concentrations of CO_2 in the atmosphere may eventually benefit some C_3 crops[1], a category that includes wheat and beans, through carbon fertilization (McGrath and Lobell 2013). Warmer temperatures could bring yield gains in high-latitude regions, if soil and precipitation characteristics are suitable (IPCC 2014). Seventy per cent of global agriculture is rain-fed, and shifting rainfall patterns may benefit certain regions, but higher temperatures generally cause water stress that limits yields (Lobell, Schlenker and Costa-Roberts 2011; Challinor *et al.* 2014). Despite potential local yield increase, at a global level, yields are expected to suffer due to elevated risks from droughts and heat stress (Schlenker and Roberts 2009; Lobell and Gourdji 2012; Jiménez-Cisneros *et al.* 2014; Porter *et al.* 2014). Additionally, climate change, together with direct effects of rising atmospheric CO_2 concentration, has also been demonstrated to benefit invasive plant species (Ziska and Dukes eds. 2014).

Climate change also affects forest productivity, including increased stress from droughts, wildfires, insects, pathogens and windstorms (Williams *et al.* 2013; IPCC 2014). However, the influence of carbon fertilization on forest productivity is not well understood given the complexity of contributing factors (Norby *et al.* 2016). In combination with other human pressures, such as habitat destruction, climate change affects biodiversity at genetic, species and ecosystem levels. Seasonal changes can disrupt the timing of gestation, birth, hibernation, resource availability and optimal productivity. Species that are able are shifting their ranges, patterns and interactions on land, in fresh water and in oceans (IPCC 2014). There are possible shifts in infectious disease distributions in flora, fauna and humans (Lafferty 2009).

The shifts in weather patterns and extreme events, such as heat waves and droughts, and environmental disruptions, including crop failures, result in greater risks to human health and survival, especially among the poor and most vulnerable groups (Smith *et al*. 2014b). Climate change is also affecting the toxicity, environmental fate and behaviour of chemical toxicants by modifying physical, chemical and biological drivers of partitioning between the atmosphere, water, soil/sediment and biota, wet/dry deposition, and reaction rates with a potential of adverse impacts on biodiversity and human health (Noyes *et al.* 2009). Recent studies have examined the link between climate change and poverty in developing countries. In general, rural households in developing countries depend on crops, forest extraction and other income sources for their livelihoods, which tend to be extremely sensitive to climate change (Wunder, Noack and Angelsen 2018). The poor are more exposed to extreme climate conditions and experience greater rainfall fluctuations, while the poorest in dry regions experience the greatest forest loss (Angelsen and Dokken 2018). Poor people are often disproportionately exposed to droughts and floods, particularly in urban areas, and in many countries in Africa (Winsemius *et al*. 2018). Poorer households tend to be located in hotter locations within hot countries, and poorer individuals are more likely to work in occupations with greater exposure to increased temperatures across and within countries (Park *et al*. 2018). It is expected that by the end of the century global labour productivity may be reduced by 40 per cent (Dunne, Stouffer and John 2013).

The climate continues to change and the impacts on the natural and human system are increasingly recognized. Social responses such as population migration and displacement exacerbate health risks and threats to geopolitical stability (Adger *et al*. 2014); these risks increase with continuing warming beyond 1.5°C as detailed in chapters 3 and 5 of the IPCC 1.5°C report (IPCC 2018). Limiting the observed warming trend to 1.5°C requires transformational changes in policies, technologies and societal goals.

4.3.2 Polar regions and mountains

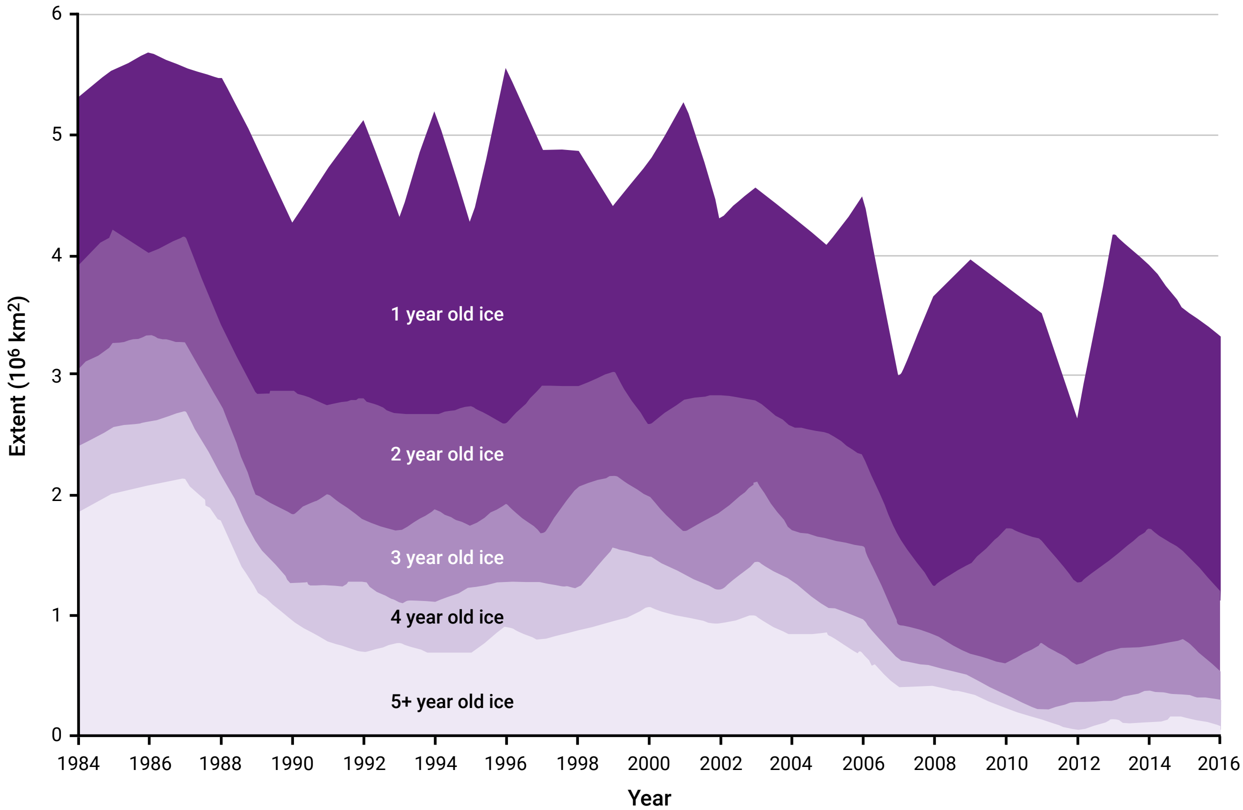
Covering approximately 20 per cent of the Earth's surface and containing the ice sheets of Greenland and Antarctica, the polar regions play a significant role in the global climate system. Land and sea ice not only regulate the energy balance of the climate system due to their high albedo, or reflectivity, but also store a record of climate information. In addition to their role as engines of global climate processes, the Arctic and Antarctic act as bellwethers of climate change because warming is amplified at their high latitudes (Taylor *et al.* 2013). Warming is also amplified at high altitudes, so mountain regions can be included in this discussion as a 'third pole' (Pepin *et al.* 2015).

Amplified warming affects all components of the polar climate system. Arctic Sea ice is shrinking in area and volume **(Figure 4.6)**. Permafrost is thawing resulting in a release of greenhouse gases, including CO_2, and snow cover extent is decreasing. Ice sheets and mountain glaciers continue to lose mass, contributing significantly to sea level rise that threatens coastal regions at every latitude (Vaughan *et al*. 2013). These transformations have consequences for polar and high-altitude ecosystems and for the people who live there. Shifting environmental and socioeconomic conditions in the Arctic in particular are delivering consequences to environments and populations further south through teleconnections within the climate system (Francis, Vavrus and Cohen 2017) and through close geopolitical connections. In fact, polar regions are gaining politico-strategic importance. The Arctic has already been subjected to resource extraction and exploitation, from hydrocarbons to diamonds (Dodds 2010; Ruel 2011), and the Antarctic is becoming an area of strategic interest for countries looking at potential resource extraction in the future. At the same time, the Arctic and particularly the Antarctic, which has a treaty devoting the continent to peace and scientific cooperation, are regions of peaceful international coordination and enhanced environmental cooperation, exhibiting governance systems that can be exemplars for environmental protection in other regions.

The ecosystem services of the polar regions that relate to global climate regulation are further enhanced by the formation of super-dense Antarctic bottom water, and to a lesser extent of North Atlantic deep water, which are significant contributors to the thermohaline circulation. The cooler ocean waters of higher latitudes, especially the Southern Ocean, also represent important carbon sinks and areas of high marine productivity.

1 The plants that utilize C3 photosynthesis (85% of all plants) have disadvantage in hot, dry conditions. C3 crops include wheat, rice, soybeans, and many others.

Figure 4.6: Arctic sea ice age and extent



Source: United States National Snow and Ice Data Center (2017).

They play a significant role in food production in the high latitudes and require careful management through agencies such as the North Atlantic Fisheries Organization and the Commission for the Conservation of Antarctic Marine Living Resources. Some high-latitude fisheries have been significantly affected by fishing activities in the last century as highlighted in the collapse of the Atlantic cod fishery (Villasante *et al.* 2011).

More than 70 per cent of the planet's fresh water is locked up in ice in the polar regions. If released, the water stored in the Greenland Ice Sheet would result in a 7.4 metre rise in sea level, the water in the Antarctic Ice Sheet would result in a 58.3 metre rise, and the water stored in all mountain glaciers would yield a 0.4 metre rise (Vaughan *et al.* 2013). In a scenario limiting temperature increase to below 2°C, the world would still see a mean rise of global sea levels by 0.4 to 0.6 metres. A business-as-usual scenario produces an average sea level rise of 0.7 to 1.2 metres by the end of the 21st century (Horton *et al.* 2014). As the latest IPCC report and multiple independent scientific studies indicate, mountain glaciers and polar ice sheets are already losing mass and are contributing on average the equivalent of 1.85 mm of sea level rise per year (Bamber *et al.* 2018).

As more fresh water is transported to the ocean from seasonal permafrost thaw, iceberg calving, glacier and ice sheet melt, and other fluvial discharge, the increase of silt, carbon and other nutrients will affect the polar regions' primary productivity in the marine food chain. The source and quality of food for higher organisms will shift, with much less primary productivity originating from ice-related algae, so that species at higher trophic levels, such as krill and fish, will be challenged (Alsos *et al.* 2016; Frey *et al.* 2016). This, combined with invasive species shifting into newly tolerable conditions and their potential threats, requires humans to adapt to new economic and cultural livelihoods and may result in conflicts, especially with regard to resource use, governance, cultural concerns and marine protected areas (Conservation of Arctic Flora and Fauna [CAFF] and Protection of the Arctic Marine Environment [PAME] 2017).Nearly all of the world's glaciers are losing mass and some will vanish in the coming decades (Kaltenborn, Nellemann and Vistnes eds. 2010; Vaughan *et al.* 2013). More than a billion people rely on mountain glaciers for water, with the majority of these people living in Asia, which has around 100,000 km^2 of glaciers (Yao *et al.* 2012). Over 200 million people rely on water from the Hindu Kush Himalayan mountains with hundreds of millions more people downstream who are affected by reduced reliability of local water sources and increased hazards, including glacial lake outburst floods. Run-off is expected to decrease until 2050 in the Ganges, Brahmaputra and Mekong basins. At the same time, the Hindu Kush Himalaya region can expect higher variability in water flows and more water in pre-monsoon months leading to more floods and droughts. The Andes are already experiencing less run-off. Changes in temperature and precipitation will affect agriculture, water resources and health (Shrestha *et al.* eds. 2015).

Further adjustment to new realities will warrant responses to increasing levels of contaminants that have been transported long distances and accumulate in the polar regions. Despite few local industrial sources, persistent environmental contaminants were detected decades ago in these remote locations and pose significant threats to local people and environments through polar food chains (Andrew 2014). Sea-ice melting will result in air-water exchange of persistent organic pollutants in areas of the Arctic that are no longer covered with ice. Likewise, melting of polar and alpine glaciers, ice sheets and shelves, and permafrost will also release persistent organic pollutants and mercury, enabling further air-soil exchange of these pernicious compounds (Arctic Monitoring and Assessment Programme [AMAP] 2015; Sun *et al.* 2017). Due to new regulations, the levels of many persistent organic pollutants are now declining, but new chemicals are a cause for increased concern, such as organophosphate-based flame retardants, phthalates, some siloxanes, and some currently used pesticides (AMAP 2017). Equally, microplastics have now been detected in all of the world's oceans (Thompson *et al*. 2004; Browne *et al*. 2011), including in deep-sea sediments (Barnes, Walters and Gonçalves 2010) and even in Arctic sea ice (Thompson *et al.* 2004; Browne *et al.* 2011; Ivar do Sul and Costa 2014; Obbard *et al.* 2014; Isobe *et al.* 2017; Waller *et al.* 2017). More research is needed to trace the distribution and impact of microplastics in the Antarctic, but their existence in the Southern Ocean (Isobe *et al.* 2017; Waller *et al.* 2017) and in the Ross Sea (Cincinelli *et al.* 2017) has already been confirmed.

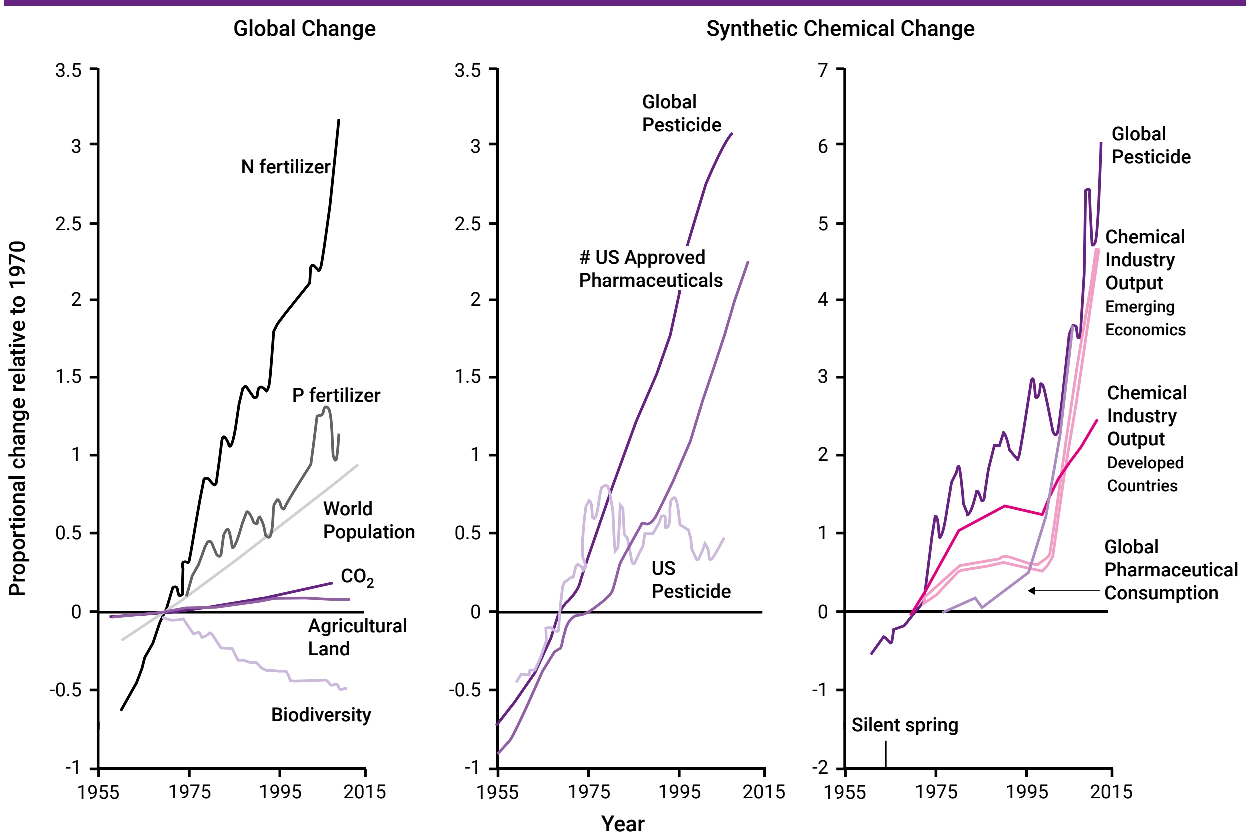
Those who live at high latitudes and in mountain regions are vulnerable to the compounding effects of air pollution, and-use changes and other factors, as well as the threats from climate change. However, people in these areas, especially the indigenous peoples who have inhabited the Arctic and mountain regions for millennia, have a rich knowledge about their environment that provides crucial insights for effective adaptation strategies (Magga *et al.* eds. 2009; Nakashima *et al.* 2012).

4.3.3 Chemicals

Modern societies produce and inhabit the most chemical-intensive environment humans have ever experienced – today, it is estimated that there are more than 100,000 chemicals on the market of modern society (European Chemicals Agency [ECHA] 2018) – and now chemical pollution is considered a global threat (Barrows, Cathey and Petersen 2018). Common categories of chemicals include pharmaceutical and veterinary chemicals, pesticides, antibiotics, flame-retardants, plasticizers and nanomaterials (Tijani *et al.* 2016). Even the more familiar chemicals, used for generations in agriculture and industry, are now used so intensively and in such concentrations as to require responsible monitoring and evaluation programmes **(Figure 4.7)** (Bernhardt, Rossi and Gessner 2017).

Global chemical pollution has been raised as a problem that needs urgent action: calls for more active involvement of governments and industry and for more research are included

Figure 4.7: Chemical intensification, 1955-2015



Source: Bernhardt, Rossi and Gessner (2017).

in all relevant studies and the existence of the problem is admitted in global change assessments and clarion calls (UNEP 2012; Stehle and Schulz 2015; Bernhardt, Rossi and Gessner 2017). However, the assimilative capacities for chemical burdens are largely categorized as undetermined and then ignored, even in efforts to inspire concern about planetary environmental issues (Diamond *et al.*2015; Steffen *et al*. 2015). The global dimension of chemical pollution manifests as these substances spread to the most remote environments on the planet, including the polar regions (Andrew 2014), high mountain peaks (Ferrario, Finizio and Villa 2017) and the deepest oceans: persistent organic pollutants were detected in fauna found at more than 10,000 metres depth in the Pacific Ocean's Mariana Trench (Jamieson *et al.* 2017). However, there are currently ongoing efforts in developed countries to carry out regular monitoring programmes to mitigate the impact of chemicals, especially pesticides, on human and environmental health (Brouwer 2018).

Some chemicals that are persistent, toxic and bioaccumulating, and may travel long distances, are listed under international conventions, such as the Stockholm Convention (persistent organic pollutants) and Minimata Convention (mercury), but scientific evidence shows that more chemicals regularly made available for commercial use display the same properties as the regulated persistent organic pollutants (Strempel *et al.* 2012). Countless new chemicals, as well as old chemicals that were not well understood, are not regulated at all even though they are suspected of causing adverse effects (Petrie, Barden and Kasprzyk-Hordern 2015; Ferrario, Finizio and Villa 2017).

Pharmaceuticals are commonly mishandled 'from cradle to grave' with over 200 different substances reported in river waters globally (Petrie, Barden and Kasprzyk-Hordern 2015). Antibiotic-resistant bacteria have evolved and spread due to mismanagement of antibacterial drugs (Marti, Variatza and Balcazar 2014; Grenni, Ancona and Caracciolo 2017). Recent research indicates that the development of antimicrobial resistance in pathogens is accelerated and achieved at lower exposure concentrations, in the presence of heavy metals and other contaminants that are commonly found in the same contaminated reservoirs (The Lancet Planetary Health 2018). The presence of such contaminants in the natural environment results from the discharge of wastewater from treatment plants that are unequipped to effectively remove these dangerous compounds (Petrie, Barden and Kasprzyk-Hordern 2015) and from mismanagement of their use for agricultural production, particularly in livestock (Hamscher and Bachour 2018).

The effects of some endocrine-disrupting chemicals are of particular concern because of potential multigenerational effects on the health of humans and wildlife (Gore *et al.* 2015). Endocrine activity or disruption has been associated with a wide variety of compounds, including some persistent organic pollutants (Kabir, Rahman and Rahman 2015) and industrial chemicals (UNEP and WHO 2013). They are present in many pesticides that are designed to interfere with the life cycles of organisms and are highly valued for those abilities (Gore *et al.* 2015). Endocrine disruption potential has also been attributed to certain chemicals present in manufactured plastics (Schug *et al.* 2016).

Products used in everyday life may contain toxic compounds that interfere with human and environmental health, spanning cosmetics, plastic containers, and household cleaners and pesticides. Addressing the issue of chemicals in products may offer new opportunities in terms of innovation through green and sustainable chemistry efforts and could represent a valuable opportunity to improve sustainable consumption and production patterns and life cycle thinking. Application of the circular economy model to chemical production and consumption could establish some measure of control from the extraction of primary materials, through the design, formulation, production, use and final disposal of the substances and products that people use (Roschangar, Sheldon and Senanayake 2015). Chemicals in everyday products, as well as endocrine disruptors and nanomaterials, have been identified as emerging policy areas under the Strategic Approach to International Chemicals Management (SAICM) (UNEP 2013b). Highly hazardous pesticides, used in agricultural practices in developing countries, are another issue addressed by SAICM: alternative approaches rely on agroecological practices to promote substitution of hazardous pesticides by pest management approaches and products that pose less risk (FAO and WHO 2016), as well as demand reduction and non-chemical alternatives.

Nanotechnology, by decreasing the particle size of materials and increasing its reactivity, may give a material some interesting properties, but these may be toxic (Schulte *et al.* 2016). There remain a number of questions about the toxicity of nanoparticles to humans and the environment, but comparison of nanomaterials of certain size and shape with asbestos indicates similar toxicological potential (Nagai and Toyokuni 2012; Allegri *et al*. 2016).

Even those substances considered under control in some regions may be distributed in developing countries with no guidance on health and safety issues and proper use. The Global Chemical Outlook (UNEP 2013b; UNEP 2013c) estimates total health-related pesticide costs – the costs of inaction – for agricultural smallholders in sub-Saharan Africa from 2015 to 2020 at US$90 billion, assuming a continued scenario of inadequate capacity for pesticide management.

Further studies evaluating the combined effects of chemical mixtures are critical, in addition to understanding the cumulative effects of chemicals over time. Equally, more information is needed on causal linkages between exposures to certain chemicals and related health effects (The Lancet Planetary Health 2018). Promoting safer and sustainable alternatives to chemicals, especially biodegradable replacements for plastics, and sound cradle-to-cradle chemicals management is essential. Institutions and instruments are available and coordination through United Nations agencies is an objective of SAICM. The costs of inaction to global society is high if measures are not taken to detoxify the environment and to create a safe-chemical future in coming decades (UNEP 2013c).

4.3.4 Waste and wastewater

The Global Waste Management Outlook (UNEP 2015) estimates the total 'urban' waste generation, including municipal solid waste, commercial and industrial waste, and construction and demolition waste, at around 7-10 billion tons per year. Waste generation rates are stabilizing in developed regions. However, Asia and Africa are expected to contribute significant amounts to global waste generation over the next century (UNEP 2015).

GEO-6 highlights key global waste management challenges consistent across the regional assessments prepared for it and prioritized in the Global Waste Management Outlook (UNEP 2015). These include food waste, marine litter, waste trafficking and crime, and the growing disparity in waste management between developed and developing countries.

Approximately one-third of the food produced for human consumption is wasted or lost annually, at a financial cost of US$750 billion to US$1 trillion (FAO 2013; FAO 2015; UNEP 2015). This wasted food could feed over 2 billion people, more than twice the number of undernourished people estimated globally (FAO 2013). Food losses and waste result in unnecessary greenhouse gas emissions, estimated at 3.3 gigatons of CO_2 equivalent in 2007, or around 9 per cent of total global GHG emissions that year (UNEP 2015). This estimate does not take into account GHG emissions as a result of land-use changes. Considering land-use changes, GHG emissions from food waste would be 25-40 per cent higher. Even without counting land-use change, if food losses and waste all occurred in one country, it would rank as the third largest country in the world in terms of CO_2 emissions (FAO 2013).

With increasing global demand for resources, the waste market has become a viable economic sector, estimated at US$ 410 billion a year, from collection to recycling. In a context of increasing costs for the safe disposal of hazardous waste, weak environmental regulations and enforcement, and increasing resource scarcity, this market creates opportunities for waste trafficking and illegal activities. This is evident in large quantities of often hazardous waste being unlawfully exported to developing countries, with the potential to cause significant, and displaced, impacts **(Figure 4.8)** (Rucevska *et al.* 2015). The illegal trafficking of end-of-life electrical and electronic equipment has become an issue of global concern (UNEP 2015; UNEP 2016b).

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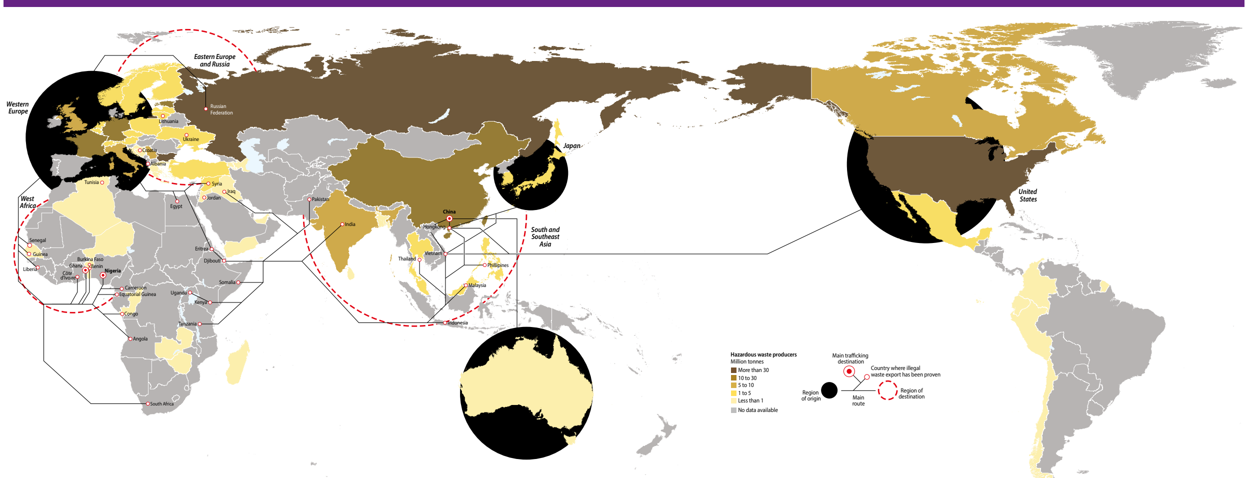
Figure 4.8: Global illegal waste traffic

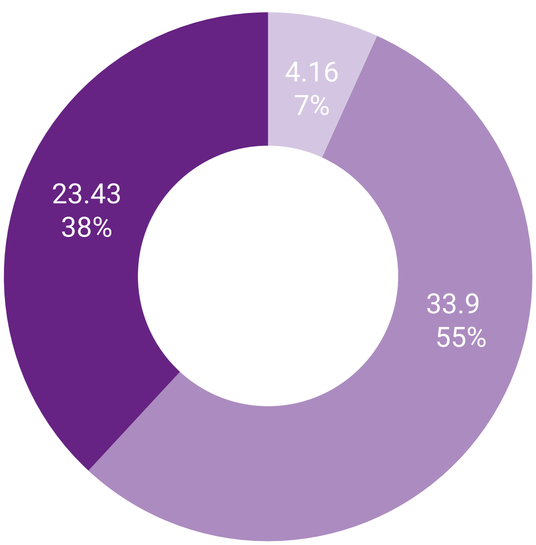


Source: Pravettoni (2015).

Developed countries have advanced their waste management systems to the point where they can consider strategies for integrating new and complex waste types; driving sustainable consumption and production; moving towards near zero waste schemes and a circular economy; and the adoption of emerging and potentially disruptive technologies on waste management. Developing countries are still grappling with basic waste management challenges, including uncontrolled dumping, open burning and inadequate access to waste services. Globally, 3 billion people lack access to controlled waste disposal facilities, according to United Nations estimates, with the potential to cause significant environmental, social and economic impacts from poor waste management (UNEP 2015). In the first seven months of 2016, an estimated 750 people died due to poor waste management at dumpsites (International Solid Waste Association [ISWA] 2016). In early 2017, some 115 people were killed in a waste landslide in Addis Ababa, Ethiopia (Gardner 2017) and 16 people were killed in the collapse of the Hulene Garbage Landfill in February 2018 in Maputo, Mozambique. A high percentage of the fatalities were women. Such dumpsites in developing countries are often home to millions of informal waste pickers (ISWA 2016; Duan, Li and Liu 2017). While developed countries chase the ideals of reduced waste, a circular economy and greater resource efficiency, developing countries must not be left behind.

Any circular economy plan incorporates wastewater in its design. This includes human sewage, industrial effluent and both agricultural and urban run-off (Mateo-Sagasta *et al.* 2013). Agriculture is the main contributor, accounting for 79 per cent of wastewater produced in arid West Asia, where it is discharged straight into the environment **(Figure 4.9)**

Figure 4.9: West Asia non-conventional annual water resources



Source: Abuzeid *et al.* (2014).

(AbuZeid and Elrawady 2014). It is estimated that in 2015, 68 per cent of the global population used at least some form of basic sanitation services (WHO and UNICEF 2017). However, 34 per cent of rural and only 26 per cent of urban sanitation and wastewater services actually prevent human contact with excreta along the entire sanitation chain in an effective manner (United Nations World Water Assessment Programme [WWAP] 2017). Moreover, 80 per cent of all wastewater produced globally is discharged into the environment without any treatment – wastewater contaminated with human faecal matter as well as all the pharmaceuticals and endocrine disruptors that are newly threatening human health and ecosystems (WWAP 2017). Although wastewater is a considerable resource for water and nutrients, it presents risks for public health and environmental integrity if not managed properly. Significant disease outbreaks and associated mortality (Saxena, Kaushik and Krishna Mohan 2015; Prüss-Ustün *et al.* 2016), eutrophication (Lewandowski *et al.* 2015) and soil salinization in arid lands (Qadir *et al.* 2014) are reported as main challenges associated with poorly managed wastewater.

4.4 Resources and materials

4.4.1 Resource use

Sustainable resource use requires sound management of renewable resources and aims to recycle non-renewable resources, leading to the concept of a circular economy in which a waste, the by-product of a process, becomes a raw material for another process. In a circular economy, efficient use of resources across their entire life cycle is critical: from extraction to manufacturing, through consumption and use, to recycling and reuse (Ellen MacArthur Foundation 2012; European Commission 2015).

From the 20th century, resource exploitation has grown considerably, especially of metals, such as iron and copper, and of minerals, such as sand and limestone for cement. Fossil fuel exploration and extraction, and its consumption, exemplify modern society's great advances, according to one narrative. However, fossil fuel exploitation has also created great challenges. The momentum of consumption has led to ever increasing scales of resource exploitation, leading to concerns over the cumulative and global consequences of such activities, as well as over local damage (Rockström *et al.* 2009).

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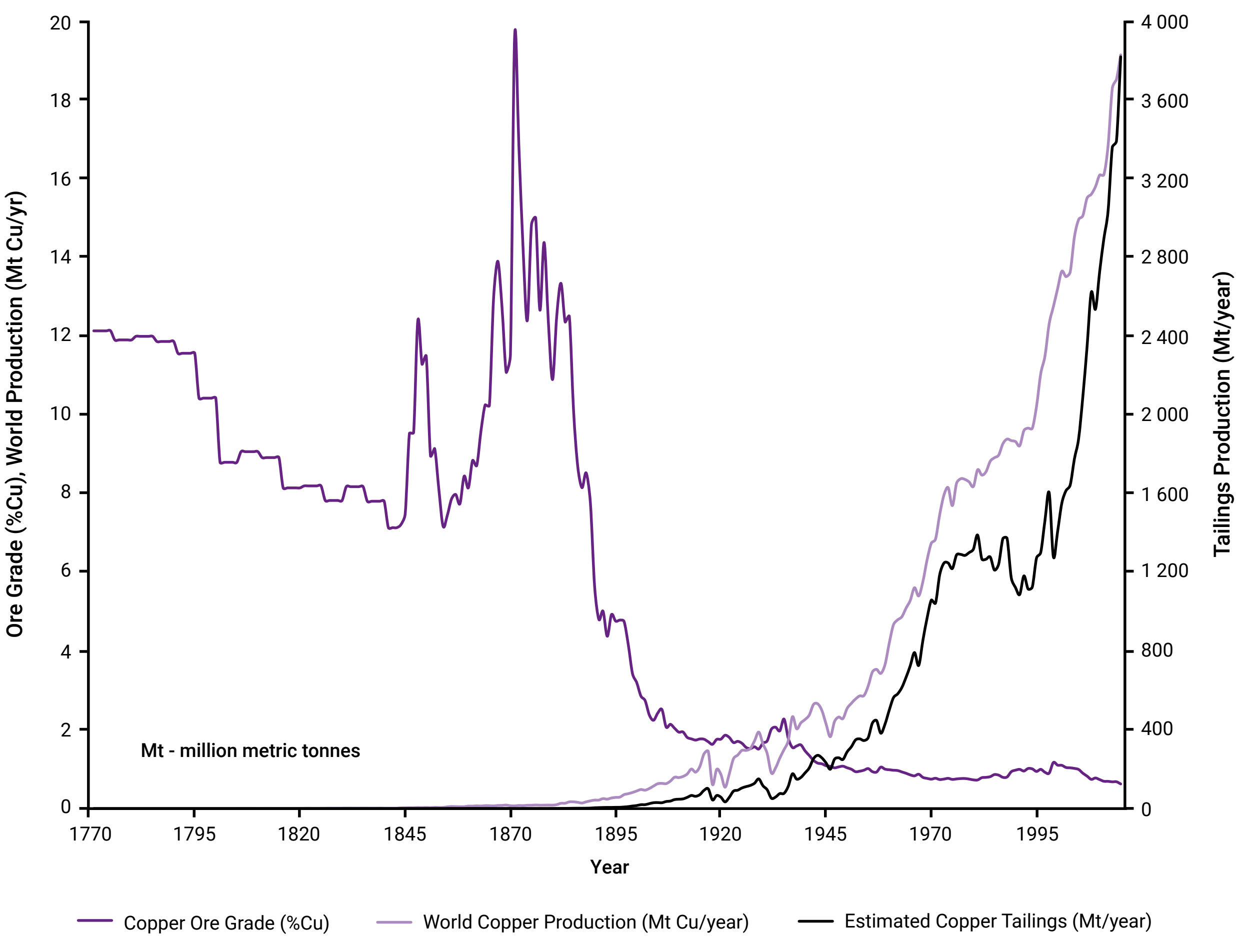
Traditionally, the discovery of new and accessible deposits of non-renewable resources has kept pace with or even outpaced growing extraction, so concern over the depletion of such resources would not be considered highly important (Mudd, Weng and Jowitt 2013; Mudd and Jowitt 2014; Weng *et al.* 2015; Mudd and Jowitt 2017). However, as a measure of their quality, the grades of most mined ores are in gradual decline, meaning that the most easily and economically refined ores have already been exploited (Ruth 1995; Mudd 2010). Larger amounts of lower grade ore have to be extracted and processed to meet global demands, as can be shown by tracking exploitation of copper ore deposits **(Figure 4.10)**.

When declining ore grades are combined with the larger project scales needed to extract enough ore to supply market demand, greater risks threaten the natural environment. More land is cleared, or simply removed and shipped away, as mountain-top removal illustrates. Larger volumes of mine waste accumulate, with heavy metals and reactive agents recombining into noxious compounds. Water pollution risks, especially from acid and metalliferous drainage, increase. Threats to biodiversity become more complex. Energy demand intensifies, along with associated greenhouse gas emissions (Norgate and Haque 2010). To meet global demands in 2014, the global metals and mining industry produced around 90 billion tons of mine waste, excluding construction materials (Mudd and Jowitt 2016). This massive mining scale requires an acute focus on environmental assessment, monitoring and management for primary resource extraction (Hudson-Edwards 2016; Mudd and Jewitt 2016). Currently, much of the mine waste is stored, exposed to changing environmental and management conditions. The 2015 Samarco tailings dam failure in Brazil, among other events, demonstrated how long-term storage strategies are not solutions (Philips 2016; Roche, Thygesen and Baker 2017).

Some mined resources are widely distributed around the world, including sand, gold, copper and lead-zinc; other resources, such as nickel, rare earth elements and phosphorous, are concentrated in a small number of countries. Given the fundamental contribution of mineral resources to modern social systems, technologies and infrastructure, these materials need to be assessed for their role in modern society. This analytical approach is known as criticality – examination of the potential implications of supply disruption, resource substitution, recyclability and environmental impacts (Graedel *et al.* 2015) For example, many metals such as iron, copper, gold and lead are recyclable. Other minerals, such

Figure 4.10: Example of ore grade decline over time for copper mining, showing world annual copper production and estimated tailings generated annually



Source: Ruth (1995); Crowson (2012); Mudd, Weng and Jowitt (2013); Mudd and Jowitt (2016).

as phosphorous, are dispersed in soils and water bodies, ultimately washing away and being effectively lost to any further use. That kind of material dissipation raises alarms over the eventual depletion of the essential resource (Ciacci *et al*. 2015; Nassar, Graedel and Harper 2015).

In contrast, when a metal is recycled, the environmental risks are typically much lower. For instance, fabricating a product from recycled aluminium uses one-twentieth of the energy than production from primary aluminium does. For the circular economy, this means that recycling should lead to reduced environmental pressures and risks, mainly due to lower energy and raw material needs (Wernick *et al.* 1996; Wernick and Ausubel 1997; Balke *et al.* 2017). The focus of a circular economy concentrates on sound product or infrastructure design, as well as on the systems in place to monitor resource use, waste and environmental repercussions (Ghisellini, Cialani and Ulgiati 2016). Other strategies may include variations of upcycling or recycling: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture and repurpose. Here, environmental and sustainability education is crucial.

An important issue arising from resource use is that the environmental and social costs are typically greatest during extraction when land is cleared, or populations displaced, while the greatest benefits accrue at the other end of the supply chain. To fully appreciate the cost-benefit ratio and the actual value of a product, it is important to consider the environmental consequences of global trade in resources, including the repercussions for local communities in areas of resource extraction. Interest is growing in tracing the origins and added values of supplied resources through sustainable supply chain management. This traceability supports action on issues such as conflict minerals, chemical and pharmaceutical waste, food contamination and illegal trade in endangered species (Mundy and Sant 2015; Paunescu, Stark and Grass 2016; Tijani *et al.* 2016; Sauer and Seuring 2017). The availability and distribution of this type of information defines a connection between supplier and consumer and encourages more sustainable resource use choices. Recent research indicates, however, that humanity has overshot the safe operating space for certain planetary systems, specifically climate change, the rate of biodiversity loss and the biogeochemical flow of the nitrogen cycle (Rockström *et al.* 2009; Steffen *et al.* 2015). Some updated analyses would add phosphorus to that overshoot list (Carpenter and Bennett 2011; Cordell and Neset 2014).

The pressures upon our planet have therefore brought global society to a decisive crossroads: the continuation of a conventional process model to 'extract-make-use-discard' through a linear economy or the transformation into a circular economy with society focused on the entire life cycle of resource use and management. Some thinkers consider that it may already be too late (Urry 2010; Scheffer 2016). Others suggest the transition from a linear economy with wasteful resource management to a circular economy with sustainable resource management can be accomplished but requires new concepts of de-growth and a post-capitalistic economic vision (Jackson and Senker 2011; Kosoy *et al.* 2012; Krausmann *et al.* 2017).

The transition to a circular economy will provide many opportunities for technology innovation and deployment that also present many new business prospects. At heart, a circular economy will require sound policies for resource accounting and waste management that create the demand for recycled resources and deliver a resource efficient and sustainable economy (Ghisellini, Cialani and Ulgiati 2016; Balke *et al.* 2017). Resource use is also intimately connected to energy technologies and policies, such as the materials required for various renewable energy technologies, highlighting the need to consider the links among material resources, energy and environmental outcomes (Akenji *et al*. 2016; McLellan 2017).

All 17 of the Sustainable Development Goals involve competition for natural resources, with many requiring efficient and sustainable use of resources and minimizing associated impacts – especially the metals considered critical for renewable energy and, consequently, for progress on climate change solutions (Arrobas *et al.* 2017; International Resource Panel 2017).

4.4.2 Energy

By 2015, global energy consumption reached around 13.5 billion tons of oil equivalent (International Energy Agency [IEA] 2018). That is expected to increase to around 19 billion tons by 2040 (IEA 2016). Much of this increase is attributed to consumption expected in developing economies that currently depend largely on fossil-based energy sources. This makes accelerated efficiency a crucial strategy to mitigate energy-related impacts. At the same time, nearly 1.2 billion people remain without access to electricity and 2.7 billion still resort to traditional fuels for cooking and heat, facing exposure to concentrated indoor air pollution (IEA 2016). Improved access to modern energy services is not only closely connected to all Sustainable Development Goals and indicators, including food security, health and quality education, but shifting to clean and efficient forms of energy also empowers women and other marginalised groups responsible for the collection and burning of primitive solid fuels (World Energy Council 2016).

Energy demand also leads to competition for water, land and even atmospheric limits; to inequitable distribution of these and other sets of natural capital, such as mineral resources and access to sensitive ecosystems; and to processes involving different approaches that often cause disputes and conflicts at several levels and magnitudes (Rodriguez *et al.* 2013; Jägerskog *et al.* 2014; McLellan 2017).

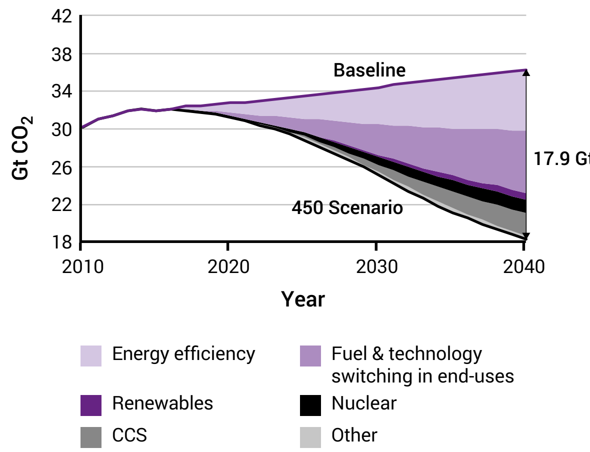
The competition between biofuels and food re-emphasizes the need to understand the nexus of energy, food, water and land use (see Chapter 8). Popp *et al.* (2014) discuss the impact of biofuel production on food supply, environmental health and land requirements, and highlight the need for integrated policies to manage the various components of the energy, food, water and land-use nexus.

The rise in water demand, while usable water reserves decline, accentuates the need to examine water-energy linkages against the backdrop of growing energy demand. Jägerskog *et al.* (2014) discuss the energy and environmental trade-offs related to hydropower. Rodriguez *et al.* (2013) also provide an overview of water requirements for generating power, particularly in the case of thermal power plants. Copeland and Carter (2017) address the energy requirement for delivering water to end users and for the disposal of wastewater in the United States of America.

At the global scale, greenhouse gas emissions amounted to 33 gigatons of CO_2 equivalent in 2014 and may reach 38 gigatons in 2040, due mostly to the burning of fossil fuels (IEA 2015). Historical data demonstrate trends in decoupling through decarbonization and improved efficiency, but the current trend still indicates a global temperature increase beyond the 2°C threshold target of the Paris Agreement **(Figure 4.11)** (IEA 2015; United Nations 2015b; IEA 2016). This likely overshoot warrants bolder action.

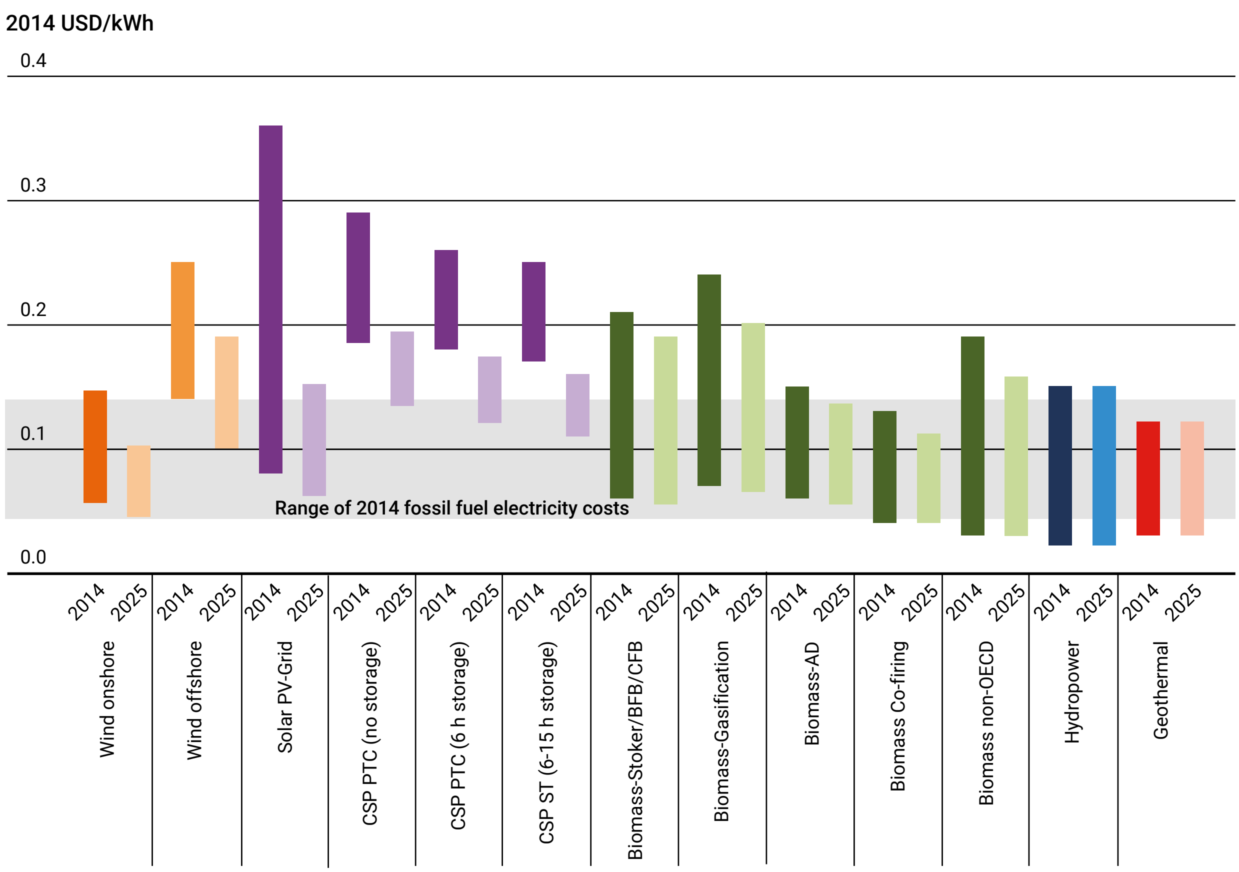
The economics of transition to low-carbon energy sources have been greatly assisted by a dramatic reduction in the cost of renewables, especially wind and solar photovoltaic systems. Solar photovoltaic systems experienced a price decline of 23 per cent for each cumulative doubling of production over the last 35 years. In many cases these costs are now lower than those of conventional fossil fuel electricity generation technologies (International Renewable Energy Agency [IRENA] 2015). Further reductions are expected making them possibly the best economic-environmental option in practically every country in the world before 2025 **(Figure 4.12)**.

Figure 4.11: Technology wedges to achieve the 2°C pathway



Source: IEA (2015).

Figure 4.12: Ranges of levelized cost of electricity for different renewable power generation technologies, 2014 and 2025



Source: IRENA (2015).

Education is crucial for developing energy literacy. Seen from the perspective of the SDGs, it enables individuals to apply and evaluate measures to increase energy efficiency and sufficiency in their own lives. It also influences public policies related to energy production, supply and usage (Aguirre-Bielschowsky *et al*. 2015; UNESCO 2017a).

4.4.3 Food systems

The global food system is central to sustainable development and to many of the SDGs. Across the complex interactions of activities including farming, fishing, food processing, retailing, preparing and consuming, and the multiple actors who perform them, the food system both significantly affects and is affected by environmental and social-economic dynamics (UNEP 2016c). Agriculture provides jobs for over 30 per cent of the global workforce, the majority in developing countries where 40 per cent of smallholder farmers and laborers are women (FAO 2011; FAO 2017a). Smallholder-dominated systems in developing countries produce more than half of all global food calories (Samberg *et al.* 2016) and contribute significantly to micronutrient production (Herrero *et al.* 2017). Fifty-seven million people work in fisheries and aquaculture, where women's roles are often invisible and underrecognized (Koralagama, Gupta and Pouw 2017), with many more in food manufacturing and retail (FAO 2016). A great number of these women and men live in poverty.

While the food system produces more than enough to feed the world's population adequately, it does not distribute it well. Over 800 million people are undernourished (FAO 2017a) and more than 2 billion suffer from micronutrient deficiencies (Global Panel on Agriculture and Food Systems for Nutrition 2016). However, over 2.3 billion people – about one-third of the human population – are obese or overweight (Abarca-Gómez *et al*. 2017). Diet-related diseases are globally pervasive, and many are associated with overconsumption of saturated fats and processed foods, such as type 2 diabetes, colorectal cancer and cardiovascular disease (Monteiro *et al.* 2013; Tilman and Clark 2014; UNEP 2016c). These diseases are becoming increasingly prevalent in low-income and middle-income countries, as animal protein and products high in fats and sugars become more widely available (Popkin 2006; McMichael *et al.* 2007).

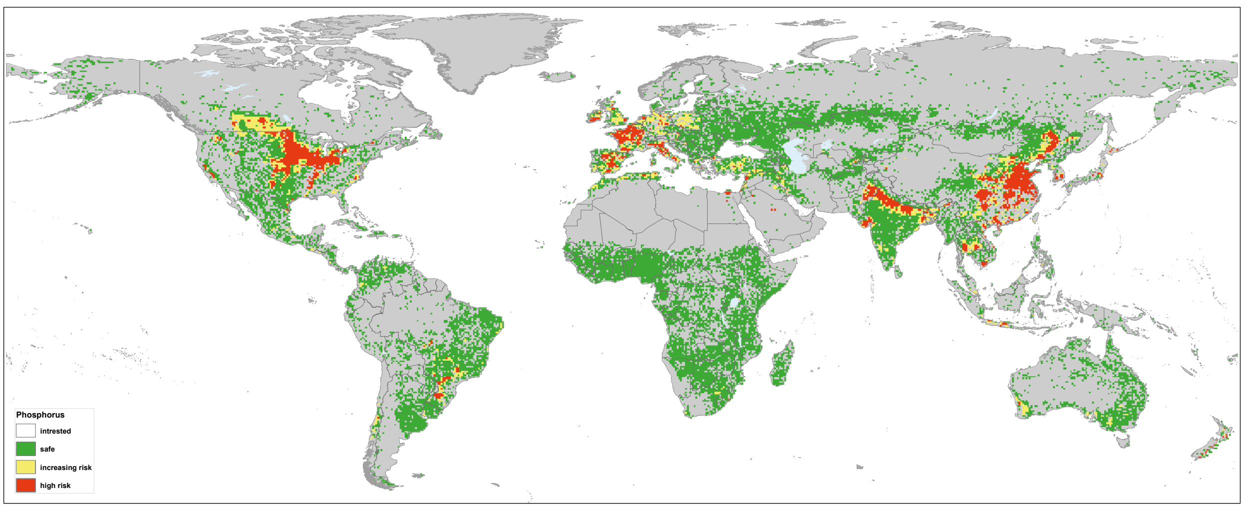
The environmental footprint of the global food system is immense. It is estimated to account for 19-29 per cent of global greenhouse gas emissions (Vermeulen, Campbell and Ingram 2012). Farming is the most expansive human activity in the world, accounting for 38 per cent of global land area, and it is the principal user of fresh water, responsible for 70 per cent of withdrawals (FAO 2017a; FAO 2017b). Food production is the main driver of biodiversity loss (Kok *et al.* 2014). It is a major polluter of air, fresh water and seawater, particularly in farming systems that make heavy or poorly managed use of chemical pesticides and fertilizers (Popp, Petö and Nagy 2013; Sutton *et al.* 2013; Zhang, Zeiss and Geng 2015). Food production systems are also a leading source of soil degradation and deforestation (Amundson *et al.* 2015; Vanwalleghem *et al.* 2017; FAO 2017a). Yet the global food system is estimated to convert only 38 per cent of harvested energy and 28 per cent of harvested protein into required food consumption after accounting for losses from food waste, trophic losses from livestock and human overconsumption (Alexander *et al*. 2017).

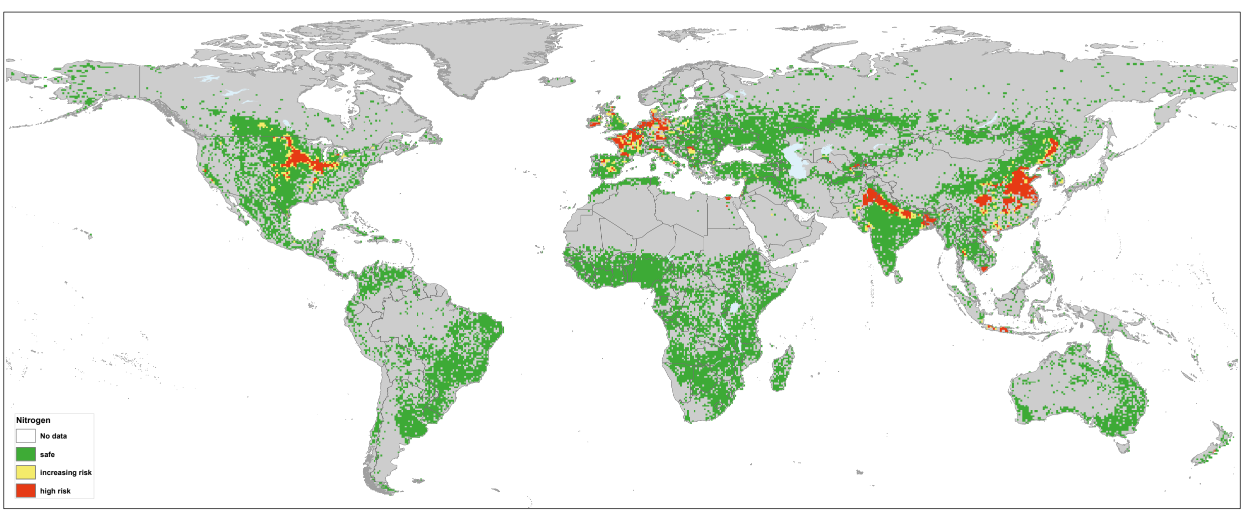
Within the global food system's environmental footprint, the consequences of livestock raising are disproportionately large. While supplying only 18 per cent of calories and 40 per cent of protein to the world's food supply, the livestock sector accounts for about half of agriculture's greenhouse gas emissions (Gerber *et al*. 2013; FAO 2017a) and almost 80 per cent of agricultural land use – a third of all cropland is used to produce feed crops (FAO 2009). Due to the livestock sector, food production is the principal cause of habitat destruction (Machovina, Feeley and Ripple 2015) and the main disrupter of the nitrogen and phosphorous cycles that produce most of agriculture's pollution (Bouwman *et al.* 2013; Sutton *et al*. 2013). As with many resource extraction activities, the environmental burden of food production is localized, and often spatially dislocated from the consumption that drives demand. Around 20 per cent of cropland area and agricultural water use is devoted to agricultural commodities consumed in other countries (MacDonald *et al.* 2015). Similarly, overexploitation of wild fish stocks and intensive aquaculture have detrimental effects on marine and terrestrial ecosystems (see Chapter 7).

Current environmental pressures from the global food system cannot be sustained, yet to meet projected demand in 2050, with current efficiencies, world agricultural production would need to increase by 50 per cent from 2013 levels (FAO 2017a) with global crop demand forecast to increase 100-110 per cent over the same period (Tilman *et al.* 2011). Flows of nitrogen and phosphorous into the biosphere and oceans already exceed globally sustainable levels **(Figure 4.13)** (Steffen *et al.* 2015). On current trajectories, agricultural emissions are incompatible with a 2°C pathway. Action to reduce the volume and intensity of agricultural emissions, the amount of food waste and, most importantly, the share of animal products in diets will be necessary if the Paris Agreement's goal is to be achieved (Bajželj *et al.* 2014; Hedenus, Wirsenius and Johansson 2014; United Nations 2015b). On a global basis, diets with lower levels of animal products and higher levels of fruit, vegetables, pulses, whole grains and nuts are necessary to meet environmental and nutritional goals (Springmann *et al.* 2018), although particular requirements for dietary change will vary according to national context.

The food system is highly vulnerable to the pressures it is exerting on ecosystem services. Habitat loss is degrading pollinator services, with implications for crops important to human nutrition (Vanbergen 2013; Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services 2016). Land degradation decreases crop yields, and abandonment rates of agricultural land due to that degradation appear to have increased (Gibbs and Salmon 2015; United Nations Convention to Combat Desertification 2017). Rising temperatures are thought to be diminishing crop yields rather than enhancing them in certain regions, especially for wheat and maize (Asseng *et al.* 2014; Porter *et al.* 2014; Moore and Lobell 2015; Schauberger *et al*. 2017). This trend is likely to have an increasingly detrimental effect on agriculture, particularly in low-latitude developing countries, although some temperate regions may benefit from warmer temperatures and longer growing seasons in the medium term, if soil and water characteristics are right (Deryng *et al.* 2014; Porter *et al*. 2014; Zhao *et al.* 2017). Water scarcity may limit the extent to which irrigation expansion can counter climate threats to crop yields;

Figure 4.13: The subglobal distributions and current status of the control variables for (A) biogeochemical flows of phosphorus; (B) biogeochemical flows of nitrogen





Source: Steffen *et al.* (2015).

in fact, it may force reversion to rain-fed agriculture in a number of important crop-producing regions by the end of this century, with further consequences for crop production (Elliott *et al.* 2013). Overexploitation is already compromising groundwater in several large aquifers critical to agriculture (Gleeson *et al.* 2012).

4.5 Conclusions

This GEO-6 assessment offers opportunities to identify cross-cutting issues as entry points for further understanding the state of the global environment. By exploring the 12 cross-cutting issues and how they relate to the Earth system topics, GEO can demonstrate where intersections and nexus issues will need synergistic solutions with the objective of achieving true transformative change.

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