8 Poverty, Livelihoods and Sustainable Development

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Executive Summary

Adverse impacts of climate change, development deficits and inequality exacerbate each other. Existing vulnerabilities and inequalities intensify with adverse impacts of climate change (*high confidence*[1]). These impacts disproportionately affect marginalised groups, amplifying inequalities and undermining sustainable development across all regions (*high confidence*). Due to their socioeconomic conditions and the broader development context, many poor communities, especially in regions with high levels of vulnerability and inequality, are less resilient to diverse climate impacts (*high confidence*). {8.2.1, 8.2.2, 8.3.2, 8.3.3}

Under all emissions scenarios, climate change reduces capacities for adaptive responses and limits choices and opportunities for sustainable development. Higher levels of global warming lead to greater constraints on societies. Climate change increases the threat of chronic and sudden onset development challenges, such as poverty traps and food insecurity (*high confidence*). Adaptation interventions and transformative solutions that prioritise inclusive and wide-ranging climate resilient development and the reduction of poverty and inequality are increasingly seen as necessary to minimise loss and damage from climate change (*high confidence*). {8.2.1, 8.2.2, 8.3.1, 8.3.2, 8.3.3}

Observed societal impacts of climate change, such as mortality due to floods, droughts and storms, are much greater for regions with high vulnerability compared to regions with low vulnerability, which reveals the different starting points that regions have in their move towards climate resilient development (*high confidence*). Observed average mortality from floods, drought and storms is 15 times higher for regions and countries ranked as very high vulnerable, such as Mozambique, Somalia, Nigeria, Afghanistan and Haiti compared to very low vulnerable regions and countries, such as UK, Australia, Canada and Sweden in the last decade (*high confidence*). Over 3.3 billion people are living in countries classified as very highly or highly vulnerable, while around 1.8 billion people live in countries with low or very low vulnerability (*high confidence*). Approximately 3.6 billion people live in low and lower middle-income countries, which are most vulnerable and disproportionally bear the human costs of disasters due to extreme weather events and hazards (*high confidence*). The population in most vulnerable countries is projected to increase significantly by 2050 and 2100, while the population in countries with low vulnerability is projected to decrease or grow only slightly. Vulnerability is a result of many interlinked issues concerning poverty, migration, inequality, access to basic services, education, institutions and governance capacities, often made more complex by past developments, such as histories of colonialism (*high confidence*). {8.3.2, 8.3.3}

A growing range of economic and non-economic losses have been detected and attributed to climate extremes and slow-onset events under observed increases in global temperatures (*medium evidence, high agreement*). If future climate change under high emissions scenarios continues and increases risks, without strong adaptation measures, losses and damages will *likely*[2] be concentrated among the poorest vulnerable populations (*high confidence*). The intersection of inequality and poverty presents significant adaptation limits, resulting in residual risks for people and groups in vulnerable situations, including women, youth, elderly, ethnic and religious minorities, Indigenous People and refugees. Climate change is *likely* to force economic transitions among the poorest groups, accelerating the switch from agriculture to other forms of wage labour, with implications for labour migration and urbanisation (*medium evidence, high agreement*). Under an inequality scenario (Shared Socioeconomic Pathway (SSP) 4) the projected number of people living in extreme poverty may increase by 122 million by 2030 (*medium confidence*). {8.2, 8.3.4, 8.4.1, 8.4.5, Figure 8.6, Box 8.5, 16.5.2.3.4}

Both climate change and vulnerability threaten the achievement of the UN Sustainable Development Goals (SDGs) (*medium confidence*). This undermines progress toward various goals such as no poverty (SDG1), zero hunger (SDG2), gender equality (SDG5) and reducing inequality (SDG10), among others (*medium evidence, high agreement*). Gender inequality and discrimination are among the barriers to adaptation (*high confidence*). {8.2.1¸8.4.5} Also maladaptation can lead to additional complex and compounding future risks and threaten sustainable development (*high confidence*). {8.4.5.5, 8.2.1.7}

Under higher emissions scenarios and increasing climate hazards, the potential for social tipping points increases (*medium confidence*). Even with moderate climate change[3] people in vulnerable regions will experience a further erosion of livelihood security that can interact with humanitarian crises, such as displacement and forced migration (*high confidence*) and violent conflict, and lead to social tipping points (*medium confidence*). Social tipping points can also be coupled with environmental tipping points. {8.3, 8.4.4}

Vulnerable population groups in most vulnerable regions have the most urgent need for adaptation (*high confidence*). The most vulnerable regions are particularly located in East, Central and West Africa, South Asia, Micronesia and Melanesia and in Central America (*high confidence*). These regions are characterised by compound challenges of high levels of poverty, a significant number of people without access to basic services, such as water and sanitation, and wealth and gender inequalities, as well as governance challenges. Areas of high human vulnerability are characterised by larger transboundary regional clusters (*high confidence*). Additional support

1 In this Report, the following summary terms are used to describe the available evidence: limited, medium, or robust; and for the degree of agreement: low, medium, or high. A level of confidence is expressed using five qualifiers: very low, low, medium, high, and very high, and typeset in italics, e.g., *medium confidence*. For a given evidence and agreement statement, different confidence levels can be assigned, but increasing levels of evidence and degrees of agreement are correlated with increasing confidence.

2 In this Report, the following terms have been used to indicate the assessed likelihood of an outcome or a result: Virtually certain 99–100% probability, Very likely 90–100%, Likely 66–100%, About as likely as not 33–66%, Unlikely 0–33%, Very unlikely 0–10%, and Exceptionally unlikely 0–1%. Additional terms (Extremely likely: 95–100%, More likely than not >50–100%, and Extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely*). This Report also uses the term '*likely* range' to indicate that the assessed likelihood of an outcome lies within the 17–83% probability range.

3 Meaning low or moderate emission scenarios.

and structures are needed to reduce the existing gaps between future adaptation needs and current capacities, and to support transitions from vulnerable livelihoods with adequate integration of the Indigenous knowledge and local knowledge (IKLK) systems. Greater investments are required under higher levels of global warming and of inequality (Relative Concentration Pathway (RCP) 4.5; RCP8.5 and SSP4) (*high confidence*). {8.3, 8.4, Box 8.6}

The direct and indirect consequences of the COVID-19 pandemic have worsened inequalities within societies, thereby increasing existing vulnerabilities to climate change and further limiting the ability of marginalised communities to adapt (*medium confidence*). The COVID-19 pandemic is expected to increase the adverse consequences of climate change since the financial consequences have led to a shift in priorities and constrain vulnerability reduction (*medium confidence*). Moreover, the COVID-19 pandemic is also influencing the capacities of governmental institutions in developing nations to support planned adaptation and poverty reduction of most vulnerable people/groups, since the crisis also means significant reductions in tax revenues (*high confidence*). {8.3, 8.4, 8.4.5.5}

Those with climate-sensitive livelihoods and precarious livelihood conditions are often least able to adapt, afforded limited adaptation opportunities and have little influence on decision making (*high confidence*). Enabling environments that support sustainable development are essential for adaptation and climate resilient development (*high confidence*). Enabling and supportive environments for adaptation share common governance characteristics, including multiple actors and assets, multiple centres of power at different levels and an effective vertical and horizontal integration between levels (*high confidence*). Enabling conditions can support livelihood strategies that do not undermine human well-being (*medium confidence*). {8.5.1, 8.5.2, 8.6.3, 5.13}

Mitigation and adaptation responses to climate change influence inequalities, poverty and livelihood security and thereby aspects of climate justice (*medium confidence*). Improving coherence between adaptations of different social groups and sectors at different scales can reduce maladaptation, enable mitigation and advance progress towards climate resilience (*medium confidence*). The poor typically have low carbon footprints but are disproportionately affected by adverse consequences of climate change and also lack access to adaptation options. In many cases, the poor and most vulnerable people and groups are most adversely affected by maladaptation (*medium evidence, high agreement*). Climate justice and rights-based approaches are increasingly recognised as key principles within mitigation and adaptation strategies and projects (*medium confidence*). Narrowing gender gaps can play a transformative role in pursuing climate justice (*medium confidence*). Climate resilient development is therefore closely coupled with issues of climate justice. Synergies between adaptation and mitigation exist, and these can have benefits for the poor (*medium confidence*). {8.4, 8.4.5.5, 8.6}

There is increasing evidence that nature-based solutions (e.g., urban green infrastructure, ecosystem-based management) can provide important livelihood options and reduce poverty while also supporting mitigation and adaptation (*medium confidence*). However, the trade-offs over time between nature-based solutions and their dynamics are insufficiently understood. Appropriate governance, including mainstreaming and policy coherence, supported by adaptation finance that targets the poor and marginalised, is essential for adaptation and climate compatible development (medium confidence). {8.5.2, 8.6.3, 5.14}

8.1 Introduction

The impacts of climate change have already significantly affected livelihoods and living conditions, especially of the poorest and most vulnerable, and will continue to undermine development during the coming century. This chapter assesses the societal consequences of climate change and related hazards in terms of adverse and irreversible consequences for the most vulnerable. To understand societal consequences of climate change, we assess impacts through the perspective of vulnerability, poverty and livelihoods of people. We identify why climate events trigger sudden and slow-onset disasters, and how the most severe, acute and chronic impacts cause and deepen human suffering. We also examine issues of climate justice. Understanding and engaging with climate justice requires a plural focus on the historical social and institutional relations and inequalities that produce climate change, cause people to be vulnerable to climate hazards and shape responses to them (Newell et al., 2021). An assessment of observed impacts on the poorest and their strategies for adaptation carries important lessons for inclusive, broad-based solutions to climate change.

As a starting point, this chapter examines linkages between climate change, specific climate-related hazards and impacts on multidimensional poverty, vulnerability and livelihoods. Past assessments have identified the linkages between climate change, poverty, livelihoods and human vulnerability, and shown how climate change leads to differential consequences for different communities and populations. The IPCC Fifth Assessment Report (AR5) identified socially and geographically disadvantaged people exposed to persistent inequalities at the intersection of various dimensions of discrimination based on gender, age, ethnicity, class and caste (IPCC, 2014a). AR5 also showed evidence that climate change is a universal driver and multiplier of risk that shapes dynamic interactions between these factors. Climate change is one stressor that shapes dynamic and differential livelihood trajectories. Also, the IPCC Special 1.5°C Report (IPCC SR 1.5°C) underscored with *very high confidence* that global mean temperature, harm and human well-being losses are increasing substantially (Hoegh-Guldberg et al., 2018; Roy et al., 2018).

This chapter builds on this, examining equitable development, robust institutions and poverty reduction as essential inputs to societies' capacity for adaptation (i.e., closes the adaptation gap) in order to avoid losses and damages (L&Ds) from climate change. It assesses quantitative spatio-temporal information on human vulnerability at a global scale and for specific sub-regions, livelihood groups and communities at the local level. The chapter assesses the newest literature on how multidimensional poverty and human vulnerability to climate change is measured and also examined the agreement of different index systems in terms of global hotspots of human vulnerability.

In addition, the chapter explores how climate change affects different livelihoods and livelihood assets and also examines factors that characterise vulnerability to climate change, focusing on different dimensions of human vulnerability and its subsystems (e.g., access to infrastructure services). In this context the chapter also assesses quantitative data to map human vulnerability as well as economic and non-economic losses that are highly relevant for understanding adverse impacts of climate change.

The chapter assesses the newest scientific knowledge on how the most vulnerable and marginalised people are experiencing different climate-influenced hazards and changes, how these groups prepare for and adapt to these changes. Hence, it examines how climate change intersects with broader processes of development. It also considers the various impacts of climate change on the livelihoods of the poorest, the capabilities, assets and activities required for a means of living. It examines the institutional conditions that promote livelihood resilience in the face of climate change. Quantitative analysis and qualitative data on observed adverse climate change impacts and future projections and trends in vulnerability show that societal impacts of climate change cannot solely be explained by looking at temperature changes or climatic hazards alone.

The chapter provides due consideration of how societal impacts of climate change are emerging as a result of climatic changes, development and vulnerability. In this regard, it also explores how past and present conditions of poverty, inequality and vulnerability determine observed and future societal impacts of climate change, including future adaptive capacities of societies exposed to climate change. It highlights new entry points to address climate risks and adaptation needs through the targeted reduction of poverty, inequity and vulnerability, linking particularly global quantitative information with local livelihood-orientated qualitative information.

The chapter outlines new approaches for identifying social tipping points, meaning moments of rapid, destabilising change across scales that can complement the discussion about physical tipping points in the climate system. It also addresses new perspectives on the baselines for assessing future vulnerabilities, and the potential for irreversible losses, emphasising not only economic but also non-economic losses, which are linked to past and present development trajectories. There is *robust evidence* on non-economic losses, including the loss of land, livelihoods, social networks, cultural values and the irreversible degradation of ecosystem functions, as observed, for example, in parts of the Amazon. Non-economic losses are intertwined with economic losses to influence human health, nutrition, well-being and social stability, and therefore also influence present and future vulnerabilities and adaptive capacities. Non-economic losses from climate change disproportionately affect the poor. People in vulnerable situations are often disproportionately affected as they are less resilient and have less access to institutional support (including protection mechanisms) and coping strategies. This knowledge is key for informing integrated strategies for sustainable livelihood transitions and adaptation.

The chapter assesses newer literature about the synergies and trade-offs for the poorest and most vulnerable people and groups between adaptation–mitigation and sustainable development strategies, which societies must negotiate in order to pursue climate resilient development. It explores synergies and mismatches in key development sectors that the poorest rely on, including agriculture, forestry and energy. It identifies the development strategies, elements of institutional design and financial mechanisms that could support risk reduction and adaptation. Our assessment reveals that successful adaptation is not solely a question of levels of funding, but depends on broader institutional design that determine societal development and enabling conditions for adaptation to and mitigation of climate change. An assessment

Human dimension of climate change at the nexus of climate change, climate hazards and socio-economic development

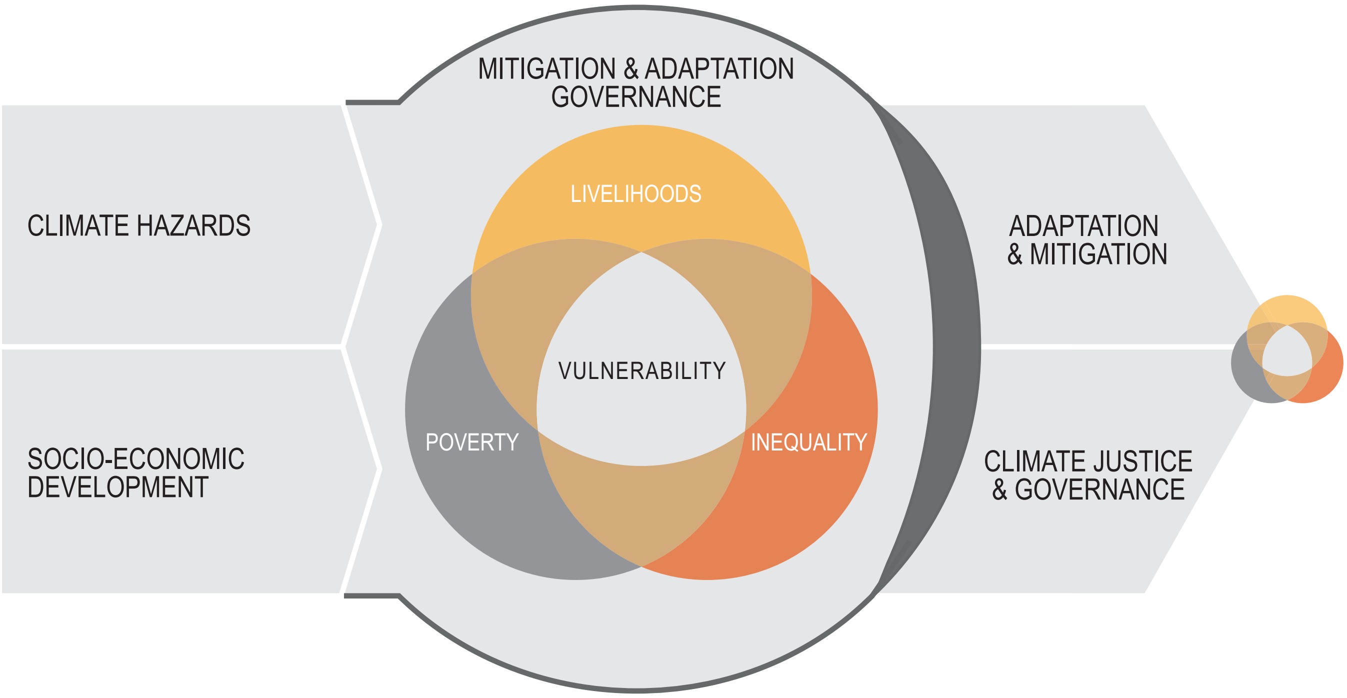

Figure 8.1 | The lens of Chapter 8 to better understand the human dimension of climate change at the nexus of climate change, climate hazards and socio-economic development.

of enabling conditions for adaptation supports the finding that more convergent, integrated and comprehensive approaches to adaptation are needed. The chapter concludes that climate justice requires consideration of the legal, institutional and governance frameworks that significantly determine whether adaptation is successful in addressing the needs of the poor.

Thus, intersections between climate hazards and socioeconomic development are assessed from the point of view of vulnerability, poverty, livelihoods and inequality (see Figure 8.1). Chapter 8 adopts this wider perspective to examine the differential nature of observed and future disproportionate vulnerabilities (i.e., who is most susceptible to climate hazards and events, where, at the core to understanding of what scale and why?), as well as the inequalities inherent in adaptation and mitigation solutions as part of a wider climate justice perspective adopted in Chapter 8, and challenges for climate resilient development.

Finally, our assessment points towards the fact that human vulnerability to climate change is a complex and multifaceted phenomenon that is often influenced by historic development processes, such as structures that originated with colonisation. Also, recent global shocks not directly related to climate change, such as the COVID-19 pandemic and its socioeconomic consequences, impact climate vulnerability and inequitable impacts occurring between countries and within countries. Recent studies show that COVID-19, and other social, economic and political crises, have worsened the circumstances of the poor and further marginalised them.

Overall, the chapter is key in terms of understanding societal impacts of climate change and factors that determine the various differential adverse consequences of climate change on societies. The information presented and assessed is fundamental for informing adaptation and risk reduction strategies, since climatic information alone cannot explain sufficiently why some regions, societies or groups are suffering significantly more under climate change compared to others. Concepts such as vulnerability, intersectionality and climate justice provide important insights on how societal impacts of climate change are influenced and determined by broader societal development contexts.

8.2 Detection and Attribution of Observed Impacts and Responses

8.2.1 Observed Impacts of Climate Change with Implications for Poverty, Livelihoods and Sustainable Development

This section reports on new evidence on the observed impacts of climate change to livelihoods and the poor since the previous assessment (IPCC, 2014a). New evidence provides additional insight into the interlinkages between climate change, poverty and livelihoods. New evidence has been evaluated according to climate change hazard categories developed for the AR6 (IPCC, 2021), and summarised in Figure 8.2.

8.2.1.1 Interactions Between Climate Hazards and Non-climatic Stressors Affecting Livelihoods

New evidence highlights the potential for multi-hazard risks to push the poor into persistent traps of extreme poverty (Räsänen et al., 2016). Risk of extreme impoverishment increases for low-income people experiencing repeated and successive climatic events, whereby before they have recovered from one disaster, they face another impact (Forzieri et al., 2016). Cascading and compounding risks arise from multiple climate hazards coinciding to produce impacts, for example, in mountainous regions, where the combination of glacier recession and extreme rainfall result in landslides (Martha et al., 2015). There is *robust evidence* that this effect has been observed around slow- and rapid-onset climate events related to drought (i.e., rising temperatures, heatwaves and rainfall scarcity), with devastating consequences for agriculture (Vogt et al., 2018; Bouwer, 2019). In particular, the urban and rural landless poor face difficulties rebuilding assets following one-off disasters or a series of shocks (Garcia-Aristizabal et al., 2015).

Climate change is one driver among many that challenges livelihoods of the rural poor, including economic transitions associated with industrialisation and urbanisation, and also governance failures such as unclear property rights and civil conflict (e.g., Nyantakyi-Frimpong and Bezner-Kerr, 2015). Recent research adds evidence about the ways that climate hazards impact non-climatic stressors with implications for poverty reduction (Nelson et al., 2016). The risk that climate hazards may push the poor into persistent extreme poverty intensifies with stagnant wages, rising costs of living, mobility traps, and ethnic or religious discrimination (Cramer et al., 2014; Carter et al., 2016). Likewise in both urban and rural environments, non-climatic factors related to governance exacerbate the impacts of climate events among the poorest, including poor service provisioning (e.g., waste collection), poor urban planning (e.g., waste water drainage) and water management failures (Di Baldassarre et al., 2010; Leal Filho et al., 2018), as well as poor rangeland management, intensification of farming land uses (i.e., overgrazing, deforestation), degradation of wetlands, shortage of water and soil erosion in rural areas (Olsson et al., 2019).

A key risk for the poor is shocks to specific livelihood assets that may force low-income groups into persistent poverty traps (Figure 8.4; Chambers and Conway, 1992; Cinner et al., 2018) but research also suggests that climate change impacts are also driving transient forms of poverty, a modality of poverty which is recurring (Angelsen et al., 2014). Recurrent poverty is, for instance, seen in relation to crop losses and decreasing agricultural production when income losses worsen living conditions (Ward, 2016; Kihara et al., 2020). Recent research shows that climate change impacts may exacerbate poverty indirectly through increasing cost of food, housing and healthcare, among other rising costs borne by the poor (Islam et al., 2014; Ebi et al., 2017; Hallegatte et al., 2018) (*high confidence*). Severe adverse impacts of climate change at present and future risks may result from permanent, sudden, destabilising changes accompanying climate events such as decreases in food security, large-scale migration, changes in labour capacity or conflict (Bentley et al., 2014). Overall, there is more evidence that even under medium warming pathways, climate change risks to poverty would become severe if vulnerability is high and adaptation is low (*limited evidence, high agreement*) (see Section 16.5.2.3.4)

Reliable and precise estimates of the impacts of climate change on persistent poverty are difficult to generate, for example, due to data scarcity and data gaps (Hallegatte et al., 2015; Hallegatte et al., 2018; Kugler et al., 2019). However, progress has been made towards detection and attribution of climate change impacts on the poorest by linking standard climate observations in low-income countries with new non-traditional forms of data (including Indigenous knowledge, historical archival data, satellite imagery, and data from digital devices) (Kuffer et al., 2016; Lu et al., 2016; Bennett and Smith, 2017; Steele et al., 2017).

8.2.1.2 Links Between Climate-related Hazards, Observed Losses, Poverty and Inequality Globally

There is *high confidence* that climate-related hazards, including both slow-onset shifts and extreme events, directly affect the poor through adverse impacts on livelihoods (see Figure 8.2), including reductions and losses of agricultural yields, impacts on human health and food security, destruction of homes, and loss of income (Hallegatte et al., 2015; Connolly-Boutin and Smit, 2016). One of the key factors that drives disproportionate impacts among poor households globally is lost agricultural income (*high confidence*) (Hallegatte et al., 2015; Islam and Winkel, 2017). Also of concern are the impacts of climate hazards to human health, which is a primary resource that the poor rely on (Figure 8.2). There are only few robust global estimates of observed income losses to the poor that comprehensively account for all climate hazards; nevertheless, (Hallegatte and Rozenberg, 2017), estimating average impacts of climate change on incomes of the poor, found that across 92 developing countries, the poorest 40% of the population experienced losses that were 70% greater than the losses of people with average wealth.

Overall, our assessment shows (see Figure 8.2) *high confidence* that two categories of climate hazards pose high risk to a broad range of livelihood resources that the poor rely on: warming trends and droughts (Figure 8.2b). Two key livelihood resource categories—life, bodily health and food security, and crop yield (representing agricultural productivity) are most at risk to a broad range of climate hazards (*high confidence,* Figure 8.2b). In addition to warming and drought, both pluvial and fluvial flooding, severe storms and sea level rise represent a high-risk cluster for livelihood impacts (*high confidence,* Figure 8.2b).

Figure 8.2 reflects the fundamental threat that climate hazards pose to the survival of plants, livestock and fish, as well as the people on which livelihoods depend (*high confidence*) (see Horton et al., 2021). The dependence of livelihoods on biological, ecological and human survival depicted in Figure 8.2 is also treated in Chapter 5. Likewise, impacts to livelihood resources can be compared to impacts to other key assets (see Working Group I (WGI) Section 12.3; WGI Table 12.2, Ranasinghe et al., 2021).

It is revealed that warming trends and droughts pose greatest risks to the widest array of livelihood resources, and are particularly detrimental to crops and human health, a long-term requirement for livelihoods and well-being (*high confidence*) (see Figure 8.2B; Section 8.4.5.3; Section 16.5.2.3.4; Campbell et al., 2018). A wide range of hazards also threaten the survival of fish and livestock that livelihoods depend

Summary of confidence on the observed impacts of 23 climate hazards on nine key livelihood resources on which the poor depend most

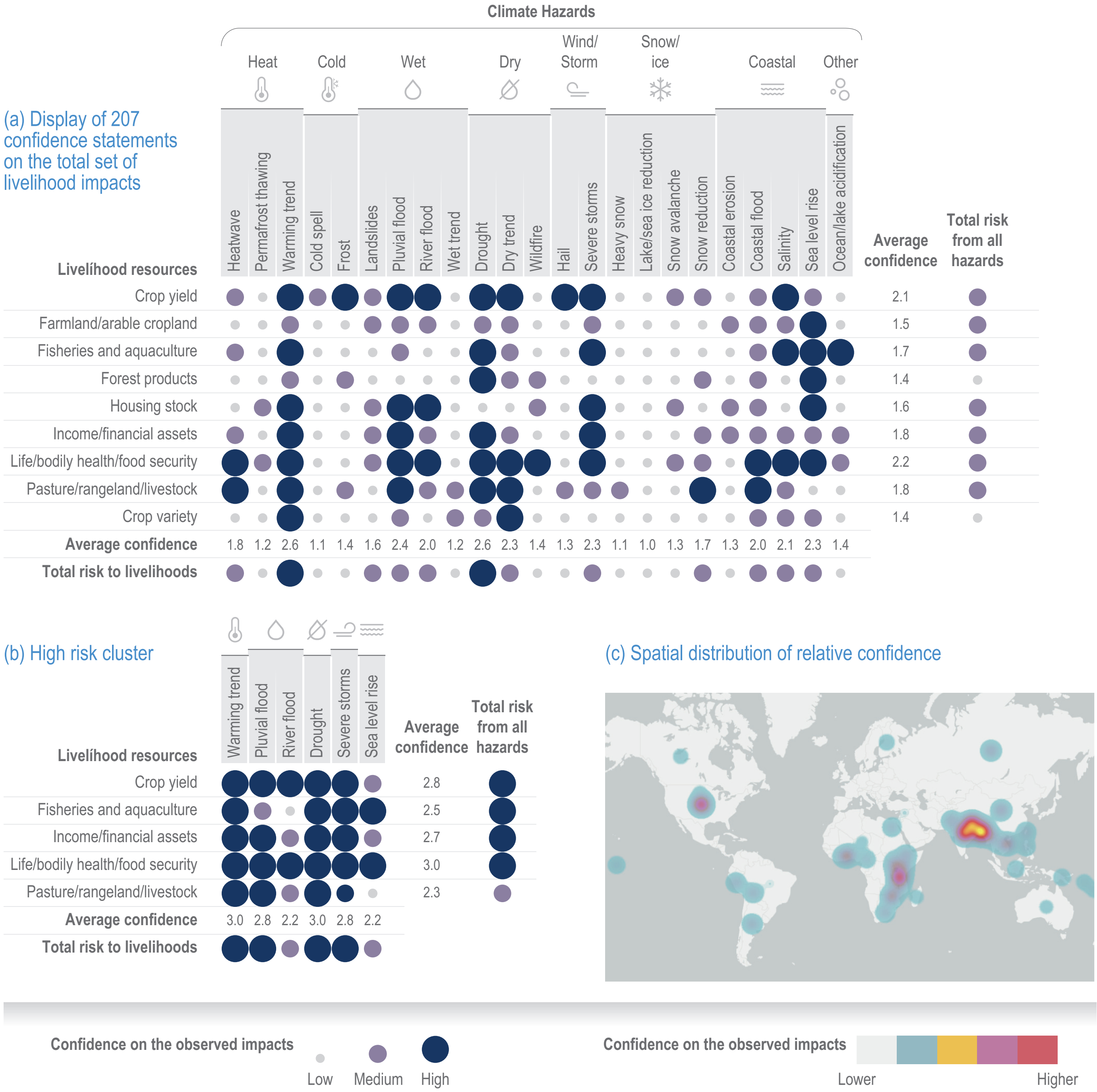

Figure 8.2 | Summary of confidence on the observed impacts of 23 climate hazards on nine key livelihood resources on which the poor depend most.

(a) A total of 207 confidence statements on the total set of livelihood impacts. Based on a standardised assessment of available literature since the AR5 (IPCC, 2014a), each impact category was assigned a confidence statement based on weight of evidence; *high confidence* is represented with HC, *medium confidence* with MC and *low confidence* with LC. An average numerical confidence score is assigned for impacts from each climate hazard, and for each livelihood resource category, representing total risk.

(b) The 'high-risk' cluster of livelihood impacts, where confidence is highest. **(c)** The spatial distribution of relative confidence. Hotspots represent highest confidence of observed livelihood impacts; however, the absence of spatial information reflects not an absence of observed livelihood risk, but the relative weight of evidence sampled in this assessment exercise.

on (*high confidence,* Figure 8.2b), as well as other sources of income for the poor. Salinity is a secondary hazard related to droughts, coastal flooding and sea level rise, and poses a fundamental risk to agriculture (*high confidence*). There is also *robust evidence* for rainfall variability driving short-term impacts to agricultural productivity as well as permanent loss of agriculture (*high confidence*).

While severe storms, pluvial and riverine floods, and coastal floods primarily impact private livelihood resources, such as homes and income (*high confidence*, Figure 8.2b), warming and droughts also affect common pool resources, such as rangeland, fisheries and forests (*high confidence*, Figure 8.2b). Multiple hazards undermine ecosystems that Indigenous Peoples and poor communities depend on for food security and income and have sustainably managed over the long term, such as forests, grazing land and marine fisheries (Barange et al., 2014; Leichenko and Silva, 2014; Béné et al., 2016; Jantarasami et al., 2018).

High confidence for observed livelihood impacts is spatially concentrated in South Asia, Africa, North America, and to a lesser extent Small Island Developing States (SIDS) (Figure 8.2c). The hazards most prevalent in all regions include warming trends, droughts and sea level rise (Figure 8.2c), and undermine crop productivity, crop varieties, and cropland in most regions (*high confidence*). Along coastlines, climate hazards threaten livelihoods particularly exposed to extreme weather, flooding and sea level rise, and where poor populations are heavily dependent on agriculture and fisheries (*high confidence*). One third of total sampled evidence on livelihood impacts was observed in just three countries—Bangladesh, India and Nepal—indicating accumulating experience with livelihood impacts in South Asia (Figure 8.2c). However, this spatial representation of confidence does not mean that observed livelihood impacts are not occurring in other regions as well. Relative to South Asia, in Central Asia and the Caribbean, for example, the weight of evidence of livelihood impacts though lighter is still *robust*. Among industrialised nations, there is *high confidence* that climate change has impacted livelihood resources in the USA.

8.2.1.3. Observed Differential Vulnerability to Climate Change, and Loss and Damage

The negative impacts of climate change on groups of vulnerable or marginalised communities generate so-called 'residual impacts' and residual risks that can remain a challenge in their lives (Warner and Van der Geest, 2013; James et al., 2014; Klein et al., 2014; Boyd et al., 2017). Such 'unacceptable' L&Ds include the loss of income sources, food insecurity, malnutrition, permanent impacts to health and labour productivity, loss of life and loss of homelands, among others (McNamara and Jackson, 2019; Schwerdtle et al., 2020). The literature on L&D provides *robust evidence* not only on economic dimensions of global L&Ds, but also experiences of non-economic losses from the impacts of climate change (see detail in Section 8.3; Barnett et al., 2016; Roy et al., 2018; McNamara and Jackson, 2019). The extreme events that have occurred in recent years highlight the potential for L&D, including 2019's Cyclone Kenneth, the strongest in the recorded history of the African continent, which made landfall in northern Mozambique causing 45 deaths and destroying approximately 40,000 houses, leaving hundreds of thousands at risk of acquiring waterborne diseases such as cholera during a prolonged recovery period (Cambaza et al., 2019).

In parallel to evidence on L&D, the science of climate event attribution has evolved from a theoretical possibility into a subfield of climate science. As attribution science strengthens, with it the evidence base linking greenhouse gas (GHG) emissions to extreme heat events, heavy rainfall and wind storms grows and becomes more robust (Otto et al., 2016; Stott et al., 2016; Otto et al., 2018; Otto, 2020; Clarke et al., 2021; van Oldenborgh et al., 2021a; van Oldenborgh et al., 2021b; Verschuur et al., 2021).

Climate justice questions arise about the observed differential L&Ds due to climatic hazards to affected populations in close connection with their vulnerability (Wrathall et al., 2015). Individual extreme weather events attributable to climate change result in L&Ds in communities and societies, which allow a quantification of the differential impacts of such events on different groups (Hoegh-Guldberg et al., 2019a). Considering the disproportionately adverse impacts of climatic hazard on most vulnerable groups and regions and their relatively minor contribution to anthropogenic climate change (Mora et al., 2018; Robinson and Shine, 2018), it is evident that vulnerability reduction and adaptation to climate change have also to be seen as an issue of climate justice and climate just development (Byers et al., 2018).

Probabilistic attribution allows an assessment of people's future climate risks and estimates about the costs of successfully adapting to them (James et al., 2014; James et al., 2019). To answer questions about impacts on people, the vulnerable and poor in particular, requires attribution, vulnerability and adaptation science need to move far beyond understanding physical events and incorporate information (including Indigenous knowledge and local knowledge (IKLK)) on people's vulnerability and capacities, and exposure and losses resulting from discrete events (Bellprat et al., 2019). Attribution science is therefore highly compatible with risk management tools (i.e., risk reduction, risk transfer, insurance, risk pooling, recovery, rehabilitation and compensation) suggested in policy (James et al., 2019).

New observations provide greater evidence on the role of extreme poverty and global inequality, most of the detrimental direct impacts of climate change (e.g., rising food insecurity) disproportionately affecting the Global South (Hasegawa et al., 2018; Mbow et al., 2019; Khan and Zhang, 2021) compared with the Global North. Poor populations in many countries are also disproportionately facing extreme L&D from heatwaves, flooding and tropical weather extremes (Gamble et al., 2016). New case studies, such as the European heatwave of 2018, illustrate significant negative impacts across crop production in the Global North (Beillouin et al., 2020), livestock value chain (FAO, 2018; Godde et al., 2021) and fishing (Plagányi, 2019). Heatwave-induced intense fires can cause property damage, physical injury and death, as well as health and psychological harm of the victims. Heatwaves also create ideal conditions for the prevalence of certain pathogens, increase the risk of temperature-related health problems and exacerbate many pre-existing diseases (Rossiello and Szema, 2019).

A focus in the chapter is on the intersections between climate hazards and differential vulnerability resulting in actual and potential economic and non-economic losses (Section 8.3, 8.4; Thomas et al., 2019). Increasingly, intersections of age, gender, socioeconomic class, ethnicity and race are recognised as important to the climate risks and differential impacts and losses experienced by vulnerable, marginal and poor in societies (*high confidence*).(Section 8.2,2.3; CCB GENDER in Chapter 18; Nyantakyi-Frimpong and Bezner-Kerr, 2015). For example, linkages between wildfires and gendered norms and values are real-

The interface between climate hazards and factors of human vulnerability

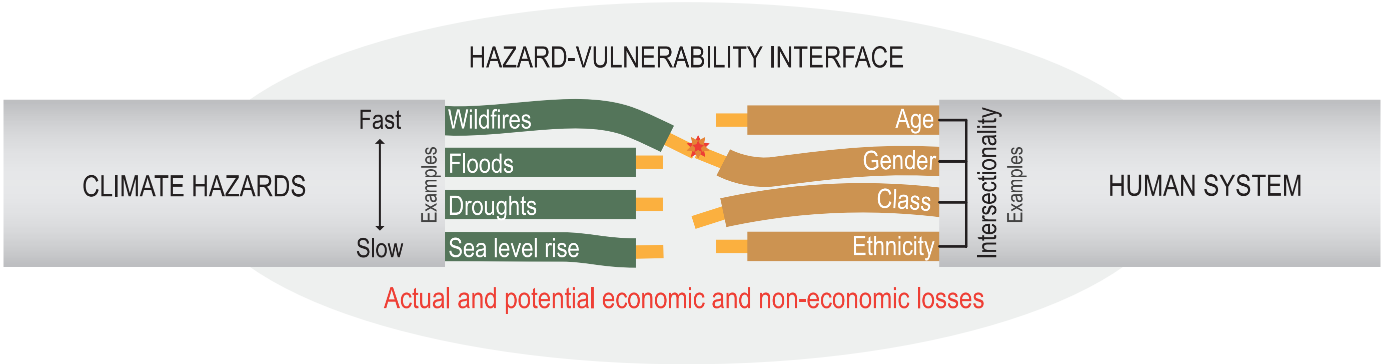

Figure 8.3 | Illustration of the relationship between climate hazards, their impacts (including economic and non-economic losses and damages) and human systems leading to systemic vulnerability. We need to understand who is vulnerable, where, at what scale and why. We cannot just look at the climate hazard (e.g., wild fires, floods, droughts, sea level rise, etc.) but must also look at who is being affected by these hazards and factors that make people and groups vulnerable (e.g., poverty, uneven power structures, disadvantage and discrimination due to, for example, social location and the intersectionality or the overlapping and compounding risks from ethnicity or racial discrimination, gender, age, or disability, etc.) (see also Cross-Chapter Box GENDER in Chapter 18; Section 5.12).

world examples (Walker et al., 2021). A broader climate agenda which considers social structures and power relations intersecting with climate change extremes is important (Versey, 2021), in order to understand disproportionate impacts of climate hazards, observed and future losses and vulnerability (see Figure 8.3).

Extreme events (e.g., heatwaves, cold periods, icy conditions) occurring in the Global North illustrate that such events cause disproportionate impacts among ageing populations, due to their immobility, isolation, infrastructure deficiencies and poor health assistance (Carter et al., 2016; Reckien et al., 2018). A well-known example is the heatwave in 2003 that killed thousands of elderly citizens across Europe (Poumadere et al., 2005; García-Herrera et al., 2010; Laaidi et al., 2011). More recently, in the Nordic region, elderly populations have been experiencing distress associated with heatwaves and extreme cold events, with significant increases in morbidity and mortality due to cardiovascular and respiratory failure, showing that both age and underlying health issues intersect with climate change impacts (Carter et al., 2016; Li et al., 2016). The elderly also experience severe impacts from extreme winter seasons, such as in Finland, where of the from 3000 deaths associated with extreme winter weather and 50,000 injuries associated with slippery pavement conditions, the majority were people over 65 years old (Carter et al., 2016). Adaptation to extreme events including heatwaves, cold periods and icy conditions in the Global South and North will increase energy demand and the individuals' carbon footprint across all income levels (van Ruijven et al., 2019).

The 2018 US National Climate Assessment has identified that southeastern USA is already experiencing more frequent and longer summer heatwaves and, by 2050, rising global temperatures are expected to mean that cities in southeastern USA may experience extreme heat (USGCRP, 2018). This includes disadvantaged African American communities, who are more exposed and hence disproportionately experience the impacts of climate change (Shepherd and KC, 2015; Marsha et al., 2018). The historically discriminated Sami in northern Sweden and Maasai in Africa are examples of Indigenous People who also face climate risks and have limited resources, capacity or power to respond (Leal Filho et al., 2017; Persson et al., 2017).

8.2.1.4 Climate-related Hazards, Livelihood Transitions and Migration

Agricultural livelihoods of the rural poor, especially in Africa, Asia and Latin America, are already in transition due to the forces of industrialisation, urbanisation and economic globalisation (De Brauw et al., 2014; Tacoli et al., 2015). Scientific evidence shows that climate change is accelerating livelihood transitions from rural agricultural production to urban wages (Cai et al., 2016; Cattaneo and Peri, 2016; Kaczan and Orgill-Meyer, 2020).

There is now *robust evidence* from virtually every region on Earth showing that the livelihood impacts from a multitude of climate hazards are driving people to diversify rural income sources (Figure 8.2; Cross-Chapter Box MIGRATE in Chapter 7). Rural households frequently accomplish the goal of livelihood diversification with an increasing reliance on migration, urban wage labour and remittances (Marchiori et al., 2012; Bohra-Mishra et al., 2014; Gray and Wise, 2016; Nawrotzki and DeWaard, 2016; Banerjee et al., 2019a). What is different about rural-to-urban livelihood transitions under climate change impacts is that they accelerate both rural and urban stratification of wealth (Barrett and Santos, 2014; Thiede et al., 2016). On the one hand, climate change impacts on rural livelihoods increase the necessity of migration as an income strategy, accelerating migration (Cai et al., 2016) even while households that cannot select individuals for migration become more impoverished (Suckall et al., 2017; Nawrotzki and DeWaard, 2018).

On the other hand, climate change impacts widen the range of households willing or needing to engage in migration to include those less able to bear the costs of urban migration (Afifi et al., 2016; Hunter and Simon, 2017). The effect is also greater urban poverty, and a higher social burden of migrants seeking urban wages (Singh, 2019). Evidence suggests that poor households often move in desperation to make ends meet. In the context of climate hazards, such as coastal inundation and salinity, economic necessity often drives working-age adults in poor households to seek outside earnings (Dasgupta et al., 2016). Labour migration in the context of climate change is also gendered, and as more men seek employment opportunities away from home, women are required to acquire new capacities to manage new challenges, including increasing vulnerability to climate change (Banerjee et al., 2019b).

Migration and displacement are directly induced by the impacts of climate change (*high confidence*) (Cross-Chapter Box MIGRATE in Chapter 7), however, migration responses to climate change are differentiated across the spectrum of households' wealth. In well-off households, migration can be used as a way to support income diversification through remittances (Gemenne and Blocher, 2017). High levels of poverty mean that a large part of the African population does not have sufficient resources to be mobile (Borderon et al., 2019; Leal Filho et al., 2020c). The poorest households, conversely, will typically lack the resources that would allow them to migrate in ways that maintain an acceptable standard of living, and may find themselves unable or unwilling to move in the face of climate change impacts (Sam et al., 2021).

There is *high agreement* and *robust evidence* that climate change impacts also have a major influence on key enabling conditions for migration, such as sociodemographic, economic and political factors (Abel et al., 2019; Borderon et al., 2019), and that climate change impacts to development and governance may affect how people migrate (Wrathall et al., 2019; CCB MIGRATE in Chapter 7). Mobility, which was considered the most viable climate change adaptation strategy to poor pastoralists, is restricted due to the political marginalisation of pastoral groups, land privatisation, governments' decentralisation policies and plantation investment (Blench, 2001; Randall, 2015; Leal Filho et al., 2020c). While migration can be an adaptation response to climate change impacts (Black et al., 2011; Gemenne and Blocher, 2017), climate change impacts can also act as a direct driver of forced displacement (Marchiori et al., 2012). Societal groups that are forced to involuntarily migrate in response to climate change impacts may lack resources to invest in planned relocation mainly due to lack of good governance systems (Reckien et al., 2018). For people displaced by climate change impacts, policy interventions have a determining influence on migration outcomes, such as the numbers of migrants, the timing of migration and destinations (Gemenne and Blocher, 2017; Wrathall et al., 2019).The process of displacement and forced migration leaves people more exposed to climate change-related extreme weather events, particularly in low-income countries which often host the highest number of displaced people (Adger et al., 2018).

Climate change may be accelerating livelihood transitions and migration in ways that accelerate urbanisation (Adger et al., 2020). Although a range of climate hazards are noted for accelerating rural-to-urban livelihood transitions (see Cross-Chapter Box MIGRATE in Chapter 7), a key theme to emerge across many case studies is the impact of rising temperatures on agricultural productivity (Mueller et al., 2014; Cattaneo and Peri, 2016; Call et al., 2017; Wrathall et al., 2018). In other words, when people cannot farm due to rising temperatures (and related stressors), they migrate. In this context, migration as a livelihood diversification strategy may evolve and take multiple forms over time (Bell et al., 2019), such as temporary migration (Mueller et al., 2020), seasonal migration (Gautam, 2017) or permanent migration (Nawrotzki et al., 2017), but generally conforms to existing patterns of migration (Curtis et al., 2015).

A key concern for the poor is climate change impacts that undermine livelihood diversification and resilience, narrowing the set of available livelihood alternatives (Tanner et al., 2015; Bailey and Buck, 2016; Perfecto et al., 2019).

8.2.1.5 The Long-lasting Effects of Climate Change on Poverty and Inequality

New studies document the long-term effects of climate change impacts on people's livelihoods that persist long after a hazard event. For example, the impact of drought on livelihoods and food security is still recognisable in Mali, 30 years after 1982–1984, the period of most intense drought during the protracted late 20th century drying of the Sahel. The most food secure households associated with persistent drought-induced famine were those that diversified livelihoods away from subsistence agriculture during and after the famine (Giannini et al., 2017). Meanwhile, a larger fraction of households with fewer livelihood activities, lower food security with higher reliance on detrimental nutrition-based coping strategies (such as reducing the quantity or quality of meals) were those unable to diversify livelihoods 30 years previously. Sufficient time has passed to consider the long-term outcomes for the poor in extreme cases featured in previous IPCC assessments, including Hurricane Katrina (2005) (e.g., Fussell, 2015; Raker et al., 2019) and Hurricane Mitch (1998) (e.g., Alaniz, 2017), forewarning that recovery is complex and requires significant sustained long-term investment in 'soft' aspects of development, including community organisation and mental health (O'Neill et al., 2020; Fraser et al., 2021).

The IPCC Special Report on 1.5°C concluded that climate change has already increased the probability and intensity of individual extreme weather events occurring (Roy et al., 2018), and our new baseline consideration should be that serious climate change impacts are already being experienced by the most vulnerable, with long-term implications for development (Box 8.1; Roy et al., 2018). In both developing and developed countries the disproportionate impacts of the compounding effects of climate change on development are felt by the most disadvantaged. For example, the residual impacts of storms like Hurricane Maria (see Section 8.2.1.1) illustrate how rising temperatures, extreme weather events, coral bleaching and sea level rise come together and create compounding hazard-cascades to leave long-lasting effects on the lives of the poor, as well as their food and water security, health, livelihoods and prospects for sustainable development—not only in developing countries (Adger et al., 2014; Olsson et al., 2014; Hoegh-Guldberg et al., 2018; Roy et al., 2018), but also in highly inequitable industrialised countries within the same region (Gamble et al., 2016). According to the US National Climate Assessment (USGCRP, 2018), damages caused to communities by Hurricanes Irma and Maria in 2017 sparked unprecedented humanitarian crises. Hurricane Maria, a category 5 hurricane, passed through Dominica, St Croix and Puerto Rico and is considered the worst climate disaster in recorded history to affect those islands (Rodríguez-Díaz, 2018). Approximately 200,000 people migrated from Puerto Rico to the mainland USA in the weeks following the storm (Alexander et al., 2019). Estimates for direct and indirect casualties in Puerto Rico point out a total of 4645 excess deaths, equivalent to a 62% increase in the mortality rate (Kishore et al., 2018). The example of Hurricane Maria and Puerto Rico illustrates that vulnerability is part of a long history of discrimination and colonial governance, which led to greater impacts on the island (Moleti et al., 2020). In Puerto Rico, the economic costs of the collapse of the island's energy, water, transport, and communication infrastructures are estimated to range from USD 25 to USD 43 billion (USD in 2017), further indebting the island and putting its long-term development at risk. Meanwhile the economic impacts of Hurricanes Irma and Maria on the Caribbean region are estimated between USD 27 and USD 48 billion, and have long-term implications for state budgets for infrastructure supporting development of the poorest.

New evidence provides little expectation of net positive impacts of climate change for the poor (Hallegatte et al., 2015). Nevertheless, some benefits of climate change adaptation include improved disaster preparedness, the accumulation of social assets, economic benefits of agricultural diversification and benefits associated with migration, as well as the political benefits of collective action (Pelling et al., 2018). In contrast, wealthier tiers of society facing climate change impacts are more able to liquidate assets to avoid losses from climate change, to be formally compensated for losses (Fang et al., 2019) and employ social positions to leverage gains from adaptation (Nadiruzzaman and Wrathall, 2015).

The poor frequently suffer the direct and indirect impacts of climate change, including the cost of adopting adaptive measures (Atteridge and Remling, 2018; Bro et al., 2020). Costs to the poor may also include the secondary impacts of first-order adaptation activities, including the livelihood consequences to people migrating due to climate change impacts. The poor frequently bear indirect impacts of adaptation interventions, such as flood protection barriers, which may displace flood waters away from high-income populations toward poorer communities (Mustafa and Wrathall, 2011). Adaptation programming may also indirectly affect the poor as public resources are drawn into risk reduction interventions, and away from spending on social welfare and safety nets (Eriksen et al., 2015). Measures to enhance social welfare and safety nets themselves help enhance the poor's resilience to climate impacts because they focus on non-climatic stressors affecting livelihoods, which interact with climate hazards. Therefore, diverting attention away from safety nets may in fact undermine adaptation efforts (Leichenko and O'Brien, 2019; Tenzing, 2020).

Box 8.1 | Climate traps: A focus on refugees and internally displaced people

Populations of concern, who are extremely vulnerable to climate change impacts with limited capacity to adapt, are those displaced and resettled in the course of conflict or disaster, either internally or across borders (Burrows and Kinney, 2016). The risk for refugees and internally displaced people (IDPs) is two-fold: on the one hand, refugee and IDP settlements are disproportionately concentrated in regions (e.g., Central Africa and the Near East) that are exposed to higher-than-average warming levels and specific climate hazards, including temperature extremes and drought. On the other, these populations frequently inhabit settlements and legal circumstances that are intended to be temporary but are protracted across generations, and at the same time, face legal and economic barriers on their ability to migrate away from climate impacts. (Adams, 2016; Devictor and Do, 2016). Large concentrations of these settlements are located in the Sahel, the Near East and Central Asia, where temperatures will rise higher than the global average, and extreme temperatures will exceed thresholds for safe habitation (Figure Box 8.1.1). Already largely dependent on state and humanitarian intervention, these immobile populations will require interventions to safely maintain residence in areas exposed to climate hazards. Adaptation planning should prioritise immobile populations living in an already destabilised development context, on improving their capacities to deal with the further consequences of climate change.

Refugees and IDPs fit into a global category of extremely structurally vulnerable people that are missing from standard poverty assessments, officially uncounted or uncountable using traditional census and survey methods (Carr-Hill, 2013). These include highly mobile populations, internally displaced by war and environmental hazards (UNHCR, 2020; IDMC, 2021); itinerant labourers; urban poor in informal settlements (Lucci et al., 2018); unauthorised migrants living in countries where they do not hold citizenship (Passel, 2006); guest workers (Reichel and Morales, 2017); the homeless and institutionalised (Caton et al., 2007); rural nomadic, pastoralist or landless populations (Randall, 2015); and Indigenous Peoples and forest-dwelling communities (Galappaththi et al., 2020). Frequently living without social safety nets, such as health care and formal education, these uncounted or 'missing millions' are vulnerable to problems associated with acute and chronic poverty, such as the spread of infectious disease and malnutrition (Ezeh et al., 2017). Because these 'missing' populations are not counted, they are frequently not a part of planning (Carr-Hill, 2013), including adaptation planning. In any particular national context, these missing populations may represent a small fraction of the population (about 5% in South Asian countries), however cumulatively hundreds of millions of people may be missing from official estimates (Carr-Hill, 2013). Over the last decade, techniques for estimating the locations, numbers and socioeconomic status of missing populations have moved beyond census and nationally representative household surveys, leveraging advances in satellite imagery (Kuffer et al., 2016; Bennett and Smith, 2017) and data from mobile digital devices (Jean et al., 2016; Xie et al., 2016; Steele et al., 2017).

Box 8.1 (continued)

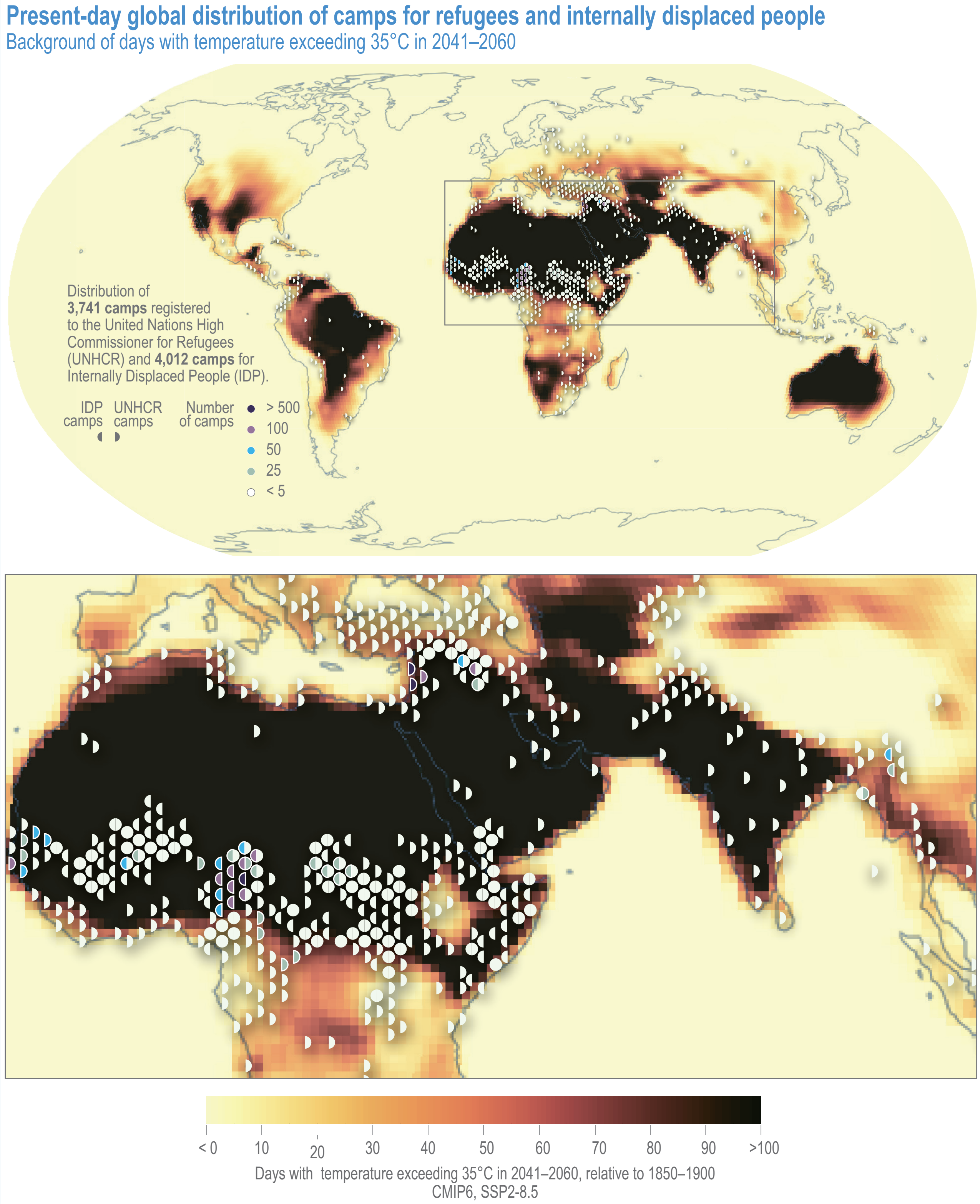

Figure Box 8.1.1 | The global distribution of the United Nations High Commissioner for Refugees (UNHCR) refugee and internally displaced people (IDP) settlements (as of 2018) overlaid on a gridded map of the days predicted to exceed safe temperature thresholds for human health in the coming decades (2041–2060 under SSP2 8.5). Semi-circles indicate the presence of refugee and IDP camps in grid cells, with darker semi-circles depicting increasingly dense concentrations of settlements. Darker background colors indicate increasingly unsafe conditions. Regions of concern include the southern edge of the Sahel, and the northern edge of the Levant

8.2.1.6 Interactions Between Climate Hazards and Social-ecological Thresholds

Climate change threatens to rapidly transform unique and threatened ecosystems (Reasons for Concern RFC1), such as tropical rain forests, coral reefs, arctic and high-mountain ecosystems, as well as the indigenous and forest-dwelling people whose livelihoods, cultures and identities are dependent on these ecosystems. In recent years, the case of Amazonia has illustrated how such systems are transforming, with detrimental consequences for Indigenous Peoples, and the vital role that Indigenous Peoples serve in protecting vulnerable ecosystems (Ricketts et al., 2010; Box 8.6). Globally, indigenous territories cover the greatest area of remaining tropical forest in comparison to other protected areas. They encompass the bulk of Earth's biodiversity and are the locus for a number of key ecosystem services across spatial and temporal scales (Walker et al., 2020). Specifically, in 2014 indigenous territories and other protected areas represented the equivalent of 58.5% of all the carbon stored in the Brazilian Amazon biome and had the lowest deforestation rate (2.1%) and fire incidences, evidencing the effectiveness in safeguarding important ecosystems services and well-being (Nogueira et al., 2018). It is estimated that indigenous territories in the Brazilian Amazon contribute at least USD 5 billion each year to the global economy through food and energy production, GHG emissions offsets, and climate regulation and stability (Siqueira-Gay et al., 2020). Given the high incidence of poverty of Amazonian countries and high proportion of traditional and Indigenous Peoples, remoteness and neglected governance place these unique ecosystems and indigenous populations as highly vulnerable to climate change impacts (Pinho et al., 2014; Brondízio et al., 2016; Mansur et al., 2016; Kasecker et al., 2018). Despite their importance, the survival of Indigenous Peoples in the Amazon is on the brink in the wake of increasing deforestation, land conflicts and invasions, cattle ranching, mining, fire incidence, health problems and human rights violation (Ferrante and Fearnside, 2019). There is *robust evidence* that both economic and non-economic L&Ds are currently, and will be, unevenly experienced by populations in vulnerable conditions, such as children, women, Indigenous Peoples and traditional communities (Pinho, 2016; Lapola et al., 2018; Roy et al., 2018; Eloy et al., 2019; Machado-Silva et al., 2020). Increasing wildfires inside protected areas, in particular, territories of Indigenous Peoples and traditional communities, is worrisome and presents challenges for the future of unique and threatened socio-ecological systems, and the ecosystem services they provide. The Amazonian indigenous territories and protected areas can deliver protection of biodiversity and important ecosystem services if appropriate governance mechanisms are in place and their land tenure rights and livelihoods are secured (Steege et al., 2015). The role of enabling environments is discussed in Section 8.5.

8.2.1.7 Linkages Between Climate Change Impacts and Sustainable Development Goals

Many of the observed outcomes of climate change, for example, migration, are also outcomes of multidimensional poverty in low-income countries (Burrows and Kinney, 2016). Future impacts may be better understood if the vulnerability and the capacity for adaptation is understood to be rooted in a sustainable development context (see Box 8.2). The UN Sustainable Development Goals (SDGs), which aim to reduce poverty and inequality, and identify options for achieving development progress, also provide insight on reducing climate vulnerability (United Nations, 2015). First, climate change impacts may undermine progress toward various SDGs (*medium confidence*), primarily poverty reduction (SDG1), zero hunger (SDG2), gender equality (SDG5) and reducing inequality (SDG10), among others (*medium evidence, high agreement*). In both developing and high-income countries, climate change hazards in connection with other non-climatic drivers already accelerate trends of wealth inequality (SDG 1) (Leal Filho et al., 2020b). Climate impacts on SDGs illustrate the complex interrelations in development. For example, in regions encountering obstacles to SDGs, characterised by high levels of inequality and poverty, such as in Africa, Central Asia and Central America, climate change is exacerbating water insecurity (SDG 6), which may then also drive food insecurity (SDG 2), impacting the poor directly (e.g., via crop failure), or indirectly (e.g., via rising food prices) (Conway et al., 2015; Hertel, 2015; Cheeseman, 2016; Rasul and Sharma, 2016). There is a pressing need to address poverty issues, since these may negatively influence the implementation of all SDGs (Leal Filho et al., 2021a).

At the same time, there is increasing evidence that successful adaptation depends on equitable development and climate justice; for example, gender inequality (SDG 5) and discrimination (SDG 16) are among the barriers to effective adaptation (*high confidence*) (Bryan et al.,

Box 8.2 | Livelihood strategies of internally displaced atoll communities in Yap

On Yap Island in the Federated States of Micronesia, displaced atoll communities have been under considerable pressure due to climate change. This is because of the island's vulnerability, as a result of its weak economic status, and the little access it has to technologies that may support adaptation efforts. This trend is seen in many SIDS (see also Chapter 15). On small islands and remote atolls where resources are often limited, recognising the starting point for action is critical to maximising benefits from adaptation. They do not have uniform climate risk profiles, and not all adaptations are equally appropriate in all contexts (Nurse et al., 2014) (*high confidence*).

The recurrences of natural hazards (e.g., El Niño-driven tropical storms, associated coastal erosion and saltwater or seasonal droughts leading to water scarcity) and crises threaten food and nutrition security through impacts on traditional agriculture, leading to income losses and causing the forced migration of coastal communities to highlands in search of better living conditions. As many of the projected climate change impacts are unavoidable, implementing some degree of adaptation becomes crucial for enhancing food and nutrition security, strengthening livelihoods, preventing poverty traps and increasing the resilience of coastal communities to future climate risks (Krishnapillai, 2018).

Box 8.2 (continued)

With support from the US Department of Agriculture and the US agency for International Development, the Cooperative Research and Extension wing of the College of Micronesia- Federated States of Micronesia Yap Campus has been providing outreach, technical assistance and extension education to regain food and nutrition security and stability. They have done this by improving the soil and cultivating community vegetable gardens, as well as indigenous trees and traditional crops. This programme implemented a three-pronged adaptation model to boost household and community resilience under harsh conditions on a degraded landscape, hence addressing poverty risks and promoting more sustainable livelihoods (Meyer and Jose, 2017).

The following three strategies: (a) gender-focused capacity development on soil health management, (b) good practices in sustainable land management (SLM) and (c) income-generation activities were employed to mitigate crop production losses and increase resilience to climate-influenced hazard events within the 258 ha of degraded lands in Gargey Village.

The project first focused on increasing the capacity development for 1100 residents of Gargey Village, including women and youth, in order to create a base of community knowledge for soil health management. Training on soil health management including the following: use of cover crops and improved fallow, legumes, composting and agroforestry systems, mulching, minimum tillage and contour farming, as well as altering production practices (planting time, spacing, pest and disease treatment, harvesting time), alternative crop production methods (container gardening, raised-bed gardening, small-plot intensive farming), hands-on training on compost preparation and seed germination.

Dissemination and use of good practices in sustainable land management

Following capacity building, the project trained villagers in the use of SLM practices to further soil resilience during ongoing and acute precipitation events. The SLM practices focused on volcanic soil management and compost preparation and use, along with the planting of native trees and crops. The protective soil cover was improved through cover crops, crop residues or mulch, and crop diversification through rotations. Local salt-tolerant crop varieties were introduced. Seed packets and seedlings were distributed to ensure a continuous supply of resilient traditional plants and to provide for sustainable post-disaster recovery.

Income-generation activities

The project also included training to increase the incomes of households by training household members in the cultivation of vegetables using various alternative crop production methods. Households were then able to sell their vegetables in the local markets.

Less hunger and more cash from leafy vegetables is a concept adopted at the household level to not only reduce poverty, but also to empower displaced communities to address the issue of malnutrition. Practices include growing a variety of nutritious vegetables as part of a large crop portfolio and using alternative crop production methods, such as small-plot intensive farming using container gardening or raised-bed gardening (Krishnapillai and Gavenda, 2014). In addition, focusing efforts on increasing the sustainable production of staple crops confers significant nutritional benefits.

More households in the settlements are consuming vegetables since home gardeners started harvesting regularly and sharing their produce with extended families or selling them to generate income. The location-specific, community-based adaptation model improved food and nutrition security and livelihoods (Krishnapillai, 2017). People can access more nutritious and reliable food sources, and they are growing their own food and selling their surplus, creating new optimism about their future.

The climate-smart agriculture (CSA) package increased land cover by more than 50% within Gargey Village. This includes the planting of 42 varieties of native trees and crops. Current major crops that are being successfully grown at this location include coconut, breadfruit, mango, noni, chestnut, pineapple, sugarcane, land taro, tapioca and sweet potato. There have been additional benefits in terms of improvement in water availability. These activities have directly benefited the resilience and food security of more than 1000 residents in Gargey Village, and lessons learnt from this project have helped to scale up similar projects at three locations in Yap that have experienced equivalent climate-damaging processes.

Overall, this case study illustrates the benefits of promoting resilient crop production in Gargey Village, as an example of displaced atoll communities. Innovative and sustainable CSA strategies have offered broader insights and lessons for enhancing adaptive capacity and resilience, on a degraded landscape. The coherent strategies and methods employed have strengthened livelihood opportunities by improving access to services, knowledge and resources. By its concurrent focus on enhancing food security through traditional crops, coupled with nutrient-rich vegetables, promoting rainwater harvesting systems and water conservation, and promoting resilient household livelihood opportunities, atoll communities brought together crucial elements needed to reduce vulnerabilities and to better cope with disasters and climate extremes, while embracing the traditional culture. The location-specific yet knowledge-intensive CSA methods deployed, offered opportunities for atoll communities to revitalise themselves, overcoming barriers while adjusting to new landscapes.

2018; Onwutuebe, 2019; Garcia et al., 2020). Likewise, both climatic and non-climatic threats to development, such as conflict (SDG 16), may seriously undermine capacity to formulate and implement adaptation policies, and design planning pathways (Hinkel et al., 2018). The risk of conflict associated with climate change has great potential to undermine other development goals (Box 8.4). Where sustainable development lags and human vulnerability is high, there is also often also a severe adaptation gap (Figure 8.12; Birkmann et al., 2021a). The SDGs may provide important cues on how to close the adaptation gap: climate action needs to be prioritised where past and future climate change impacts threaten SDGs, and where investment in SDGs improve capacity for adaptation (see Section 8.6).

8.2.2 Poverty–Environment Traps and Observed Responses to Climate Change with Implications for Poverty, Livelihoods and Sustainable Development

Across all geographical regions, there is evidence that anthropogenic climate change is hindering poverty alleviation and thereby constraining responses to climate change in five main ways:

- By worsening living conditions (Hallegatte et al., 2017; Hsiang et al., 2017)
- By threatening food and nutrition security due to undernutrition and reduced opportunities for income generation (Burke et al., 2015)
- By disrupting access to basic ecosystems services such as rainwater, soil moisture (reducing the productivity of agricultural land) or via the depletion of habitats (e.g., mangroves, fishing grounds) that particularly vulnerable and poor people are depending on (Malhi et al., 2020)
- By creating favourable conditions for the spread of vector-transmitted diseases (Liang and Gong, 2017)
- By threatening underlying gender inequalities exacerbated by climate impacts, such as access and control to productive inputs and reinforcing social-cultural norms that discriminate against gender, age groups, social classes and race (Singh et al., 2019b).

Responses to observed impacts such as glacier melt, sea level rise and increases in the frequency of extreme weather events such as droughts, hurricanes and floods need to take into account how they influence other policy issues and sectors, including poverty alleviation, human health and well-being (Orimoloye et al., 2019), water/energy and the built environment (Andrić et al., 2018), transportation and mobility (Markolf et al., 2019), agriculture (Hertel and Lobell, 2014) and biodiversity/ecosystems (Nogués-Bravo et al., 2019), only to mention a few. Recent literature provides evidence that impacts of climate change together with non-climatic drivers can create poverty–environment traps that may increase the probability of long-term and chronic poverty (Figure 8.4; Hallegatte et al., 2015; Djalante et al., 2020; Malhi et al., 2020; McCloskey et al., 2020) (*high confidence*).

Schematic representation of a poverty-environment trap that can increase chronic poverty

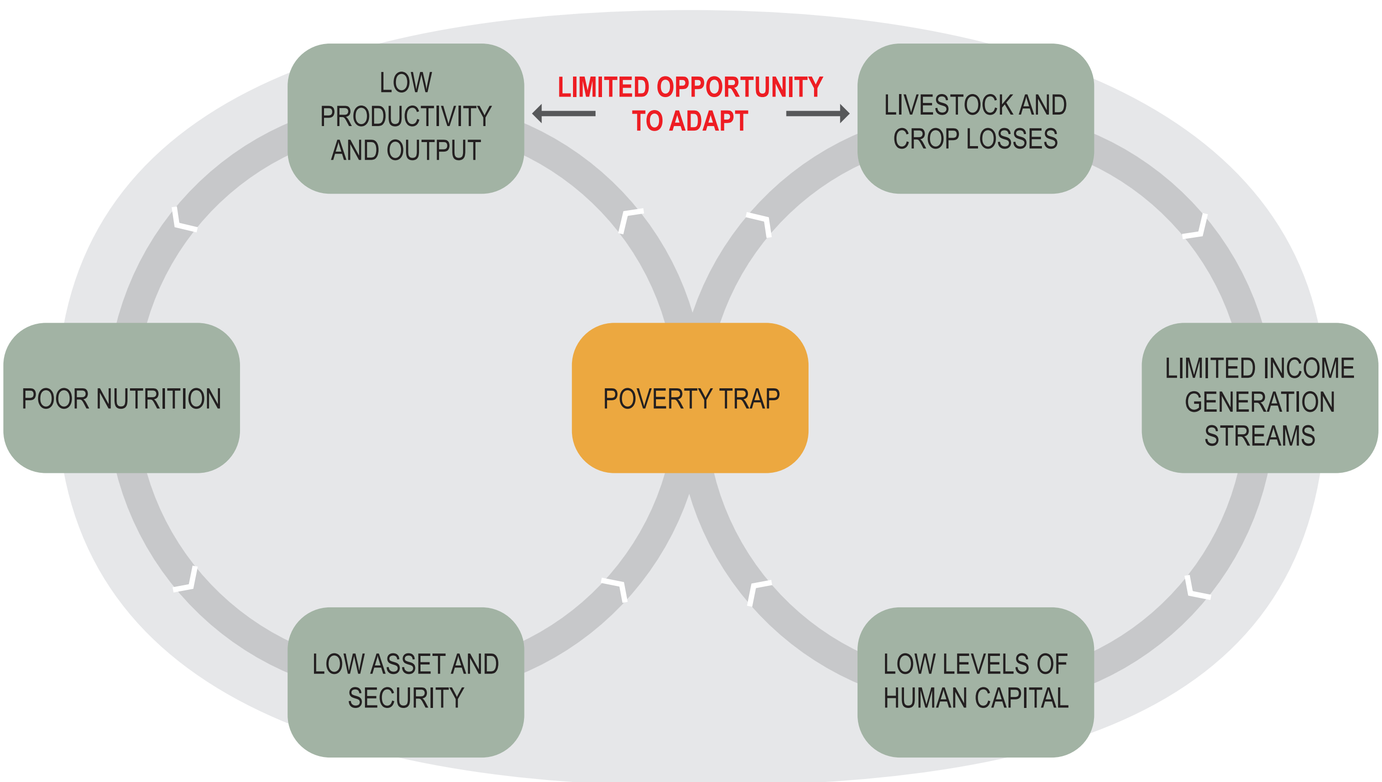

Figure 8.4 | Schematic representation of a poverty–environment trap that can increase chronic poverty.

Box 8.3 | COVID-19 pandemic

During the COVID-19 pandemic, countries such as India were affected by hydro-meteorological hazards (Raju, 2020) making it extremely difficult to handle a public health crisis in the context of compounding risks and cascading hazards (Phillips et al., 2020). The COVID-19 pandemic can increase the adverse consequences of climate change since it has the potential to delay some key adaptation actions. On the other hand, the pandemic also highlights the importance of better preparedness to the impacts of climate change (Djalante et al., 2020). Overall, the COVID-19 pandemic has worsened the economic situation within many countries and local communities particularly for already marginalised groups (Gupta et al., 2021). The accumulation of crises, such as the COVID-19 pandemic alongside climate change impacts, underscore the fact that stressors do not occur in isolation, but are interlinked, with clear implications for structural vulnerability and adaptation options available to the poorest (Sultana, 2021). Responses to COVID-19 have led to significant economic and social distress within and across societies and local communities, especially in poorer countries. The direct health and economic impacts of the lockdowns have further limited the ability of many people across the developing world to pursue income-generating activities, and sustain livelihoods that are already affected by climate hazards. In addition, poor or most vulnerable groups face further marginalisation due to misinformation that these groups transmit the virus to other wealthier groups and areas. The pandemic has intensified inequalities in both developing countries (FAO, 2020) and in industrialised nations (Anderson et al., 2020; McCloskey et al., 2020), whereby vulnerable groups are especially affected (Raju et al., 2021). Whereas different models and scenarios contain different data and figures, there is *high agreement* that it is likely that socioeconomic impacts are particularly severe within selected global regions and areas that are already characterised by a rather high level of human vulnerability (see also Section 8.3). This also implies that the capacity of people to prepare for present and future climate change impacts will further decrease within these countries and population groups under the direct and indirect consequences of the COVID-19 pandemic.

Moreover, the COVID-19 pandemic is not only influencing climate change research (Leal Filho et al., 2021b) but is also influencing the capacities of governmental institutions and nations to support planned adaptation and poverty reduction favouring the most vulnerable groups, since the crisis also means among other issues a significant reductions in tax revenues (Clemens and Veuger, 2020). COVID-19 may also force people to seek alternative sources of income that can lead to the further erosion of long-term adaptive capacities. In many settings, the pandemic has had significant impact on businesses and SMEs (Schmid et al., 2021). The important role of governmental support for buffering crises and periods of income loss of individual households (e.g., unemployment) and private businesses (e.g., SMEs) has also been demonstrated during the COVID-19 pandemic in Organisation for Economic Co-operation and Development (OECD) countries (OECD, 2020b).

Livelihood disruptions and an increasing probability of higher levels of poverty and of structural vulnerability in various countries have already been observed (Laborde et al., 2020b). These vulnerabilities and the new layers created by the pandemic must be seen with an intersectional lens (Raju, 2019; Sultana, 2021).

In addition, the COVID-19 pandemic has also revealed the unequal access to vaccine and the importance of national state institutions to buffer negative impacts, for example, of the lock downs or in terms of unemployment. The COVID-19 pandemic recovery also sets some basis for a stronger narrative towards a green recovery approach (Djalante et al., 2020; Forster et al., 2020).

In addition, observed climate change responses, including autonomous and planned adaptation, can exacerbate poverty and vulnerability (Eriksen et al., 2021). There is *robust evidence* that planned responses to climate change, such as large-scale adaptation projects, in some context can also increase vulnerability due to the reinforcement of inequalities and the effects of further marginalisation (Fritzell et al., 2015; Eriksen et al., 2021). There is increasing evidence that the responses to indirect impacts of climate change, such as to shifts in marine or terrestrial ecosystems due to climate change (Seddon et al., 2016) also affect different groups differently and impact poverty and livelihood security. Apart from influences on agriculture trends (Reichstein et al., 2014) and changes in yields (Reyes-Fox et al., 2014; Craparo et al., 2015), climate change has significant (direct and indirect) impacts on livelihood assets and resources such as forests, livestock production and fisheries, which may undermine the livelihoods security in the medium and long run.

8.2.2.1 Characteristics of Responses

Many of the observed responses to climate change aim to reduce exposure of people to climate-related hazards, such as flood defences, sea walls and embankments (Gralepois et al., 2016), rather than aiming specifically to address structural vulnerability to climate change, which means the root causes of vulnerability (e.g., Mikulewicz, 2020; McNamara et al., 2021a). Evidence suggests that responses to the impacts of climate change should consider the physical climate event, and also historical and institutional root causes that make people or systems vulnerable. However, addressing structural vulnerability must be balanced with the political context and the range of options available to people, communities or countries (see Section 8.3). Political frameworks need to consider both types of responses, to revive democratic debate and citizenship (Pepermans et al., 2016). In addition to reducing poverty and vulnerability, planned climate change responses must also be intersectoral, in order to increase their effectiveness. This requires higher levels of vertical and horizontal coordination and integration (GIZ, 2019). Horizontal coordination encompasses, for example, the integrated coordination of responses to climate change across different sectors, which requires suitable governance structures and processes that allow for such a coordination (Di Gregorio et al., 2017; Burch et al., 2019). Vertical integration is needed in order to ensure that effective responses also include different levels of governance and benefit from knowledge at different scales. The inclusion of local knowledge within national or provincial adaptation strategies requires such linkages and vertical coordination. Overall, there is an increasing body of literature that highlights the importance of improved integration and coordination also in order to promote a higher effectiveness of strategies and an improved consideration of social justice and climate justice when designing and implementing responses (Levy and Patz, 2015).

However, evaluating the effectiveness, social impacts and social justice of climate change responses is not uniform across locations, nations and regions for three principal reasons:

- Temporal dimensions of responses: effective and appropriate climate change responses require that strategies and responses are tested in a specific context and that ongoing learning and adaptive management is a necessary to avoid maladaptation or other unintended consequences (Eriksen et al., 2021),
- Goal of responses: responses may have distinct and locally specific goals, such as reducing vulnerability (Sarker et al., 2019), which is distinct from increasing resilience (Alam et al., 2018). Vulnerability reduction and the increase of resilience (i.e., raising the ability to cope) are two different goals and often involve different processes.
- Level of responses: there is a need to ascertain the relevant level at which the responses are needed or expected (e.g., the individual level, community level, regional level). This analysis, however, also needs to consider the differential capacities of people, for example, the limited capacities of poor people or constrained capacities of most vulnerable countries (see also Section 8.3).

Effective responses to climate change impacts for one group could impose higher costs and negative consequences for other groups, in terms of shifts in exposure and vulnerability. This category of response is known as maladaptation. Maladaptation actions defined in the IPCC SR1.5°C (IPCC, 2018b) and in the Land Report (IPCC, 2019a) are the ones that usually have unintended consequences, and can lead to increased negative risk to poor population mostly in the Global South to climate hazards by either increasing GHG emissions or by increasing the vulnerabilities to climate change with diminished welfare, now and in the near future (Roy et al., 2018). For example, migration to urban centres can represent a significant adaptation opportunity for the migrants themselves, but can also increase the vulnerability of their community of origin or destination (e.g., through a depletion of the workforce or an addition pressure on environmental resources and infrastructure respectively) (Gemenne and Blocher, 2017). Some types of observed responses to climate change may not yield long-term benefits. For example, food imports during droughts or adverse climate conditions are not a fully adequate response, since they may alleviate a problem on the one hand (i.e., an imminent food shortage due to crop failure) but, on the other, lead to no long-lasting improvements in physical conditions and create new dependencies that can increase vulnerability in the long run (Zimmermann et al., 2018).

In the AR5, the maladaptation outcomes emerge when climate change impacts and risks are disproportionately born by the poorest populations (Olsson et al., 2014). Since then, most maladaptation evidence emerges as a consequence of failure to address root causes of vulnerabilities that emerge under high and multiple forms of inequalities. In fact, the literature shows that adaptation practices can indeed redistribute vulnerabilities and increase risks to already poor and marginalised people with risk to maladaptation outcomes mainly in the Global South countries (Atteridge and Remling, 2018).

The maladaptation outcomes also emerge when responses are not equitable at the policy level, and exacerbate the precarity of vulnerable populations by excluding them from benefits and support, while attending to the needs of people of the most enfranchised segments of society (Thomas and Warner, 2019; Asplund and Hjerpe 2020). In Tanzania, the political marginalisation of pastoralist access to critical riparian wetlands and increasing expansion of agriculture may result in adaptation pathways that heighten risk for these groups, while reducing risk for others (Smucker et al., 2015). Salim et al. (2019) found that adaptation to flooding in Jakarta privileges political economic elites, while poor infrastructure in poorest neighbourhoods exacerbates loss of assets, housing and displacements (Salim et al., 2019). In Bangladesh, intense and consecutive flooding led to national and regional adaptation plans, that resulted in maladaptive trajectories as local poverty context and precarities of properties were not carefully considered and disconnected from local autonomous practice (Rahman and Hickey, 2019).

Overall, the assessment shows that understanding impacts of climate change should not be limited to the analysis of direct impacts or physical changes under different climatic conditions, but needs also account for the distributional effects that responses to climate change may imply. For example, responses implemented in order to benefit one sector or social group (e.g., farmers), should not undermine the well-being of others (e.g., pastoralists). Documented cases of maladaptation (see Eriksen et al., 2021) hint that responses to climate change can exacerbate existing inequality in some cases and may discourage other types of responses (see also Sections 8.5; 8.6). Furthermore, responses to similar climate change impacts and hazards may be extremely differentiated according to various social contexts (see Section 8.3). In some cases, responses to climate change (e.g., relocation programmes) can even trigger social tipping points when climate change responses lead to major social transformations, such as forced displacement (see Section 8.4).

Also the influence of new global phenomena, such as urbanisation, issues of urban health (Schmid and Raju, 2020) and the consequences of the COVID-19 pandemic need to be considered when assessing actual and potential consequences of different responses to climate change. For example, inequalities, vulnerabilities and poverty pockets are expected to change and increase, particularly in urban areas in countries with rapid urbanisation processes and high levels of poverty (Djalante et al., 2020), hence urban and urbanisation trends need more attention. Urbanisation processes add another level of complexity (Raju

Box 8.4 | Conflict and governance

Climate change impacts carry the risk of amplifying or aggravating existing tensions within and between communities or countries (Sakaguchi et al., 2017). There is, however, *limited evidence* for a universal direct causal linkage between climate change and violent conflicts (Mach et al., 2019). The triggering of conflicts related to climate impacts is strongly determined by contextual factors, such as the type of government or the level of development (Mach et al., 2019). A study of 156 countries (Abel et al., 2019) showed that an increase in periods of drought exacerbate the risk of conflict, especially in democratic countries. This influence was particularly marked during the period 2010–2012 in countries of western Asia and northern Africa that were undergoing political transformations, such as the Arab Spring. Conflict can then represent people's discontent in governments' inefficient responses to climate impacts (Abel et al., 2019). Research has noted conditions under which climate change can increase the risk of armed conflict, which includes ethnic exclusion, agricultural dependence, large populations, insufficient infrastructure, dysfunctional local institutions and low levels of development (von Uexkull et al., 2016; Ide et al., 2020).

Since the AR5, there is *robust evidence* of the socially destabilising measures and high-risk income alternatives that the world's poorest commonly take to cope with the impacts of climate change on livelihoods (Blattman and Annan, 2016). To avoid impoverishment, households often pursue risky livelihood alternatives, with high potential for return on investment (Sovacool et al., 2018), but which in some cases undermine environmental quality (Bolognesi et al., 2015), violate laws (Ahmed et al., 2019), contradict social norms (Hagerman and Satterfield, 2014), erode institutions (Sovacool et al., 2018), or affect intra- and inter-community cooperation (Nadiruzzaman and Wrathall, 2015). At the same time, a narrowing of livelihood options carries a strong potential for participation and association with violent non-state organisations and movements, either criminal or ideological (Nett and Rüttinger, 2016). In order to reduce the risk of instability and violence associated with climate change, a broadening of livelihood options among the most vulnerable people appears to be an effective policy approach (Miguel et al., 2004).

The determinants of violence in the context of climate shocks are primarily poor institutional planning and response to impacts, such as the capacity of a government to respond to and manage environmental risk (Selby et al., 2017). In Latin America, for example, evidence on social conflicts related to disputes over access to water in the context of drought and decreasing water availability point to institutional failures, such as poor, inequitable or corrupt water governance (Poupeau et al., 2017). Such observations are not confined to low-income countries. In industrialised countries, failure of governments to address climate change is *likely* to fuel discontent, a condition in which violent outcomes are possible (Ide et al., 2020).

In this regard, specific attention ought to be paid to how responses to climate change exacerbate inequalities within societies and create tensions between different groups—typically between those who are able to protect themselves from climate change impacts and those who do not have sufficient resources or are not prioritised in the responses to climate change. Frequently the possibility of migration from climate change is conflated with conflict outcomes from climate change; however, there is *limited evidence* and *low agreement* that climate change and migration will result in increased conflict (Okpara et al., 2016b), while there is *robust evidence* and *medium agreement* that climate change can exacerbate existing tensions, which can in turn result in political violence and an increase in asylum-seeking (Marchiori et al., 2012). In the future, conflict in the context of climate change impacts may increase the number of migrants seeking asylum, although at present there is scant empirical evidence for this (Schutte et al., 2021). Recent evidence also provides support for social conflict around inequitable climate mitigation policy as well (e.g., fossil fuel subsidies and emissions reductions targets) (Rentschler, 2016).

In recent years, research on the climate–security nexus has developed considerably, and has highlighted risks pertaining to conflicts, geo-political rivalries, critical infrastructure, terrorism or human security (Gemenne et al., 2014). While different studies have identified strong past correlations between climatic variations (of temperature and rainfall in particular) and the occurrence of violent conflicts (Hsiang et al., 2013), others have stressed the need for stronger explanatory models or the risk of a selection bias (Benjaminsen et al., 2012; Solow, 2013; Buhaug et al., 2014).

While climate change may increase armed conflict risks in certain contexts (Mach et al., 2019), responses to climate change will be crucial to mitigate these risks. Poor institutional responses can directly drive violence, and there is *robust evidence* that inequitable responses further exacerbate marginalisation, exclusion or disenfranchisement of some populations, which are commonly recognised drivers of violent conflict.

Robust evidence suggests environmental problems (related to climate change) can be dealt with cooperatively, hence leading to more positive and peaceful relations between groups (Wolf et al., 2003; Ide, 2019). To avert violent outcomes induced by climate change, stronger local and national climate adaptation institutions within vulnerable societies, and stronger cooperative resource governance mechanisms between vulnerable countries (such as transboundary water governance agreements) are needed.

Table 8.1 | Selected observed climate change adaptation responses in urban and rural areas commonly associated with positive implications for poverty, livelihoods and sustainable development.

Modality of response	Impacts to urban communities	Impacts to rural communities (e.g., farmers, pastoralists)
Integrated natural resource management (e.g., van Noordwijk, 2019)	Better conservation of green areas and reduced exposure to floods	Conservation of natural resources (e.g., water, soil, pasture, forest, wildlife, biodiversity, aquatic life)
Disaster risk management (e.g., Mall et al., 2019)	Pre-disaster risk management and post-disaster risk management measures reduce loss of life and damage to property	Disaster risk management may play an important role in avoiding or limiting the impacts of floods, droughts and other extreme events
Physical/structural improvements (e.g., Vallejo and Mullan, 2017)	Improving physical/structural measures to prevent property damage and foster ecosystems integrity	Flood defences may help to prevent property losses, planting of trees may stabilise slopes, reduce soil erosion and siltation, rainwater harvesting increases water availability, protection of biotopes supports biodiversity
Relocation of vulnerable communities (e.g., McNamara and Des Combes, 2015)	Moving vulnerable communities before and during climate-induced hazards may reduce loss of life	Reduces the exposure of vulnerable communities to climate change and extremes hazards (e.g., floods and droughts), lessens their vulnerability, improves access to better resources and builds their capacity to adjust to a new context
Education and communication (e.g., Monroe et al., 2017)	Public education and awareness, improved communication may reduce the damages and losses from adverse impacts of climate change and from extreme events	Fosters awareness creation, reducing the degree of vulnerability to certain climate-induced hazards and help build the capacity to adapt

Table 8.2 | Selected climate change mitigation responses.

Modality of response	Impacts on urban communities	Impacts on rural communities (e.g., farmers, pastoralists)
Land use planning (e.g., Frose and Schiling, 2019)	Helps to reduce GHG emissions and support environmental conservation, preventing urban heat islands	Helps to reduce pressure on the natural resources (deforestation, land filling, damaging wetland) and promotes carbon sequestration
Improving industrial processes (e.g., van Vuuren et al., 2018)	Unlocks many opportunities for improvement, including the optimised use of energy, reuse of waste in production, reducing GHG emissions, use of biomass and more efficient equipment	In rural settings, industrialisation and technological innovation may directly assist vulnerable communities through provision of inputs (e.g., water storage, drip irrigation, forecast information), or reuse of biowaste in agriculture or energy production, hence reducing costs and pollution levels
Renewable energy (e.g., Cronin et al., 2018)	Reduction of GHG emissions and reduction of the cost of electricity	Some options (e.g., solar, wind) may help to reduce deforestation, reduce GHG emissions and promote healthier air within households
Energy efficiency (e.g., Abrahamse and Shwom, 2018)	Efficient end-users' energy utilisation reduces energy wastage, reduces costs and lowers carbon emissions	Efficient end-users' energy utilisation leads to natural resource conservation and a reduction of GHG emissions
Local/individual actions (e.g., Shaffril et al., 2018; Tvinnereim et al., 2018)	Can contribute to reduce carbon footprints	Fosters personal and community motivation to manage individually and communally owned resources, helps to reduce GHG emissions and foster resources conservation

et al., 2021). This is particularly the case in rapidly growing medium-sized cities in Africa that at present do not have sufficient resources to cope and adapt, and to implement climate-sensitive land use planning (Birkmann et al., 2016).

Tables 8.1 and 8.2 present a summary of a set of common climate change responses observed, classified according to their main approach. All these responses demand a certain level of commitment, the support of adequate policies and enough budget for their implementation (Archie et al., 2018). The observed climate change adaptation responses—differentiated along urban and rural settings—underscore the very different nature of various responses and the need for cross-sectoral approaches.

While Table 8.1 shows selected adaptation responses, Table 8.2 shows selected mitigation responses that highlight that some mitigation responses (e.g., increasing energy efficiency) also have a potential benefit for the poor or more vulnerable groups, for example, through the reduction of costs for electricity. Both tables underscore that climate change mitigation and adaptation responses are strongly interlinked with broader development issues (industrial production, land use planning, education, etc.) at different scales.

8.2.2.2 Observed Impacts and Implications for Structural Inequalities, Gender and Access to Resources

This section examines the mutual reinforcement of climate change impacts and structural inequalities. There is *robust evidence* that negative impacts and harm posed by climate change are also a result of social and political processes and existing structural inequalities (Sealey-Huggins, 2018). Climate change encompasses unevenly distributed impacts on women, youth, elderly, Indigenous Peoples, communities of colour, urban poor and socially excluded groups, exacerbated by unequal distribution of resources and poor access for some (Rufat et al., 2015; McNeeley, 2017; Sealey-Huggins, 2018). Structurally disadvantaged people, who are subject to social, economic and political inequalities resulting historically from discrimination, marginality or disenfranchisement because of gender, age, ethnicity, class, language, ability and/or sexual orientation, are disproportionately vulnerable to the negative impacts of climate change hazards (Kaijser and Kronsell, 2014; Otto et al., 2016). High levels of vulnerability at national scale (see Section 8.3) are often linked to complex histories, including long-term economic dependencies established and reinforced in the context of colonisation.

Links between climate change, structural racism and development are less well established as an element of disproportionate impacts of climate change (Sealey-Huggins, 2018). Discrimination is not restricted to structural racism and includes discrimination of all kinds, including that of gender and caste, because of which a considerable population is directly bound to suffer the harsh impacts of the climate change. The climate change and gender literature has come a long way in demonstrating concrete examples of how structural inequalities operate. The political and micro-political aspects and how they interact with structural inequalities are also important to understand vulnerability. Henrique and Tschakert (2020) shows how the many adaptation efforts benefit powerful actors, while further entrenching the poor and disadvantaged in cycles of dispossession. This critical analysis recommends acknowledging injustices, embracing deliberation and nurturing responsibility for human and more-than-human others. Garcia et al. (2020) describes the socio-political drivers of gendered inequalities that produce discriminatory opportunities for adaptation. They use an intersectional subjectivities lens to examine how entrenched power dynamics and social norms related to gender create barriers to adaptation, such as lack of resources and agency. The analysis shows a pronounced dichotomy as women experience the brunt of these barriers and a persistent power imbalance that positions them as 'less able' to adapt than men.

Historical marginality and exclusion are context-specific conditions that shape vulnerability (Leichenko and Silva, 2014). There is also *robust evidence* that gender inequalities contribute to climate vulnerability, and that consideration of gender is a key approach to climate justice (see Cross-Chapter Box GENDER in Chapter 18). There is *robust evidence* for the differentiated impacts of climate change and climate-orientated policies on women (McOmber, 2020). For example, Friedman et al. (2019) show that, in Ghana, homogeneous representations of women farmers and a technical focus of climate-orientated policy interventions may threaten to further marginalise the most vulnerable and exacerbate existing inequalities. Climate change impacts can also heighten existing gender inequalities (Jost et al., 2016; Glazebrook et al., 2020). On the one hand, climate change impacts can be gendered as a result of customary roles in society, such as triple workloads for women (i.e., economic labour, household and family labour, and duties of community participation), and occupational hazards from gendered work indoors and outdoors (Murray et al., 2016). On the other, climate change hazards interact with changing gender roles in society, such as urban migration of both men and women in ways that break with tradition (Bhatta et al., 2016).

Gender influences the way that people also experience loss and process psychological and emotional distress of losses, such as mortality of children and other relatives in climate-related disasters (Chandra et al., 2017).Women's capacities are often constrained due to their roles in their household and society, institutional barriers and social norms. These constraints result in low adaptive capacity of women, which make them more vulnerable to hazards. As more men seek employment opportunities away from home, women are required to acquire new capacities to manage new challenges, including risks from climate change. Banerjee et al. (2019b) finds that capacity-building interventions for women staying behind, which aimed to strengthen autonomous adaptation measures (e.g. precautionary savings and flood preparedness), also positively influenced women to approach formal institutions. Besides, the intervention households were more likely to invest a part of the precautionary savings in flood preparedness measures than control households.

Next to the direct differential impacts of climate change on different social groups, the impacts of climate change can also exacerbate inequality due to the lower access and limited ability to benefit from services provided by ecosystems. Marginalised poor people often significantly depend on the access to surrounding environments, natural resources and ecosystem services for their livelihoods, for leisure or cultural practices. Thus shifts in such resources, for example, due to the bleaching of coral reefs or shifts in fish stock, also cause severe challenges and risks to these communities (Leal Filho, 2018; Le, 2019; UNTTSDCC, 2014).

Overall, the assessed literature highlights that climate change impacts are not emerging in isolation from development context and development pathways. Economic and social ramifications mean that they may exacerbate poverty and marginalisation (Finkbeiner et al., 2018; Dogru et al., 2019). Choudhary et al. (2019) and Orimoloye et al. (2019) highlight how the effects of climate change can be even more prejudicial to poor countries, which, in most cases, already suffer from weak governance, high prevalence of informal settlements and lack of resources. Health, livelihood assets and economy are examples of aspects that will worsen as a result of the negative impacts of climate change and failure to provide opportunities for sustainable adaptation (United Nations, 2015). These facts highlight the importance of mitigation and adaptation measures especially in these regions characterised by high levels of vulnerability (see also Section 8.3).

8.2.3 Observed Impacts and Responses and their Relevance for Decision Making

Many countries base their adaptation strategies on National Adaptation Programmes of Action (NAPAs), which often correlate different levels of decision making and governance (Golrokhian et al., 2016). Whereas the involvement of national governments is needed for designing appropriate responses to climate change, recent studies underscore the need to also consider IKLK within adaptation and risk reduction strategies, thus fostering stronger linkages with local communities, leading to improved vertical integration between different strategies, programmes and actors (Ford et al., 2016; Vij et al., 2017; Singh et al., 2020). The relevance of addressing the issue of vulnerability and poverty to reduce the climate change risks has been demonstrated within the assessed literature on the impact of climate change (Hallegatte et al., 2017). In this regard, it is noticeable that not many NAPAs explicitly aim to reduce poverty, even though poverty reduction is associated with vulnerability reduction to climate change (Demski et al., 2017).

Table 8.3 | Some common barriers in implementing climate change responses and their implications.

Dimensions	Barriers in implementing effective climate change responses	Implications
Governance	Unfavourable political frameworks (Gupta, 2016)	Governance structures can undermine autonomous adaptation (Section 8.4; Table 8.6); inability to include gender differentiated vulnerabilities in governance schemes (Bryan et al., 2017)
Social	Attitudes to risks and cultural values may hamper responses (Billi et al., 2019)	Social norms of reciprocity and cohesion may erode as a consequence of climate change responses (Volpato and King, 2019); socio-cultural conditions as key barriers to gender differentiated support to impact reduction (Bryan et al., 2017)
Institutional	Limited availability coordination and prioritisation processes (Patterson and Huitema, 2019)	Lack of anticipatory risks undermining local efforts to cope with hazards (Singh et al., 2019a)
Behavioural	Psychological distress may cause insecurity and behaviour of some groups may increase vulnerability (Van Lange et al., 2018)	Psychological distress associated with loss of attachment to a place has also been observed among vulnerable communities in regions such as South Asia (Maharjan et al., 2020)
Financial	Limited financial resources to support adaptation projects (Khan et al., 2019)	Lack of financial resources and assets among urban poor increase their exposure and vulnerabilities to the increasing climate hazards (Salim et al., 2019)
Structural	Unsuitable infrastructure may increase exposure (Chinowsky et al., 2015; Vallejo and Mullan, 2017)	Structural marginalisation of Indigenous Peoples and their IKLK can exacerbate risks of maladaptation among SIDS countries (McNamara and Prasad, 2014; Aipira et al., 2017; Granderson, 2017); infrastructure projects to adapt to climate change impacts may increase the vulnerability of poor slum people
Technical	Lack of access to technologies which may support adaptation (e.g., climate services) (Bel and Joseph, 2018)	The highest level of illiteracy among women prevent their engagement to access technology and risk reductions in vulnerable communities (Balehey et al., 2018)

Next to issues of observed impacts and responses to climate change, it is important to assess observed barriers in implementing climate change responses. The discussion of barriers is complemented later in the chapter with an assessment of the enabling environments for adaptation (see Section 8.5.1). Some of the most common barriers outlined in the scientific literature are summarised in Table 8.3.

There are various characteristics of responses to climate change, which aim to protect livelihoods and prevent poverty expansion (i.e., an enlargement of the group of people already affected by poverty). Some of them are:

- Timely: meaning that responses need to take place within a matter of weeks or months and not over years (Wise et al., 2014).
- Targeted: with a focus on the affected communities and groups, to help alleviate the pressures they are under (e.g., Aleksandrova, 2020).
- Sustainable: with long-lasting results leading to self-sufficiency of the affected communities and their resource base, as opposed to short-term ones relying on external support (e.g., Caetano et al., 2020).
- Integrated: the impact of climate change is multifaceted and far reaching and requires the engagement of various actors (e.g., the vulnerable community, government agencies, local and international nongovernmental organisations, civil societies, media) (Ayal et al., 2020).

Finally, responses such as those outlined in Table 8.1 and Table 8.2, need to ensure the active participation of local stakeholders considering their diverse interests, so that they are grounded in reality. In addition, responses need to be complemented with operational procedures and time frames so that they can be more systematically pursued and implemented (Alves et al., 2020).

8.3 Human Vulnerability, Spatial Hotspots, Observed Loss and Damage, and Livelihood Challenges

This section assesses the literature on vulnerability—the assessment of vulnerability at global and national scales—and explores economic and non-economic losses of people and livelihoods exposed to and impacted by climate change. The section examines how climate change threatens livelihoods and juxtaposes global and local level assessments of vulnerability based on empirical data at different scales. The analysis of recent literature underscores that climate change impacts and adaptation needs cannot be understood by looking at climate change only. Vulnerability and livelihood security are seen as an important component for understanding the human dimension of climate change (Rhiney et al., 2016; Cardona, 2017; Byers et al., 2018; Eriksen et al., 2020; Wisner, 2020; Birkmann et al., 2021a; Cole et al., 2021).

Linkages between global and individual vulnerability and livelihood security, including aspects of intersectionality are also assessed. Overall, this Section 8.3 reveals that different countries, societies and specific groups within a society have very different starting points on their move towards climate resilience.

8.3.1 Assessments of Risk and Vulnerability

Conventional assessments of risks and the benefits of adaptation and risk reduction measures in the context of climate change primarily focus on the financial value of the avoided losses (in USD) and the assets that are going to be protected from adverse consequences of climate change or extreme events due to specific measures (e.g., dyke construction). Even though these assessments fall short of measuring the real costs of addressing climate change impacts (see DeFries et al., 2019), they often support the definition of priorities in terms of protecting economic values and assets. However, these

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assessments do not sufficiently account for how climate change impacts and imposes risks on poor people, nor do they capture issues of climate justice and more complex societal impacts and future risks. For example, various observed losses in the context of climate change cannot be sufficiently expressed in terms of an economic value (see Section 8.3.5), but these items or assets are highly relevant for various people with limited economic resources (Hallegatte et al., 2017). Consequently, the assessment of risks from climate change facing particularly poor people requires comprehensive assessments of human vulnerability, resilience and the impacts of climate change on human well-being going beyond a simple temperature–societal-impact understanding. Knowledge about methods and approaches to assess human or human–environmental vulnerability and livelihood security, including aspects of intersectionality, is important in order to explore whether or not adaptation and development programmes are able to reduce vulnerability. The body of literature on these issues has grown significantly since the AR5 publication (IPCC, 2014a; Moser, 2014).

This literature underscores that approaches to assess resilience, vulnerability and human well-being include global assessments that can inform strategies and priority settings for adaptation and risk reduction in the context of climate change (*high confidence*) (WHO, 2014b; Young et al., 2015; Feldmeyer et al., 2017; GIZ and BMZ, 2017; Hallegatte et al., 2017; Birkmann et al., 2021a; Garschagen et al., 2021; Toolkit, 2021).

These quantitative global assessments that have emerged within the last decades have not been sufficiently assessed in former IPCC reports, for example, in terms of the agreement on spatial hotspots or in terms of regional clusters of vulnerability and the linkages between past societal impacts and levels of vulnerability. The assessed literature shows that conditions and phenomena that characterise systemic vulnerability (hazard independent vulnerability), such as high levels of poverty and gender inequality, limited access to basic infrastructure services or state fragility are highly relevant for understanding societal impacts of climatic hazards and future risks of climate change (e.g., Cutter et al., 2003; ADB, 2005; Cutter and Finch, 2008; World Bank, 2008; UNISDR, 2009; Crawford et al., 2015; Rufat et al., 2015; Carrao et al., 2016; Gupta, 2016; Rahman, 2018; Andrijevic et al., 2020; Jamshed et al., 2020a; Feldmeyer et al., 2021; Garschagen et al., 2021). These factors and context conditions also influence individual vulnerability at household or community level. Access to basic services, such as water and sanitation, are linked to human rights and if not granted increase the likelihood that people disproportionately suffer from climate-induced hazards, due to their pre-existing lack of access to such services. In addition, increasing climate hazards further constrain the access to such services (United Nations, 2018; Kohlitz et al., 2019; Gupta et al., 2020).

There is an increasing evidence base that successful adaptation and risk reduction strategies need to acknowledge not only climate change and/or specific climate hazards (sea level rise, flooding, droughts, etc.), but also human vulnerability and existing adaptation gaps and thereby the different starting points that societies or different groups have towards climate resilience (see UNEP, 2016; Birkmann et al., 2021a). Recent reports underscore that development and capacity indicators are useful to assess the broader adaptation challenges and adaptive capacities at global scale independent of a specific climatic hazard. Examples include the percentage of population with access to improved water sources and improved sanitation, the number of physicians per 1000 people or the dependency ratio (UNEP, 2018). These indicators are also part of more comprehensive vulnerability assessments, such as those assessed within this section namely the vulnerability components of the INFORM risk index (e.g., INFORM, 2019) and of the WorldRiskIndex (e.g., Birkmann and Welle, 2016; Birkmann et al., 2021a; Feldmeyer et al., 2021). Recent literature underscores that measuring vulnerability is key for assessing factors that significantly determine actual and future adverse consequences of climate change and complex risks (Cutter and Finch, 2008; Cardona et al., 2012; de Sherbinin et al., 2019; Peters et al., 2019; Jamshed et al., 2020c; Visser et al., 2020; Feldmeyer et al., 2021). However, there is also important critique on indicator-based assessments of vulnerability (see de Sherbinin et al., 2019; Rufat et al., 2019; Visser et al., 2020), particularly with regard to issues of validation and its use in decision-making processes. Nevertheless, we observe an emerging agreement in the literature that resilience building and adaptation to climate change has to be informed by climate and multidimensional assessment of the vulnerability of people, different groups and coupled human–environmental systems, including both quantitative and qualitative assessment approaches (IPCC, 2014b; UNEP, 2018; Singleton et al., 2021; Birkmann et al., 2022). Since, interdependencies between regional (supranational/sub-continental), national, community and individual vulnerability have often been overlooked, this chapter assesses both global and regional vulnerability, as well as local livelihood vulnerabilities.

While past research regarding the nexus between climate change and poverty often focused on vulnerable groups in rural areas of low-income countries (de Sherbinin, 2014; IPCC, 2014a; Barbier and Hochard, 2018), new global mega-trends, such as urbanisation, underscore the need to assess both rural and urban communities and their vulnerability. In many rapidly growing cities in the Global South, access to land and to housing is a challenge, particularly for the poor and marginalised, contributing to a further increase in informal settlements that often emerge in highly hazard-exposed areas (Jeschonnek et al., 2014; Rana et al., 2021). In addition, migration from rural areas to urban centres, also due to increasing adverse impacts of climate change on rural livelihoods, can add another level of complexity (Flavell et al., 2020). Moreover, the context in which such urbanisation processes take place is key. For example, rapidly growing medium-sized cities, for example in West Africa, often do not have sufficient financial, technical and institutional resources to adapt urban structures to climate change (Birkmann and Welle, 2016; Birkmann et al., 2016; de Sherbinin et al., 2017). Hence, vulnerability in urban contexts is an emerging issue for international, national and local adaptation programmes. Rather than focusing on mega-cities and their exposure as primary hotspots, more attention has to be given to rapidly growing small- and medium-sized cities and their adaptation needs from the perspective of vulnerability reduction and poverty.

8.3.2 Global Hotspots of Human Vulnerability to Climate Change

8.3.2.1 Hotspots and Spatial Patterns of Multidimensional Vulnerability

The assessment of literature published since the AR5 suggests that alongside already deteriorated specific conditions that determine individual vulnerability and livelihood security to climate change (see Section 8.2), high levels of poverty, lack of access to basic services (human rights to water and sanitation), poor governance and conflicts are important factors that characterise vulnerability and systemic human vulnerability in particular (EC-DRMKC, 2020; Wisner, 2020; Feldmeyer et al., 2021; Garschagen et al., 2021; GIZ, 2021). These context conditions within a country or region limit the access to effective adaptation options particularly for the poor and marginalised groups.

Recent studies underscore that human vulnerability—thus the predisposition to be adversely affected—is largely determined by past and present development processes, rather than by the occurrence of individual events (Wisner, 2016; Cutter, 2018; Birkmann et al., 2020). Also the consequences of the COVID-19 pandemic will create newly poor, particularly in countries that are already characterised by high levels of vulnerability (see Box 8.3; Laborde et al., 2020b; Lakner et al., 2020).

Quantitative studies and assessments published since AR5 provide additional insights about human vulnerability to climate change and resilience of societies at different scales using different indicator sets and approaches (Feldmeyer et al., 2017; Hallegatte et al., 2017; EC-DRMKC, 2020; Birkmann et al., 2021a; Feldmeyer et al., 2021; Garschagen et al., 2021).

While quantitative measures of vulnerability are widely used at different scales (Cutter et al., 2016; Garschagen et al., 2021), there are also studies that caution the use of such indices in policy making or risk reduction efforts (Rufat et al., 2019; Spielman et al., 2020). Such assessments of vulnerability have to be internally and externally validated and handled with care when applied in decision-making processes in terms of their options and limits. At the same time, these assessments capture important conditions and structures that make people more susceptible to various climate hazards and climate change impacts. The relevance of these conditions is confirmed by quantitative impact assessments as well as many specific case study assessments (Welle and Birkmann, 2015; Feldmeyer et al., 2021; Birkmann et al., 2022). For example, the access to basic services (e.g., water and sanitation) (Bollin and Hidajat, 2013; Pandey et al., 2017b; UNEP, 2018; United Nations, 2018; Gupta et al., 2020; Jamshed et al., 2020a) and broader modes of engagement in governance and governance fragility (Crawford et al., 2015; Rahman, 2018; Andrijevic et al., 2020) significantly influence how climatic hazards translate into severe or non-severe losses and harm (see Section 8.5.2).

The lack of such support structures and resources can severely constrain opportunities of people to cope with and adapt to climate change, since it is not only the climate hazard, but also exposure and particularly the vulnerability of a society, a specific community or an individual household that determine adverse societal consequences of climatic hazards. International vulnerability and resilience assessments show that vulnerability varies across countries of similar wealth or income because multidimensional vulnerability, well-being and resilience depend on a larger set of factors (Birkmann and Welle, 2016; Hallegatte et al., 2017; INFORM, 2019). In this regard, vulnerability assessment is significantly different from climate exposure mapping.

The findings of these global assessments suggest, among other issues, that options to reduce vulnerability and enhance resilience do exist in various countries at different levels, in part irrespective of their income level (Feldmeyer et al., 2017; Hallegatte et al., 2017). Vulnerabilities at national and regional-level influence community and individual vulnerability, particularly through structures that determine entitlements, the access to resources and processes of marginalisation (Watts and Bohle, 1993; Thomas and Warner, 2019).

While different assessments use different sets of indicators, most of the global assessments with national-scale resolution (Birkmann and Welle, 2016; Kreft et al., 2016; Feldmeyer et al., 2017; Hallegatte et al., 2017; Eckstein et al., 2019; INFORM, 2019; ND-GAIN, 2019; Garschagen et al., 2021), contain indicators that cover different aspects of economic poverty, inequality, access to basic infrastructure services, education and human capital (e.g., adult literacy rate) and some also include issues of gender inequality, specific vulnerable groups or insurance against extreme events. The assessments also differ, for example, in terms of their consideration of aspects of governance, such as corruption and conflict, or the consideration of social safety nets, such as insurance coverage, or the number of people affected by hazards (Feldmeyer et al., 2017; INFORM, 2019), as well as in terms of the consideration of losses experienced in the past or issues such as biodiversity as an aspect of adaptive capacity (Hallegatte et al., 2017; Birkmann et al., 2022). Moreover, the assessments differ in terms of the consideration of specific indicators and the inclusion or non-inclusion of specific hazard exposure (Welle and Birkmann, 2015; Hallegatte et al., 2017; INFORM, 2019; ND-GAIN, 2019; Birkmann et al., 2022).

Recent comparative studies of global assessments of vulnerability show *high agreement* on the spatial clusters that have very high or very low vulnerability to climate change, compared to larger differences in terms of exposure and risk (Birkmann and Welle, 2016; Hallegatte et al., 2017; INFORM, 2019; Feldmeyer et al., 2021; Garschagen et al., 2021; Schleussner et al., 2021). The comparison of the averaged ranking results at the scale of 'climate regions' using the vulnerability components of INFORM and the WorldRiskIndex—as two comprehensive global assessment approaches of systemic vulnerability (hazard independent vulnerability) (see Figures 8.5; 8.6)—also finds a *high agreement* in terms of most vulnerable regions and regions with low vulnerability (Figure 8.5; Feldmeyer et al., 2021). The assessment at this scale reveals that global hotspots of human vulnerability can be found in climate regions in East Africa, Central Africa and West Africa, followed by high vulnerability in Central America, South Asia and Southeast Asia, for example. Garschagen et al. (2021) in a comparison of further risk indices also found that there is *high agreement* on global assessments of vulnerability compared to exposure or overall risk.

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Agreement between global vulnerability indices

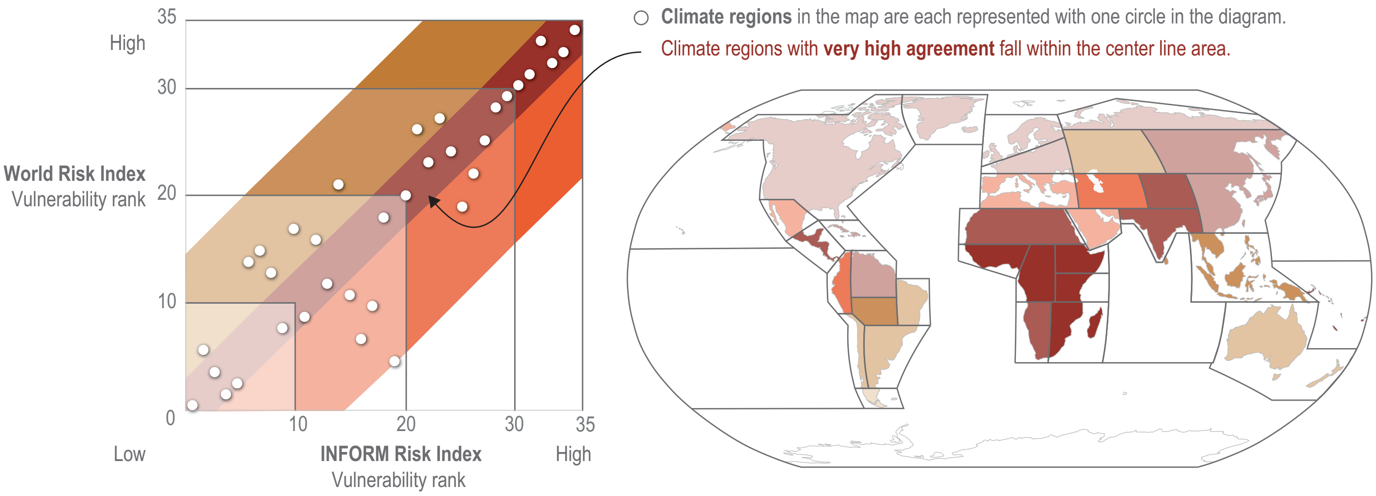


Figure 8.5 | Aggregated vulnerability map at the scale of climate regions based on the averaged ranking of the INFORM Index's vulnerability component and the averaged ranking of the vulnerability component of the WorldRiskIndex. Based on the rankings of the INFORM index (INFORM, 2019) and the WorldRiskIndex (Birkmann and Welle, 2016; Feldmeyer et al., 2017). The map and diagram show agreement between the two global vulnerability indices when ranking climate regions according to their vulnerability—darker colours show regions of higher vulnerability. The diagram shows how the 35 climate regions are ranked by each index and also serves as a legend for the map above.

The analysis of vulnerability assessment results of the INFORM Risk Index and WorldRiskIndex[4] at the level of countries coupled with population data confirms a *high agreement* on most vulnerable countries. It also shows that global hotspots of human vulnerability are not just single countries, but often emerge within regional clusters, particularly in Africa, but also in Asia and Central America (see Figure 8.6 and Birkmann et al., 2021a). These regional clusters (Figure 8.6) are characterised by high levels of vulnerability in terms of socioeconomic, demographic, environmental and governance conditions that make people more likely to face adverse consequences once a climate hazard occurs. The internal and external validation of these index systems shows its statistical validity and robustness (Welle and Birkmann, 2015; Marin-Ferrer et al., 2017; Birkmann et al., 2022). It also confirms a quantitative relationship between most vulnerable regions and fatalities and severely affected people due to climate-influenced hazards (Birkmann et al., 2022). The vulnerability map in Figure 8.5 shows the vulnerability level (systemic societal vulnerability) linked to national scale and provides additional information about the population density within these countries. The background map does not show specific vulnerable populations within countries. Selected examples of sub-national human vulnerabilities have been added as additional information in terms of case studies based on information from other chapters within this report (see, for example, Box 8.7; Sections 5.12; 10.3.3; 10.5.1; 13.8.1; 14.4.7; 15.3.4; Cross-Chapter Paper 6.2.7).

Figure 8.7 provides an aggregated regional overview of selected indicators used within the vulnerability index mapped in Figure 8.6. The overview shows that the many compounded challenges faced by African countries are starkly pronounced, but also in other regions, especially Asia, Central and South America, and among SIDS, there are several challenges such as inequality, governance issues and displacement, which all increase the vulnerability and constrain adaptive capacities of these regions to climate change.

However, it is also important to note that vulnerability assessments do have their limitations (Heesen et al., 2014; Rufat et al., 2019). For example, in high-income countries, specific groups can be highly vulnerable to climate change due to marginalisation and discrimination due to ethnicity or gender. Gender inequality, for example, is also high in some countries classified in the literature as having low vulnerability (see Birkmann et al., 2021a; Birkmann et al., 2022). Nevertheless, these countries have, in theory, sufficient financial resources and governance capacities to deal with these challenges, while this is different for many country clusters classified as highly vulnerable.

Countries and regional clusters with low vulnerability (see Figures 8.5; Figure 8.6), such as Australia and New Zealand or Iceland and North Europe, encompass population groups that are exposed and vulnerable to climate hazards, such as sea level rise or droughts but, within these regions' context, conditions exist that allow the negative impacts

4 Both index system analyse risk and vulnerability at the country level and are updated yearly. The WorldRiskIndex (WRI) conceptualizes vulnerability as having susceptibility, lack of coping capacity and lack of adaptive capacity components. It is based on 28 indicators (23 vulnerability indicators) for 171 countries. It uses different weights based on statistical tools complemented by expert judgements and equal weights for the three components. The index is composed of additive functions for vulnerability components (Welle and Birkmann_2015). The INFORM Risk Index conceptualizes vulnerability as having two components namely socioeconomic vulnerability and vulnerable groups while lack of coping capacity is considered as a separate component. The INFORM index consists of 18 indicators to assess vulnerability and 14 indicators for measuring lack of coping capacity. It analyses risk and vulnerability for 191 countries. It uses equal weights for indicators and components and uses a multiplicative function for aggregating components to compose the final index (Marin-Ferrer et al., 2017). In this chapter, the lack of coping capacity component of INFORM is included in vulnerability calculations in line with the IPCC framing of vulnerability. The vulnerability map presented in this report is based on both WRI and INFORM indices (see Birkmann et al. (2022), Feldmeyer et al. (2021), Garschagen et al. (2021) for agreement between the WRI and INFORM indices)

and losses to be buffered (also for most vulnerable groups). These regions have higher financial and institutional capacities to support people at risk and planned adaptation at a different magnitude within their region, for example, as seen in compensation payments for drought exposed farmers (Hochrainer-Stigler and Hanger-Kopp, 2017; Australian-Government, 2021) or flood affected households in Germany in 2021. Also, the percentage of households insured against climate-influenced hazards, such as floods or storms, is significantly higher in these regions (North America, Western Europe) compared to regions such as Western Africa or Micronesia (Welle and Birkmann, 2015; Feldmeyer et al., 2021; Birkmann et al., 2022).

While climate change differentially impacts people in vulnerable situations within countries, including the poor, children, women, marginalised Indigenous or other ethnic minority people (Rhiney et al., 2016; Méndez et al., 2020), the global assessment results underscore that, in most vulnerable regions and countries, very limited resources and structures exist to support these groups when droughts, floods or storms occur and place an additional burden on these groups.

The assessments of human vulnerability also point towards important adaptation options that are not visible if one focuses on climatic hazards or temperature changes alone (Figure 8.9; Dückers et al., 2015; Cutter et al., 2016; Birkmann et al., 2021a). Fundamental for vulnerability reduction and adaptation are social insurances and infrastructure programmes, as well as legislation that improves the access of poor and marginalised groups to basic infrastructure services and security. For example, the 'free basic service programme' of the national government of South Africa (GovSA, 2021) is one example where a national government (Government of South Africa) has committed itself to providing a basic amount of free water, electricity and sanitation to low-income households, particularly indigent people, such as those living in informal settlements or remote rural areas. Coupled with incentives, for example in terms of a higher use of renewable energy (e.g., solar home systems in rural areas) (see GovSA, 2021), these investments can support vulnerability reduction and mitigation of GHG emissions. However, the programme design and implementation has also been criticised (see Nel and Rogerson, 2005; Muller, 2008), as is witnessed by ongoing service delivery protests (Mutyambizi et al., 2020). This example shows that current national programmes can—even if they are not classified as adaptation measures—provide important entry points to reduce human vulnerability to climate change.

The relevance of human vulnerability has also been confirmed by recent assessments. The assessment of vulnerability studies and mortality data found that the average mortality[5] from floods, storms and droughts is 15 times higher in regions and countries ranked as very highly vulnerable (e.g., Afghanistan, Haiti, Mozambique, Nigeria, Somalia) compared to regions and countries with very low vulnerability (e.g., Canada, Italy, Sweden, UK) (Birkmann et al., 2022). These patterns are confirmed by other studies (e.g., CRED and UNDRR, 2015; CRED and UNDRR, 2016; CRED and UNDRR, 2020b) that examined disaster mortality per hazard event in low and lower middle income countries compared to high income countries and therewith also point towards major differences between countries with high and low vulnerability (Pelling et al., 2004; CRED and UNDRR, 2015; CRED and UNDRR, 2016; CRED and UNDRR, 2020b). Even if one takes solely 'highly vulnerable countries' such as India, Pakistan and the Philippines (and not 'very highly' vulnerable countries), mortality is still nine times higher compared to very low vulnerability countries. Similarly, studies further revealed that average number of adversely affected people per hazard event (e.g., loss of the house) is 11 times higher in regions and countries categorised as having very high vulnerability compared to very low vulnerability (Birkmann et al., 2022). In addition to floods, droughts and storms, published EM-DAT data for wildfires and heat stress, confirmed higher suffering (higher average mortality) in more vulnerable regions compared to less vulnerable regions, particularly when excluding extreme outliers (CRED, 2020). These findings point towards the fact that in regions identified as highly vulnerable in the assessments even moderate future climate change and future climate hazards are likely to push people further into poverty and lead to significant destabilisation processes in terms of livelihoods security (Wallemacq and House, 2018; Birkmann et al., 2022).

8.3.2.1.1 Historic roots of vulnerability in regions classified as highly vulnerable

While increasing attention is given to issues of human vulnerability, less attention has been given to the historical conditions that foster systemic vulnerability of societies. It is important to acknowledge that drivers and root causes of systemic human vulnerabilities and development challenges are not always new, and sometimes—for example in various countries in Africa, Asia and the Caribbean—can be linked to histories of imperialism, colonial structures (Grasham et al., 2019), and subsequent development and governance contexts (Southard, 2017; Zhukova, 2020). Thus, root causes of present structures of human and human–environmental vulnerability often have historic dimensions, for example, chronic poverty and structural inequality in Africa (Grasham et al., 2019) or the Caribbean are still influenced by the colonial power relations outside of these countries making solutions for vulnerability reduction more difficult (see e.g., Douglass and Cooper, 2020). In addition, national borders, such as in many regions in Africa, sometimes cut through ethnic groups and therewith ignore important interrelations between communities on both sides of the border.

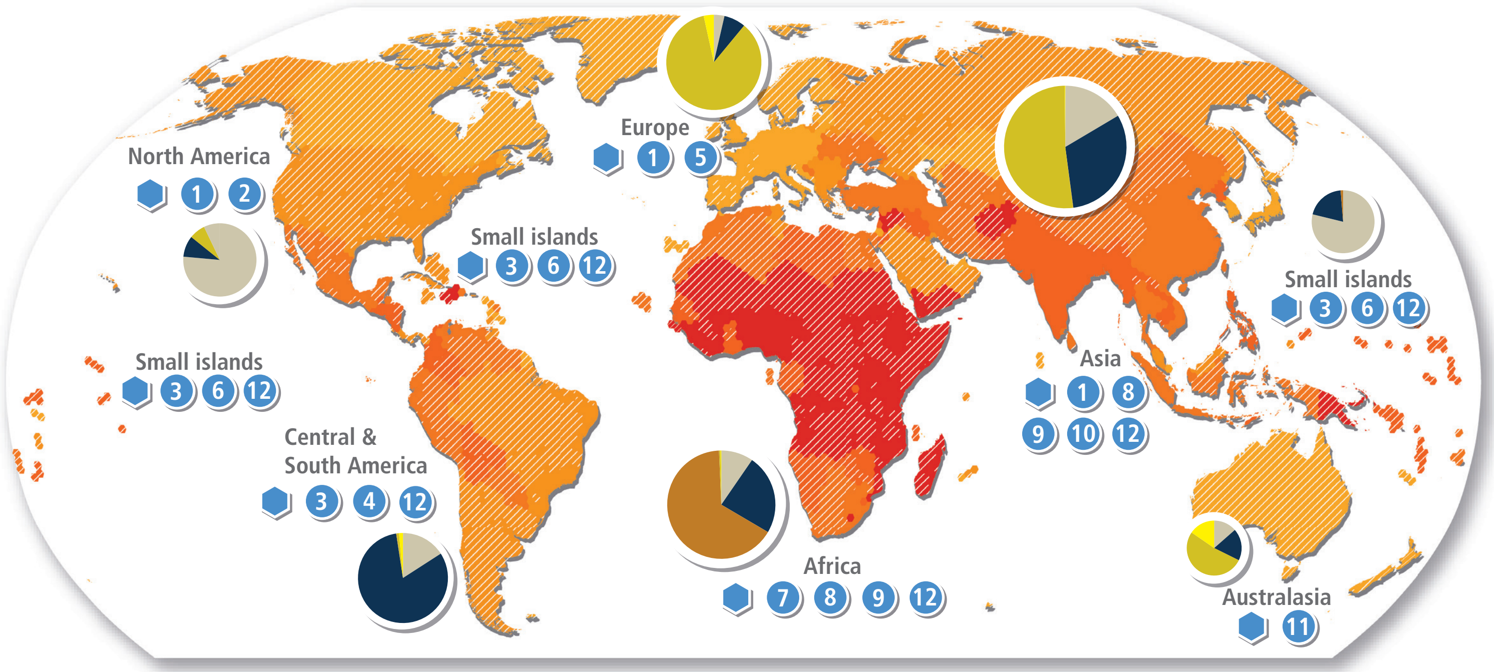
8.3.2.1.2 People residing in most vulnerable versus least vulnerable regions

While global assessments often allow for country rankings, it is similarly important to better understand how many people are living in these different levels of vulnerability. The quantitative assessments underscore that a significantly higher number of people live in countries with very high and high vulnerability compared to the population living in countries classified as having low and very low vulnerability. An analysis that measured the vulnerability of countries according to the INFORM Risk Index and the WorldRiskIndex vulnerability index components, differentiating vulnerability values into seven vulnerability classes found that nearly twice as many people are living

5 Measured as death per hazard event and calculated by averaging the country values of mortality per event falling in different vulnerability categories.

Observed human vulnerability to climate change is a key risk factor and differs globally

Vulnerability at the national level varies. Vulnerability also greatly differs within countries.
Countries with moderate or low average vulnerability have sub-populations with high vulnerability and vice versa.



Relative vulnerability

- Very high
- High
- Medium
- Low
- Very low

Population density

- High
- Low

Examples of Indigenous Peoples with high vulnerability to climate change and climate change responses (4.3.8, 5.10.2, 5.13.5, Box7.1, 8.2.1, 15.6.4) and the importance of Indigenous Knowledge (Box9.2.1, 11.4, 14.4, Cross-Chapter Box INDIG)

Pie charts

Flood Storm Drought Heat Wild Fires

The size of the pie charts show average mortality per hazard event per region between 2010 and 2020.
The slices of pie charts show the distribution of deaths from a particular hazard.

Examples of vulnerable local groups across different contexts include the following:

1. **Indigenous Peoples of the Arctic** | health inequality, limited access to subsistence resources and culture | CCP 6.2.3, CCP 6.3.1
2. **Urban ethnic minorities** | structural inequality, marginalisation, exclusion from planning processes | 14.5.9, 14.5.5, 6.3.6
3. **Smallholder coffee producers** | limited market access & stability, single crop dependency, limited institutional support | 5.4.2
4. **Indigenous Peoples in the Amazon** | land degradation, deforestation, poverty, lack of support | 8.2.1, Box 8.6
5. **Older people, especially those poor & socially isolated** | health issues, disability, limited access to support | 8.2.1, 13.7.1, 6.2.3, 7.1.7
6. **Island communities** | limited land, population growth and coastal ecosystem degradation | 15.3.2
7. **Children in rural low-income communities** | food insecurity, sensitivity to undernutrition and disease | 5.12.3
8. **People uprooted by conflict in the Near East and Sahel** | prolonged temporary status, limited mobility | Box 8.1, Box 8.4
9. **Women & non-binary** | limited access to & control over resources, e.g. water, land, credit | Box 9.1, CCB-GENDER, 4.8.3, 5.4.2, 10.3.3
10. **Migrants** | informal status, limited access to health services & shelter, exclusion from decision-making processes | 6.3.6, Box 10.2
11. **Aboriginal and Torres Strait Islander Peoples** | poverty, food & housing insecurity, dislocation from community | 11.4.1
12. **People living in informal settlements** | poverty, limited basic services & often located in areas with high exposure to climate hazards | 6.2.3, Box 9.1, 9.9, 10.4.6, 12.3.2, 12.3.5, 15.3.4

Figure 8.6 | Global map of vulnerability. This map shows the relative level of average national vulnerability as calculated by global indices (INFORM and WRI see details in 8.3.2). Areas shaded light yellow are on average the least vulnerable and those shaded darker red are the most vulnerable. The map combines information about the level of vulnerability (independent of the population size) with the population density (see legend) to show where both high vulnerability and high population density coincide. The map reveals that there are densely populated areas of the world that are highly vulnerable, but also highly vulnerable populations in more sparsely populated areas. There are also highly vulnerable communities and populations in countries with overall low vulnerability as shown with local case studies alongside the map. The pie charts show the number of deaths (mortality) per hazard (storm, flood, drought, heatwaves and wildfires) event per continental region based on EM-DAT Data (CRED, 2020). The size of the pie chart represents the average mortality per hazard event while slices of each pie chart show the absolute number of deaths from each hazard. This reveals that over the past decade, there were significantly more fatalities per hazard in the more vulnerable regions, e.g., Africa and Asia. The analysis of the data shown in this map revealed that over 3.3 billion people are living in countries classified as very highly and highly vulnerable, while approximately 1.8 billion people live in countries with low and very low vulnerability (Birkmann et al., 2022). These vulnerability values are based on the average of the vulnerability components of the INFORM Index (INFORM, 2019) and WorldRiskIndex (Birkmann and Welle, 2016; Feldmeyer et al., 2017) with updated data from 2019 classified into five classes using the quantile method. Other studies applied more vulnerability classes within their assessment and therefore provide slightly different numbers (Birkmann et al., 2021a). However, despite different calculation methods, the conclusion remains that there are significantly more people residing in countries with very high and highly vulnerability compared to those living in countries classified as having low or very low vulnerability.

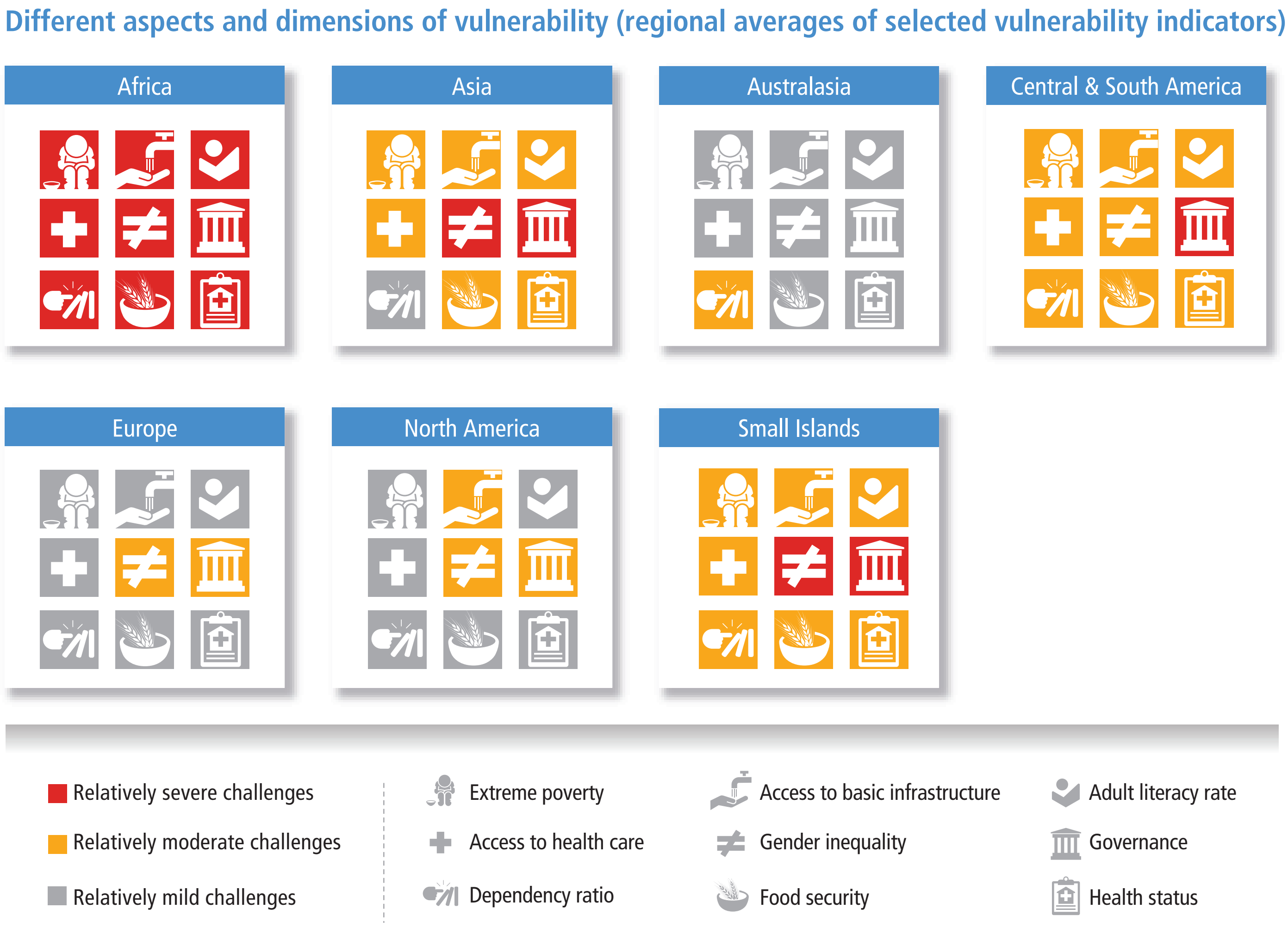


Figure 8.7 | The figure shows selected aspects of human vulnerability, such as extreme poverty and inequality, and access to health care and basic infrastructure as regional averages. These vulnerability aspects are a selection of indicators from the indicator systems (the INFORM Risk Index and WorldRiskIndex 2019) used for the global vulnerability map (Figure 8.6). These normalized indicator scores were averaged for each region and classified into three levels of severity using the natural breaks method. This figure provides a more differentiated picture about the various dimensions of vulnerability that different regions and countries face and the severity of such challenges in each region. Such vulnerability challenges increase the risk of severe adverse impacts of climate change and related hazards (Birkmann et al., 2022).

in most vulnerable countries compared to the number living in less vulnerable countries (Birkmann et al., 2021a). Another study that uses the same data and differentiates vulnerability into five classes (also considering the lack of coping capacity within the INFORM index, see (Marin-Ferrer et al., 2017)) concludes that about 3.3 billion people are living in countries classified as highly vulnerable, while approximately 1.8 billion people live in countries with low vulnerability (Birkmann et al., 2022). Additional assessments based on the classification of income groups of countries reveal that approximately 3.6 billion people live in low and lower middle-income countries, which are most vulnerable and disproportionally bear the human costs of disasters due to extreme weather events and hazards (World Bank, 2019b; CRED and UNDRR, 2020b; EC-DRMKC, 2020; UN-DESA, 2020a; UN-DESA, 2021; Birkmann et al., 2022). While these numbers are different, both results underscore that the absolute and relative number of people living in most vulnerable contexts is significantly higher compared to those that live in a country with a low vulnerability status (Birkmann et al., 2021a; Birkmann et al., 2022). These differences have also been observed in former years (Welle and Birkmann, 2015; Feldmeyer et al., 2017).

That means, even moderate changes in the global mean temperature, as identified in the recent IPCC report SR1.5°C (IPCC, 2018c) and in scientific literature (Hoegh-Guldberg et al., 2019a), can mean substantial increases in risks for more than 3 billion people due to high levels of vulnerability.

Overall, there is *robust evidence* and *high agreement* in the recent literature that countries and regions classified as highly vulnerable face multiple development challenges at once, in which high levels of poverty interact with limited access to water and sanitation or with high levels of forced migration and, in some cases, with state fragility making solutions difficult (Hallegatte et al., 2017; Marin-Ferrer et al., 2017; Feldmeyer et al., 2021; Garschagen et al., 2021; Birkmann et al., 2022). High levels of vulnerability within these regional clusters are the product of current development challenges, but are often caused by long and complex histories, including issues of colonisation and marginalisation, for example, in hotspots in Africa (Birkmann et al., 2021a).

8.3.2.2 Transboundary Vulnerability and Adaptation

Next to the identification of the level of agreement between different vulnerability assessments (Garschagen et al., 2021) and the spatial hotspots, global assessments of vulnerability and adaptation readiness also point towards the need for a transboundary perspective and transboundary cooperation in terms of vulnerability reduction and adaptation (Tilleard and Ford, 2016; Birkmann et al., 2021a). Newer research points towards the fact that various phenomena of vulnerability, particularly in highly vulnerable regions, spill over national borders and emerge in rather regional clusters, such as forced migration and poverty in West and Central Africa, as well as conflicts in the Near East and Asia (IDMC, 2020). This means that regional and transboundary challenges contribute to the formation of systemic human vulnerability, for example, forced migration that is occurring within countries, but also across international borders that is also influenced by climate change (Kaczan and Orgill-Meyer, 2020). In summary, these findings point towards the need for more transboundary approaches in vulnerability and risk reduction, adaptation and development. Recent literature and data presented in Figure 8.6 and (Birkmann and Welle, 2016; Feldmeyer et al., 2017; Hallegatte et al., 2017; INFORM, 2019; Birkmann et al., 2021a) demonstrate the need to strengthen approaches to monitor the regional dimensions of vulnerability and to develop strategies and programmes that consider transboundary vulnerability in risk reduction and cooperation at different scales. This includes, for example, cooperation between national-level institutions, but also transboundary networks of cities or communities (Tilleard and Ford, 2016; Benzie and Persson, 2019; Birkmann et al., 2021a). The transnational nature of climate change impacts means that addressing them requires concerted efforts among nations (IPCC, 2014b; Dzebo, 2019).

In addition, national response strategies for specific transboundary climate-influenced hazards, such as river flooding, droughts or coastal flooding can also significantly influence neighbouring countries and can affect exposure and vulnerability of the respective country (Nadin and Roberts, 2018; Booth et al., 2020). Likewise, climate change may affect transboundary resources (e.g., underground water reserves) and transboundary ecosystems (e.g., in terms of the migration of species) (Vij et al., 2017) and thereby further reduce the capacity of vulnerable groups to cope and adapt. In addition, recent research indicates that social inequities are also coupled with access to and quality of environmental resources in urban environments—meaning social and environmental justices are interconnected (see Schell et al., 2020).

Individual adaptation projects to specific climate hazards in regions classified as highly vulnerable are needed. However, recent studies underscore that deeper development challenges need to be addressed in order to make progress towards adaptation and vulnerability reduction and to avoid maladaptation (Eriksen et al., 2021). Adaptation and development projects, such as the construction of a dam as a response to water shortages in one country can significantly influence the exposure to water shortages and the response capacities of another country downstream. Often, transboundary challenges are a result of policy and resource management choices or uncertainty, and addressing them requires a greater engagement between governing bodies, which may also guide more suitable responses in the context of climate change adaptation and vulnerability reduction (Earle et al., 2015; Tilleard and Ford, 2016; McLeman, 2018; Birkmann et al., 2021a).

Most of those countries and regional clusters identified as highly vulnerable have contributed little to the overall amount of GHG emissions and therefore support for (transboundary) adaptation from the international community is required in these places and for those living under these conditions in order to support and achieve climate justice.

8.3.2.3 The Effect of Higher Levels of Global Warming for Most Vulnerable Regions and Specific Livelihoods

Evidence exists that threats to land-based livelihoods and risks of undernutrition increase significantly with higher levels of global warming (Hoegh-Guldberg et al., 2019a). With global warming of 1.5°C or less, impacts of climate change on livelihoods are still significant, for example, for West Africa and the Sahel there will be an estimated reduction of the area suitable for maize production of about 40%. The consequences of global warming of up to 3°C would mean a high risk of undernutrition for entire regions (see Hoegh-Guldberg et al., 2019a) that are already classified as most vulnerable (see Figure 8.6). That means the consequences of significant warming are a particular challenge for regional hotspots of vulnerability. Small changes in crop productivity, already observed due to increasing droughts, floods or changes in rainfall patterns, could lead to severe health risks and undernutrition. This is because of existing precarious living conditions and the limited capacities that people and institutions have to build and enhance coping and adaptive capacities at the level of individual households, communities and state institutions (see UNEP, 2018; Birkmann et al., 2021a). The risk of loss of life, displacement and adverse health consequences due to climate change in these most vulnerable regions (such as Micronesia, South Asia, West Africa—see Figures 8.5; 8.6) is higher compared to regions classified as having medium or low vulnerability (Birkmann et al., 2022). Nevertheless, other regions and countries classified as less vulnerable, for example in Asia, are experiencing disasters and have a relative high share of the observed global fatalities or losses, when considering non-climatic natural hazards (CRED and UNDRR, 2020a; see also Section 8.3.2.1). In addition, changing climatic hazard and exposure patterns have to be considered. However, the agreement of major global index systems on exposure is significantly lower compared to vulnerability (Garschagen et al., 2021).

Moreover, the assessment reveals that in most vulnerable regions a double burden of existing destabilised livelihood conditions and additional climatic hazards is already visible and largely influences societal impacts of climate change. For example, flooding along the White Nile in Uganda and South Sudan hit vulnerable communities that were displaced due to conflicts and were thus uprooted again by flooding (IDMC, 2020). Societal impacts and future risks of climate change to societies need to incorporate information about vulnerability and exposure—including capacities of people to cope and adapt (Wisner, 2016; Cardona et al., 2020). There is increasing evidence that individual and societal capacities to cope and adapt also depend on how governmental and national institutions can support people at risk (see Section 8.6). For example, climate information services depend on a functioning weather service. Likewise, social safety nets as an adaptation strategy require financial resources, which are often absent for most people in highly vulnerable regions. In addition, examples of national programmes that target most vulnerable groups, such as the free basic service programme in South Africa, show that next to the adaptation to individual hazards, strategies exist that aim to reduce systemic human vulnerability (see GovSA, 2021).

At the same time, there is scientific evidence that more intense and frequent climate-influenced hazards (e.g., storms, flooding, droughts, heat stress) can undermine decade-long poverty reduction efforts, particularly in most vulnerable regions (Mysiak et al., 2016; Formetta and Feyen, 2019; Laborde et al., 2020b; Lakner et al., 2020). There is *high agreement* that, with global warming of about 3°C, such undermining of poverty reduction efforts will intensify and more regions will face development setbacks due to the spatial and temporal expansion of climate hazards, including the further erosion of capital that enables people to develop adaptive capacities (*high confidence*) (see Section 8.5). Such trends can further exacerbate poverty traps (see Section 8.2.2). According to a World Bank report, between 32 and 132 million people could fall into extreme poverty by 2030 due to the impacts of climate change (Jafino et al., 2020). Models estimate that at 3°C warming and under Shared Socioeconomic Pathway (SSP) 1, there would be an additional 245 million people exposed to poverty. Under SSP2 this number would increase to 904 million additional people exposed to poverty (SSP2) and under SSP3 (with significant challenges for equity) about 1918 million additional people could be exposed to poverty in the year 2050 (Byers et al., 2018).

Overall, the assessments above underscore that adaptation and risk reduction require not only information about changing climatic conditions, but also assessments that capture the development contexts and structural inequality that determine and influence human vulnerability. Strategies that reduce poverty and inequality and that improve the access of people to basic services need to become a higher priority in adaptation and development planning in order to avoid more than 3 billion people currently and even more in the future being exposed to severe adverse consequences of climate change. Reducing vulnerability to climate change is therefore indispensable for climate justice and just transitions (*high confidence*).

8.3.2.4 Compound Challenges: Vulnerability and State Fragility

Literature in the area of climate change risk management and adaptation highlights the importance of overall governance systems and their functioning and inclusiveness in terms of vulnerability and risk reduction (Burch et al., 2019). Empirical evidence and scientific studies show linkages between issues of governance, conflicts and high levels of state fragility and systemic human vulnerability (see Figure 8.8; Section 8.5.2; Eklöw and Krampe, 2019; Peters et al., 2019; Mawejje and Finn, 2020)

The comparison of state fragility and vulnerability at the level of regions (United Nations Statistics Division regions) based on the vulnerability information of the INFORM and WorldRiskIndex systems and information from the Failed State Index indicates clear linkages (see Figure 8.8), meaning that societal development and governance challenges often interact and, in many cases, are influenced by complex histories (see FFP, 2020; Birkmann et al., 2021a; Feldmeyer et al., 2021). Strategies to reduce systemic vulnerability and multidimensional poverty have to account for these broader governance challenges that hamper resilience building and the development of adaptive capacities to climate change at various levels.

Strategies to strengthen adaptation to climate change have therefore to acknowledge these interdependencies between climate change, vulnerability, development and governance (see Section 8.6.5). The results of different global vulnerability assessments and the role of governance conditions underscore that next to individual adaptation projects in specific sectors, integrated strategies and programmes are needed that reduce systemic vulnerability and support enabling conditions for adaptation for most vulnerable groups (see Section 8.6.5).

8.3.2.5 Trends in Vulnerability and Poverty in Light of Climate Change and the COVID-19 Pandemic

Literature that assesses trends of poverty and vulnerability, as well as exposure to climate change, reveals that geographic patterns of poverty and vulnerability are uneven and changing over time (Feldmeyer et al., 2017). However, a robust finding of different studies is that population growth in most vulnerable country groups and regions 'is' and 'will be' significantly higher in the future compared to population growth in countries classified as having low vulnerability (see Section 8.4.5.2). In summary, a significant increase of population is expected in highly vulnerable countries in the future. In addition, global studies predict that, by 2030, almost 50% of the world's poor will be living in countries affected by state fragility, conflict and violence (UNISDR, 2009; Hallegatte et al., 2017).

Comparison of vulnerability and state fragility of global regions

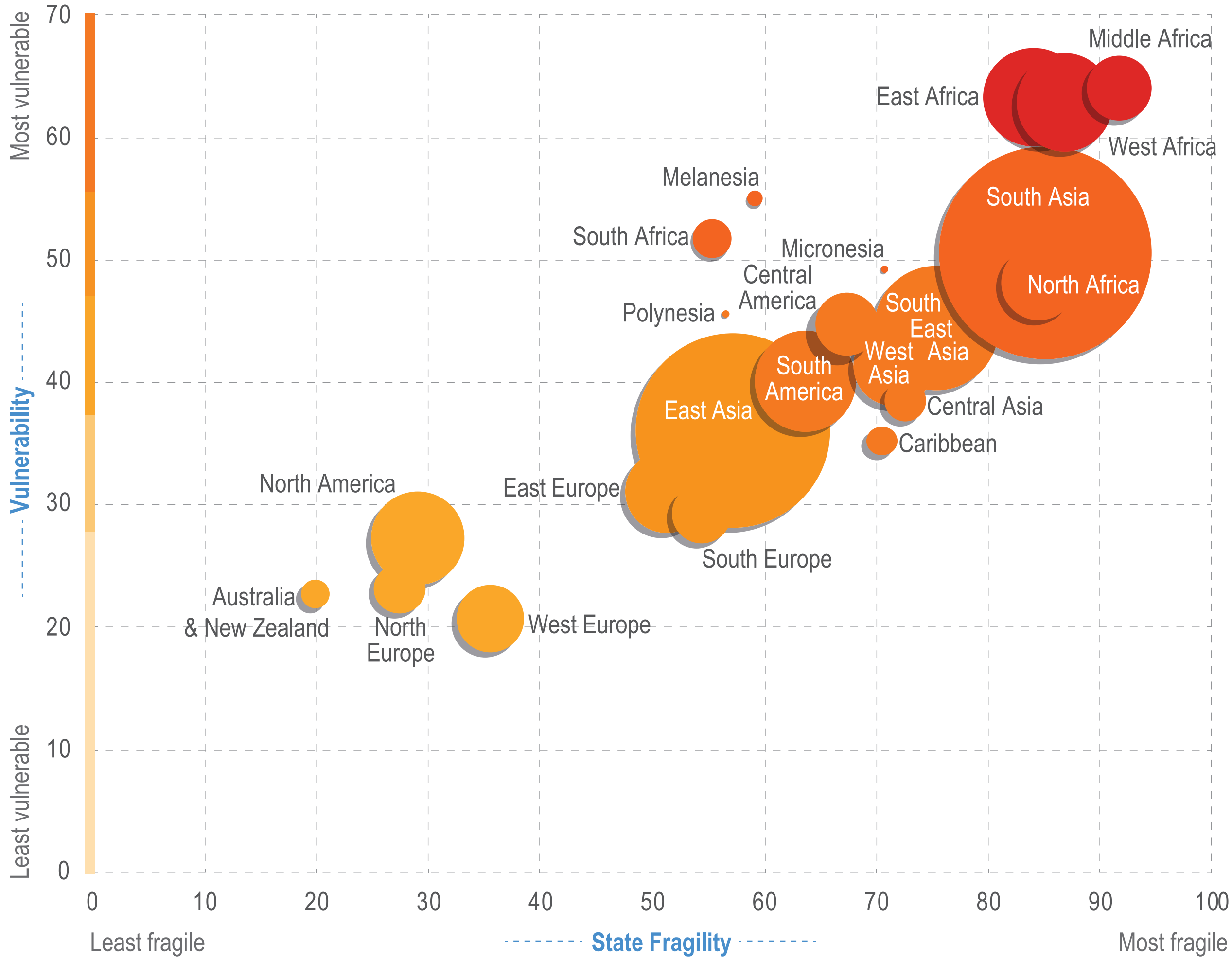


Figure 8.8 | Comparison of the vulnerability and state fragility of global regions. The vulnerability values are the average of the vulnerability component of the WorldRiskIndex 2019 (Birkmann et al., 2021a; Feldmeyer et al., 2021) and the vulnerability and lack of coping capacity components of the INFORM Risk Index 2019 (Marin-Ferrer et al., 2017) classified into five classes using the equal count method (Birkmann et al., 2022). The state fragility values are based on the Fragile States Index 2019 (FFP, 2020) and regions are based on the intermediate and sub-regions of the United Nations Statistical Division. The size of each circle is proportional to the population (World Bank, 2019b) in the respective region.

Another important phenomenon that modifies trends in vulnerability to climate change and poverty is the COVID-19 pandemic (see Box 8.3). It is *likely* that the COVID-19 pandemic with its global repercussions will continue to modify and, in many cases, intensify poverty and human vulnerability (Laborde et al., 2020a; Sumner et al., 2020). Recent studies that estimate the impact of COVID-19 on global poverty agree that a significant increase of poverty due to COVID-19 and the respective lockdown of countries is already observed or expected in the near future (Laborde et al., 2020b; Sumner et al., 2020). These studies underscore that 80% of those newly living in extreme poverty (living on under 1.9 USD d^{-1}) due to COVID-19 would be mainly located in two global regions: sub-Saharan Africa and South Asia (Sumner et al., 2020). Consequently, the COVID-19 pandemic is *likely* to further increase inequality at different scales and increase the burden within regions already characterised by a significant adaptation gap in terms of high vulnerability (see also Figure 8.6). This implies that the capacity of people to prepare for present and future climate change impacts will further decrease within these countries and for specific vulnerable people or groups in these regions.

Recent scientific studies in the context of climate-influenced hazards and disasters also underscore that various regions and countries classified as highly vulnerable are characterised by a high persistence of human vulnerability and chronic poverty (Feldmeyer et al., 2017; UN-DESA, 2020b; World Bank, 2020). For example, various highly vulnerable regions in Central, West and East Africa, countries such as Afghanistan, Democratic Republic of Congo and Haiti, and also SIDS in Melanesia and Micronesia have been characterised by high levels of poverty for decades (World Bank, 2020). Several of these highly vulnerable regions are also *likely* to experience a further increase in climate hazards such as sea level rise in Melanesia and Micronesia and in coastal zones of West Africa and more severe droughts in Africa (IPCC, 2021).

Map with observed changes in agricultural and ecological droughts (IPCC, 2021) overlaid over human vulnerability

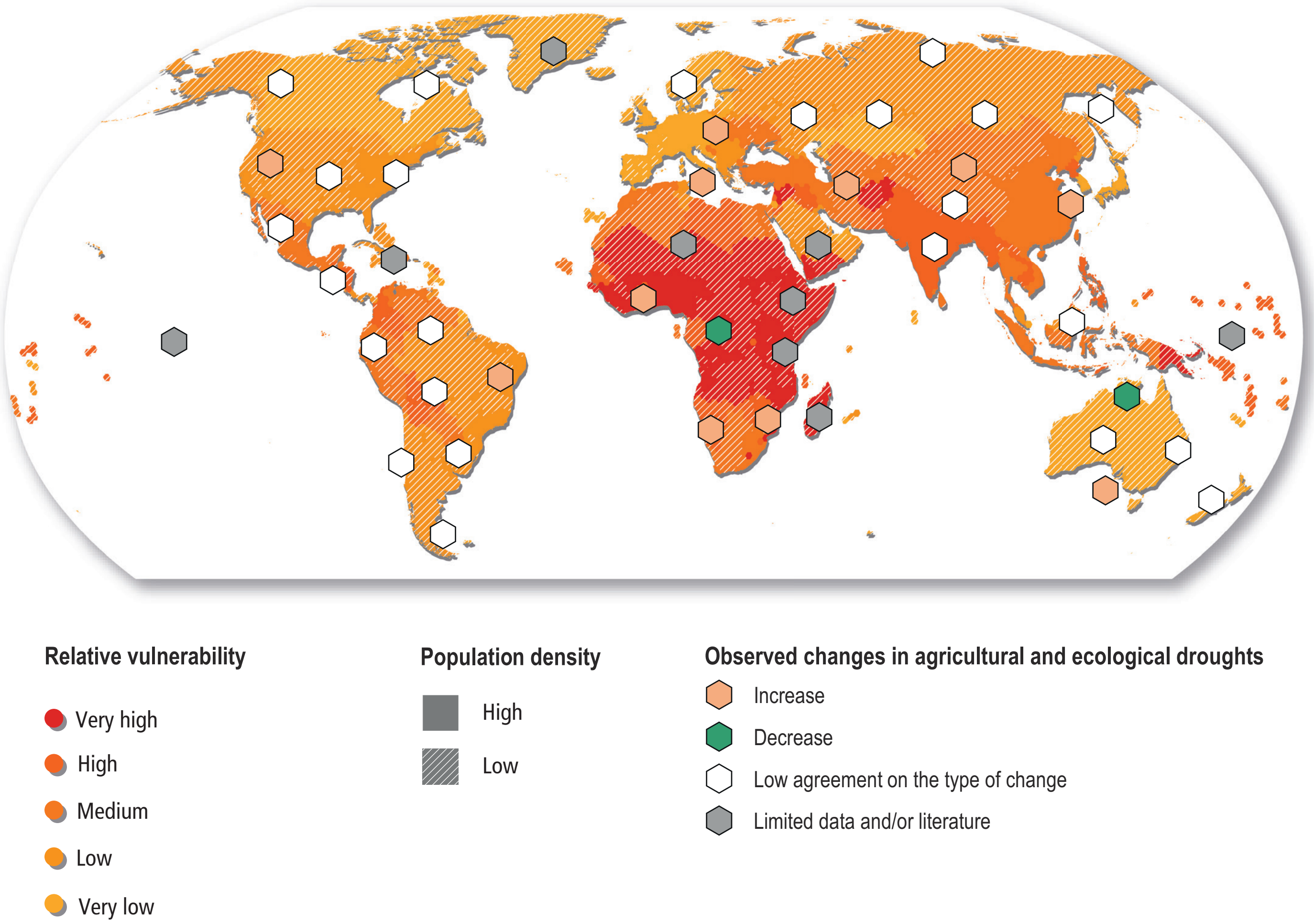


Figure 8.9 | Map with observed changes in agricultural and ecological droughts (IPCC, 2021) overlaid over human vulnerability (see Figure 8.6) provides a more comprehensive overview for defining adaptation priorities.

There is *robust evidence* that in many world regions the exposure to climatic hazards is increasing with additional global warming (Chin-Yee, 2019; Hoegh-Guldberg et al., 2019a; IPCC, 2021). In addition, development patterns and practices such as urbanisation and migration to exposed areas, for example, to coastal zones in West Africa or South Asia is increasing exposure. While the spatial and temporal exposure to impacts from climate change and extreme events increases with higher levels of global warming (Hoegh-Guldberg et al., 2019a), in all global regions and various climate zones (IPCC, 2021), the burden is greater for the most vulnerable regions where people have limited support and capacities to build adaptive capacities for future impacts of climate change.

In this regard, vulnerability assessment results provide an important additional layer of information for decision making in terms of defining adaptation and risk reduction needs and priorities, as shown in Figure 8.9. The figure shows the published climatic information regarding observed changes in agricultural and ecological droughts (IPCC, 2021) combined with a background map of vulnerability. For example, the combined information reveals that even if the agreement on the type of changes observed in droughts is low for North and southeast Africa, it is the high vulnerability in this region that requires urgent attention (see Figure 8.9).

Recent reports on extreme poverty and human rights (Alston, 2019) show that millions already face malnutrition due to devastating drought. In addition, the linkages between ecosystem vulnerability and human vulnerability and human well-being are important aspects that need more attention, since, for example, the degradation of marine ecosystems that support food systems for hundreds of millions of people will threaten food security (see for details Cross-Chapter Box MOVING PLATE in Chapter 5).

While the findings of the Alston report underscore the urgency to act in order to protect people's livelihoods, particularly in low-income countries, it also shows that extreme poverty (Alston, 2019) and different dimensions of poverty are found in middle- and high-income countries.

A study of the World Bank (Hallegatte et al., 2017) estimates that losses in terms of well-being are significantly higher than actual asset losses experienced (Hallegatte et al., 2017). A higher proportion of the global absolute economic losses occurred in high-income countries. About 56% of all disasters reported occurred in high-income countries, while the low-income countries account for 44% of the recorded disasters. However, low-income countries account for about 68% of the total deaths reported, high-income countries for about 32% (CRED and UNDRR, 2020b). In contrast, average absolute economic losses[6] were significantly lower in most vulnerable countries compared to low vulnerable countries (Birkmann et al., 2022). Economic loss trends from EM-DAT database (CRED, 2020) must be interpreted with caution. Economic loss data is often incomplete and needs to be improved. However, these differences in terms of economic losses can also be explained in part by the significant wealth differences and the monetary value of assets exposed. Consequently, there is a need to critically reflect on the measures used to assess L&D from climate change. Interestingly, the number of people affected by droughts, floods and storms as a percentage of the total population and per hazard event again points to the disproportionate suffering of most vulnerable countries (Birkmann et al., 2022).

Overall, there is *robust evidence* that at the global scale poor and most vulnerable people, particularly in regions classified as highly vulnerable, are disproportionately affected by well-being losses and loss of life in the context of climate change and climate-influenced natural hazards (CRED and UNDRR, 2015; Hallegatte et al., 2017; Birkmann et al., 2022) (*high agreement*). In this context, non-economic losses also need to receive more attention (see Section 8.3.3.2). While there is an emerging understanding that inequality and multidimensional poverty are important determinants of systemic vulnerability to climate change (Dennig et al., 2015; Hallegatte and Rozenberg, 2017; Islam and Winkel, 2017) that affects more than 3 billion people today, only very few countries explicitly aim to reduce poverty and income inequality as an adaptation measure (see e.g., Brazil Ministry of Environment, 2016) *(high agreement)*. Reducing vulnerability is a prerequisite for climate justice and just transitions.

8.3.3 Livelihood Impacts, Shifting Livelihoods and the Challenges for Equity and Sustainability in the Context of Climate Change

This section complements the global and regional assessment of vulnerability in the previous section with a more precise assessment of observed local conditions and livelihood impacts and shifts. First, the section reviews linkages between vulnerability and livelihood impacts of climate change broadly. Second, it examines the range of observed disproportionate impacts according to economic (e.g., income) and non-economic (e.g., cultural) impacts of climate change. Third, it examines current risks of adaptation limits and compounding effects across social groups and associated livelihood shifts.

8.3.3.1 The Implications of Vulnerability for Past and Present Livelihood Impacts of Climate Change

Climate change impacts add to livelihood challenges and can further increase inequality and poverty (see Section 8.2.1), whose root causes are social, institutional and governance related. Various regional clusters of high vulnerability (see Figure 8.6) are also influenced by historical processes, such as colonialism and power relations that made people and countries vulnerable (Schell et al., 2020). Thus, vulnerability to climate change is not primarily linked to the degree of exposure to climate change impacts, but determined by societal structures and development processes that shape context and individual vulnerability (see Section 8.3.2), and values and lived experiences of climate hazards (Djoudi et al., 2016; Walker et al., 2021). Intersectionality approaches are central to grasping differential vulnerability (Thomas et al., 2019) for past and present livelihood impacts of climate change (see Figure 8.3; Section 8.2.2.2). Assessing observed local conditions and livelihood impacts and shifts requires us to consider reinforcing social phenomena such as age, gender, class, race and ethnicity, which shape social inequalities and experiences of the world and also intersect with climate hazards and vulnerability (Walker et al., 2021).

This understanding helps to clarify how social structures, institutions and governance mechanisms matter to address social causes in addition to climate magnifiers while holding them accountable (see Section 8.5). For example, low-elevation coastal zones concentrate high levels of poverty in some specific areas: 90% of the world's rural poor are concentrated in the low-elevation coastal zones of just 15 countries, and this population keeps growing (Barbier, 2015). Yet studies on the economic impacts of climate change and also integrated assessment models typically overlook the distributional effects of these impacts according to vulnerability and exposure and do not sufficiently account for agent and societal heterogeneity (Balint et al., 2017; Sovacool et al., 2021).

Since the AR5, *high confidence* is attributed to the fact that the, mostly detrimental, climate change impacts and risks are experienced mainly by the poorest people around the world (Olsson et al., 2014; Roy et al., 2018). There is *high confidence* that climate change impacts will put a disproportionate burden on low-income households and thus increase poverty levels (IPCC, 2014a; Hallegatte and Rozenberg, 2017).

There is *robust evidence* that economic development based on the exploitation of natural resources can significantly increase the vulnerability of communities at the local level. For example, there is a correlation between political arrangements and environmental degradation that brings about both disasters and an increase in disaster risk (Cannon and Müller-Mahn, 2010; Pereira et al., 2020), while development is recognised by some as a key element for adaptation (Cannon and Müller-Mahn, 2010).

Maladaptation is an important thread given its relevance to assess ways that well-intentioned development can exacerbate past and existing vulnerabilities and undermine livelihoods (see Section 8.2.2.1). Evidence shows that some local development projects can undermine

6 Calculated by averaging the country values of economic losses per event falling in different vulnerability categories.

resilience and increase the vulnerability of neighbouring communities, leading to maladaptation (Magnan et al., 2016; Schipper, 2020; Eriksen et al., 2021). Development projects can also negatively affect the vulnerability and create new ones of the very community where they are implemented (Burby, 2006; Magnan et al., 2016; Atteridge and Remling, 2018; Thomas and Warner, 2019; Work et al., 2019). Maladaptation has also received growing attention since AR5 as a projected future climate risk for vulnerable social groups (see Section 8.4.5.5) and in the context of adaptation constraints and trade-offs in climate resilient development (see Sections 8.5.1; 8.6.1), Despite maladaptation, there is however *robust evidence* that inclusive and sustainable development at the local level, can reduce vulnerability (Cannon and Müller-Mahn, 2010; Patnaik et al., 2019).

8.3.3.2 Economic and Non-economic Losses and their Relevance for Poverty and Livelihoods

Economic losses include income and physical assets and non-economic losses include mortality, mobility and mental well-being losses from climate change (see Section 8.3.4). The IPCC WGII AR5 (IPCC, 2014a) primarily associated L&Ds with extreme weather events and economic impacts, and treated it primarily as a future risk. New evidence provides insights into present-day L&Ds from slow-onset impacts (e.g., sea level rise) (Adamo et al., 2021) and non-economic losses (e.g., cultural impacts, emotional and psychological distress) (McNamara et al., 2021b) which previously received much less attention. AR5 had more focus on L&Ds in high-income regions than in regions most at risk, such as SIDS and least developed countries (LDCs) (van der Geest and Warner, 2020).

Impacts of climate change are affecting the economic and non-economic dimensions of people's lives, including subsistence practices of communities that are experiencing decreases in agriculture productivity and quality, water stress, increases in pests and diseases, disruption to culture, and emotional and psychological distress, to cite just a few (Savo et al., 2016). For example, the cumulative effects of slow-onset events threaten food security especially among the poor in Latin America and the Caribbean—regions which face the largest gender gap in terms of food security globally (Zuñiga et al., 2021). In general for Global South countries, the global average temperature warming (including the Paris target of 1.5°C) means substantially higher warming and including higher frequency and magnitude of extreme events, that will result in significant impacts on societal vulnerability (Aitsi-Selmi and Murray, 2016; Djalante, 2019).

Measuring losses from climate change impacts in terms of poverty and inequality can be difficult, and part of the lack of assessments of non-economic L&D can be attributed to the limited observational climate data on poor countries and population impacted, which are mostly concentrated in the Southern Hemisphere (Roy et al., 2018).This is also due to the challenges posed by the limited data available for assessing attribution (Cramer et al., 2014; Harrington and Otto, 2020; Otto et al., 2020a) and lack of a comprehensive set of adaptation metrics (Otto et al., 2020b). Economic L&Ds from climate change are often assessed and reported after disasters or within crises, however, non-economic losses from climate change are often overlooked as is their relevance for poverty and livelihoods. For those who experience both economic and non-economic losses, the impacts of climate change are very real and profound (Tschakert et al., 2017; Roy et al., 2018) Particularly in low-income and most vulnerable regions, it is not the absolute economic loss, but the combination of economic and especially non-economic losses that need to receive higher attention and need to inform adaptation strategies.

8.3.4 Observed Disproportionate Impacts According to Economic and Non-economic Losses and Damages Due to Climate Change

Since AR5 a new discourse on L&D has emerged with new typology and elaboration of a definition. L&D has a long and contentious history and is enshrined in the Paris Agreement (see Cross-Chapter Box LOSS in Chapter 17). Despite ambiguity about what constitutes L&D (Boyd et al., 2017), it focuses on how to avert, minimise, and address the negative impacts of climate change, including those that cannot be avoided through adaptation. It can also be thought of as the observed residual risk (and potentially irreversible losses) from climate change when adaptation limits are encountered and mitigation has failed (Boda et al., 2020). L&D is considered a policy mechanism (see Cross-Chapter Box LOSS in Chapter 17). There is also a burgeoning science for L&D (Mechler et al., 2019b) which advances the breakdown on compounding vulnerabilities and highlights the disproportionate effects of climate change on the vulnerable and marginal (see Box 8.5 for illustration of distributional effect of both the drought and responses in the Cape region in South Africa). New evidence provides additional insight into L&D from slow-onset events related to climate change (sea level rise, drought) (see Anjum and Fraser, 2021; Lund, 2021) For example, (Singh et al., 2021) found growing evidence of urban droughts leading to economic losses (e.g., groundwater overextraction, financial impacts) and non-economic losses (e.g., conflict, increased drudgery).

The literature is assessed according to this new L&D typology, which includes both extreme and slow-onset events and has a strong emphasis on climate justice and disproportionate impacts of climate hazards (see Figure 8.3), with a new focus non-economic L&D.

8.3.4.1 Economic (e.g., Income, Assets) Impacts of Climate Change and Vulnerability

While extreme events are not new, the intensity and frequency of extreme events are stacking, leading to additional increase in poverty or vulnerability in some regions, exacerbated by COVID-19, and up against existing development pathways leading to significant impact on economic losses globally (*high confidence*). There is *robust evidence* that many African countries experience climate-related losses in terms of loss of crop yields, destroyed homes, food insecurity through increased food prices, and displacement (Box 8.5; Olsson et al., 2014). Attention has been focused on low-income groups, women and children, poor rural communities, and Indigenous Peoples such as the example of the Dupong, an Indigenous Peoples in Ghana using Indigenous strategies to limit adverse impacts of climate change-induced water shortages (Opare, 2018). In Kenya, economic L&D during droughts between 2009 and 2011 incurred costs that included trucking emergency water and food supplies, and loss of livestock and livelihoods. Cross-sectoral economic effects were estimated to reduce gross domestic product (GDP) by 2.8% yr^{-1} (King-Okumu et al., 2021). Past studies have similarly shown that in the context of extreme events, such as floods or droughts, the most commonly sold assets are livestock and land. The sale of property particularly reduces the asset base, creates long-term vulnerabilities to future events and can trigger chronic poverty *(high confidence*). People may face food shortages in the future from lack of crop production (Opondo, 2013).The sale of cattle affects the household asset base, as well as important access to animal traction power for farming.

In South Asia, there is *robust evidence* of economic impacts of climate change (Cao et al., 2021), for example in the Sundarbans (a transboundary ecosystem with components in both India and Bangladesh, with the problem of unproductive livelihoods being common across residents of both countries) observations show local livelihoods are rapidly becoming unproductive (loss of fish, and increasing salination making agriculture increasingly difficult) (Ghosh, 2018); conditions that are exacerbated by climate change impacts (*high confidence*). Cyclone and storm surges induced by climate change force saline water into agricultural lands along the coast, which damages crops not only in the year the cyclone hits, but for several years afterwards (Rabbani et al., 2013). They showed in Shyamnagar Upazilla in Satkhira district the proportion of salinity-free farmland has gone down over the past 20 years, from more than 60% to nil (Rabbani et al., 2013). Vietnam has also experienced effects of flooding and salinisation in the Mekong delta, coupled with rapid social development. Intensified floods and droughts have dramatically resulted in loss of livelihoods in agriculture and fisheries in some areas of the basin (Evers and Pathirana, 2018). In Vietnam, the expected salinisation increases livelihood shifts into areas that are riskier, such as shrimp farming. Furthermore, the Vietnamese Mekong Delta is characterised by strong migration processes towards cities, particularly Ho Chi Min, meaning that abrupt livelihood shifts are already happening. There are emerging examples of Indigenous Peoples affected by climate change in indigenous farming mountain communities of the Nepal Himalaya. (Sujakhu et al., 2019). The Philippines has experienced extreme events, such as Typhoon Haiyan in 2013, which left more than 7353 people reported dead or missing, damaged or swept away more than 1.1 million houses and injured more than 27,000 people (McPherson et al., 2015). More than 4 million were displaced. The cost of damages has been estimated at USD 864 million with USD 435 million for infrastructure and USD 440 million for agriculture in affected regions (McPherson et al., 2015).

Sea level rise, coastal flooding and surge inundation are increasingly pressing problems across the urban Pacific, including the urban and coastal population of Vanuatu (McDonnell, 2021). Pacific region islands, such as Vanuatu (Handmer and Nalau, 2019), are particularly vulnerable to climate change. Kiribati and Tuvalu are impacted by exceptionally high tides that affect the urban atolls of South Tarawa and Funafuti, and cyclonic activity causing extensive economic damage in Tuvalu (Curtain and Dornan, 2019). Limited migration opportunities for low-income households can result in forced immobility, and high tides, sea level rise and cyclonic damages could result in relocation of significant groups of the population.

A pertinent example of economic losses is the example of the Torres Strait in Australia. This example shows evidence of communities living on remote islands. Boigu is a low-lying mud island inundated by the sea during high tides and storm surges. Those most exposed and vulnerable to climate change have limited livelihood assets and face challenges to secure external support with government and others. Place-based values evoke a reluctance to relocate or retreat with economic losses such as community infrastructure, housing and cultural sites (McNamara et al., 2017). In the Great Barrier Reef, Australia sea level rise and sea level global temperature warming affects fisheries' productivity and tourism (Evans et al., 2016). Unprecedented burn area of wild forest fires in Australia between September 2019 and January 2020 (Boer et al., 2020) extended over almost 19 million hectares, destroyed over 3000 houses and killed 33 people (Filkov et al., 2020).

The 2018 European heatwave in Northern and Eastern Europe caused multiple and simultaneous crop failures—among the highest observed in recent decades (*high agreement*). These yield losses were associated with extremely low rainfall in combination with high temperatures between March and August 2018 (Beillouin et al., 2020). Across Europe, in 2018, people experienced one of the worst harvests in a generation. Northern and Eastern Europe experienced multiple and simultaneous crop failures—among the highest observed in recent decades. These yield losses were associated with extremely low rainfalls in combination with high temperatures between March and August 2018. This compounding of extreme conditions in 2018 led to one of the highest negative relative yield anomalies at the scale of Eastern and Northern Europe, across a large array of crop species (Beillouin et al., 2020).

Extreme climate events are disproportionately impacting economies of the most vulnerable everywhere (*medium evidence, high agreement*). In the Caribbean, Central America and USA, Hurricanes Katrina, Harvey, Irma, Maria and Michael are examples of extreme climate events that have displaced households, destroyed homes, and led to loss of income among the poor and marginalised (Klinenberg et al., 2020). Puerto Rico was devastated by Hurricane Maria but received less support from the Federal Emergency Management Agency (García, 2021). Evidence is emerging on unequal governance responses in the USA versus Puerto Rico (Joseph et al., 2020). Floods, storms and heatwaves have impacted poorer communities and wildfires in California have impacted many wealthy groups, and also infrastructure used by all, for example, with lengthy electrical power blackouts. However, they have particularly impacted those vulnerable to disasters, such as undocumented Latino/a and Indigenous immigrants in the case of the Thomas Fire in California's Ventura and Santa Barbara counties (Méndez et al., 2020). In 2017, Hurricane Irma hit Ragged Island in the Bahamas as a category 5 storm, leaving the island in ruins and deemed 'unliveable' by its authorities, with most infrastructure left as rubble, no essential utilities remained, schools and health clinics were in ruins and the stench of dead animals was overwhelming. This storm resulted in significant economic L&D by the community through loss of their homes, churches, schools, agricultural land and infrastructure (Thomas and Benjamin, 2020).

Across South America, groups of farmers, children, elderly, Indigenous Peoples and traditional communities are increasingly exposed to floods, droughts, wild forest fires and losses in crop yields, resulting in significant economic costs (*medium evidence, high agreement*) (see

Box 8.6). Urban communities, in particular those living in informal settlements, are exposed to heatwaves. In Peru, analysis of water risks posed by climate change in the Vilcanota-Urubamba basin, Southern Peru, revealed seasonal water scarcity and glacial lake outburst floods (GLOFs), pose a serious threat for highly exposed and vulnerable people. It showed that very high-risk potentials of 134 current and another 6 out of 20 future glacier lakes as potentially highly susceptible to outburst floods. A total of eight existing and one possible future lakes indicate future river discharge could be reduced by some 2–11% (7–14%) until 2050 (2100). Farmers, in particular smallholders, in some regions face losses to irrigated agriculture and hydropower capacity with effects on water scarcity and food security (Drenkhan et al., 2019). However, other assessments also point towards positive effects of water reservoirs and hydropower in terms of water storage, flood management and irrigation (Ahmad et al., 2014; Liu et al., 2015; Kuraku et al., 2019)

There are additional dimensions of economic losses that are of a more diffuse nature. In particular, climate change is also expected to negatively affect labour supply, particularly in temperature exposed industries (agriculture, mining, manufacturing, construction), due to increases in the number of extreme hot days (Graff Zivin and Neidell, 2014; Garg et al., 2020). Low-income countries have on average a large share of workers in such industries and will thus be especially hard hit. Aside from labour supply, a number of studies also document negative impacts to manufacturing productivity (Acharya et al., 2018; Pogacar et al., 2018; Somanathan et al., 2021). These findings provide a channel to explain macroeconomic consequences of climate change (Burke et al., 2015). However, there are also non-economic costs in that extreme heat will cause increased discomfort to workers, such as psychological stress, disease and in extreme cases, death among the workforce in developing economies, as well as tropical and sub-tropical countries (Ansah et al., 2021).

8.3.4.2 Non-economic loss and damage (e.g., Mobility, Well-being)

Climate change L&D presents an existential threat to some (Boyd et al., 2017). For example, Pacific Island countries have contributed least to total GHG emissions, but the nations of the South Pacific are highly vulnerable to rising sea levels, tropical cyclones and other climate-related risks (Nand and Bardsley, 2020). For example, across Oceania there is significant risk that sea level rise will lead to forced relocation. Pacific leaders underscore the importance of losses, including deep connections between their world views and their land, and that leaving their islands can only be considered an option of 'last resort' (McDonnell, 2021).

Non-economic loss and damage (NELD) is values based (subjective and intangible) and relates to norms, social values and highlights intersectional experiences and perspectives on climate risk. The discourse on L&D includes a framing of NELD as loss of human and non-human life, and mental and physical health that is experienced widely across the world in vastly different ways associated with social values (Tschakert et al., 2019). There are respectable arguments for the case that all life has intrinsic value (Vetlesen, 2019). The NELD framing of climate impacts highlights that not all risks are measurable. While difficult to measure, there are a growing number of cases of NELD globally (*medium evidence, high agreement*). Illustrative examples of NELD from climate change include the Pacific (McNamara et al., 2021b) and SIDS in the Caribbean. (Martyr-Koller et al., 2021). For example, the hurricane season in 2017 was particularly extreme resulting in climate-induced displacement with direct implications for NELD, including threats to health and well-being and loss of culture and agency (Thomas and Benjamin, 2020).

In the context of the Pacific Islands, NELDs are thought of as interconnected and span human mobility and territory, cultural heritage and Indigenous knowledge, life and health, biodiversity and ecosystem services, and sense of place and social cohesion (Carmona et al., 2017; Ojwang et al., 2017; McNamara et al., 2021b). There are gaps in our understanding of NELD, much of the evidence is from the Global South and at smaller scales (*high agreement*), NELD is not explicitly linked to attribution science yet and evidence often lacks coverage on certain groups (Boyd et al., 2017; Carmona et al., 2017; Ojwang et al., 2017). Non-economic losses are often associated with displacements and migration in terms of climate change and human vulnerability (Section 8.2.1.4), studies show that the impacts of extreme flooding, droughts and/or hurricanes and cyclones that can lead to a sense of lost identity and place, and emotional distress, that are hardly assessed dimensions of impacts and risks (Adger et al., 2014; Barnett et al., 2016; Tschakert et al., 2017; Serdeczny et al., 2018). Non-economic losses are particularly relevant for understanding adverse consequences of climate change on the poor and most vulnerable population groups (*high confidence*). These NELD categories are still overlooked in vulnerability assessments and adaptation planning. A novel way to consider NELD in assessments is to interconnect with a sustainable development perspective (Boyd et al., 2017; Boda et al., 2020).

In order to categorise the different types of NELD that exist, (Serdeczny et al., 2016), reviewed the literature and came up with a set of systematic categories that capture what is usually thought about as having intrinsic value and according this framing of NELD this includes: human life, sense of place and mobility, cultural artefacts, biodiversity and ecosystems, communal and production sites and agency and identity (Serdeczny et al., 2016; Serdeczny, 2019). For example, there is emerging evidence on linkages between slow-onset events and mobility decisions, trajectories and outcomes (Zickgraf, 2021). In addition, categories include psychosocial and emotional distress (van Der Geest and Schindler, 2016). For example, research shows potential increased risk of intimate partner violence following disasters, noting that societies that are vulnerable to climate change may need to prepare for the social disasters that can accompany disasters revealed by natural hazards (Malik and Stolove, 2017; Rai et al., 2021).

Geographical focus on non-economic losses in the literature is largely on the Global South with studies mainly smaller in scale (*high agreement*). Many events studied include severe storms, floods and landslides. Key groups affected include low-income groups, agro-pastoralists, women and girls, children and youth, Indigenous Peoples, ethnic and religious minorities. In Europe, the Samis face significant challenges to health as ecosystems deteriorate (Jaakkola et al., 2018). In Zimbabwe, Storm Idai affected 270,000 people and subsequent flooding and landslides left 340 people dead and many others missing (Chanza et al., 2020). There is evidence of loss of cultural heritage sites due to sea level rise and coastal erosion as well as other climate variability (Brooks et al., 2020). Haile et al. (2013) show flood casualties in Ethiopia include children drowned while playing outside during the 2007 flood period although official data is hard to come by (p. 489). Moreover, loss of place was experienced in Itang, where many of the local houses are built from wood, grasses and mud walls, which are easy to reconstruct, but are not strong enough to withstand an extreme flood. Here, 38% of the surveyed houses were severely damaged by the 2007 flood. These houses were constructed as an adaptation strategy but could not withstand the floods. In Kenya, Opondo (2013) shows loss of human life was the most severe impact of floods. For example, in the focus group discussion with men, 'it was reported that a boat capsized on River Nzoia at Siginga and ten people died' (p. 457). In Mozambique, Brida et al. (2013) show loss of sense of place occurred after flooding in the central districts of Caia and Mopeia, which had a devastating impact on homes and livestock (Brida et al., 2013). Health impacts of the forest fires in Amazon basin countries have disproportionately affected vulnerable people and social groups (see Box 8.6).

In the literature on NELD, there are many examples of loss of life (*high agreement*). In Nepal, one of the deadliest landslides in Nepal history resulted in the death of 156 people (van der Geest, 2018). Evidence from Landslide Jure and consecutive rainfall in Sindhupalchok in Nepal showed the experience led to mental stress, such as fear of new landslides, in about 68.4% of people interviewed (van Der Geest and Schindler, 2016). One study in Nepal showed that almost a quarter (23%) of the households interviewed had sold property, including homes, livestock and heirlooms in response to flooding (Bauer, 2013). Human deaths are increasingly associated with L&Ds from tropical cyclones and typhoons, such as in the southern coastal districts of Bangladesh, in particular Khulna and Satkhira (Chiba et al., 2017). A case study from Mindanao, Philippines, by Chandra et al. (2017) also reported physical injuries and loss of life from the most powerful typhoon for over a century in 2012, affecting more than 6 million people and killing at least 1000 people (Eugenio et al., 2016). Beckman and Nguyen (2016) reported that in Vietnam floods in 2004 washed away 24 houses in the commune, with the loss of families when their houses were washed away.

An illustrative example is climate-induced loss of well-being and (im) mobility in Bhola Slum, an informal settlement in Dhaka, Bangladesh. Research revealed that IDPs from the southern coast experienced loss of belonging, identity, quality of life and social value produced in people a nostalgia and desire to return home (Ayeb-Karlsson et al., 2020). Another example is of urban climate change justice experienced by migrants in the Indian cities of Bengaluru and Surat, where environmental marginalisation can be attributed to a lack of recognition of citizenship rights and informal livelihood strategies driven by broken social networks and a lack of political voice, as well as heightened exposure to emerging climate risks and economic precariousness. In this case, migrants experience extreme forms of climate injustice in their invisibility to formal government and are even actively erased from cities through force or discriminatory development policies (Chu and Michael, 2019).

NELD also includes the loss of social networks. This has lasting implications for psychological health as well as for coping with crises following disasters or challenges posed by adverse climate change impacts. For example, many households in villages affected by Cyclone Aila in Dacope and Koyra upazilas of Khulna district in Bangladesh migrated to other places permanently after the cyclone, as these affected villages were subject to long-term flooding (e.g., 2–3 years) following the cyclone. They migrated as they were unable to restore their livelihoods and, thus, were unable to secure necessary income for survival (Saha, 2017).

The examples show the multifaceted nature of intangible and non-economic losses that people experience in the context of climate change and the daily risks they are exposed to. Conventional vulnerability assessments cover some aspects that are linked to the likelihood of experiencing non-economic losses, such as aspects of health, governance, education and in some cases also forced migration and the role of social networks. Overall, the elements of this assessment here underscore that it is not just the climatic stressor, but rather the underlying context conditions that decide whether an extreme event translates into a disaster.

8.3.5 Economic and Non-economic Losses and Damages Due to Climate Change and their Implications for Livelihoods and Livelihood Shifts

This section examines the intersections between L&Ds and livelihood shifts. This requires an examination of the differentiated aspects of livelihoods. Understanding economic (e.g., loss of food crops, infrastructure, assets etc.) and non-economic losses (e.g., health, well-being, loss of place, agency) and their consequences for livelihoods is important that the intangible aspects become clearly visible and receive greater attention in loss assessments and in designing adaptation strategies and programmes. Figure 8.10 provides a summary of examples of observed impacts of climate hazards on economic and non-economic capital and the section assesses livelihood implications across regions. It shows examples of climate hazards attributed to climate change in studies since AR5, across a range of geographical sites for heatwaves, drought, hurricanes, and floods and non-economic L&Ds. Figure 8.10 reveals examples of climate hazards attributed to climate change in studies since AR5 across a range of geographical sites for extreme and slow-onset events, such as heatwaves, drought, hurricanes and sea level rise. These are associated with non-economic L&Ds. The figure underscores that non-economic L&Ds lead to significant livelihood threats and livelihood changes. In addition, the limits of adaptation become evident (Chapter 16).

8.3.5.1 Livelihood Shifts Resulting from L&D from Climate Change

While there are limited studies that view economic and NELD from climate change at a global scale of livelihood transformations there is *robust evidence* on the granular linkages, at community, national and regional levels, between losses, coping strategies and livelihood shifts. Across Africa, climate change is impacting crop yields and destroying homes, resulting in loss of infrastructure and leading to non-economic losses associated with involuntary migration and displacement (Olsson et al., 2014), and loss of livestock and assets (see IPCC SR 1.5°C, Chapter

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3, (Hoegh-Guldberg et al., 2018), resulting in long-term reduction in the capacity for agriculture and land management. For example, in March 2019 Tropical Cyclone Idai in Mozambique, Zimbabwe and Malawi led to substantial losses of agriculture, infrastructure, and access to aid and support, all of which contributed to significant displacement in each country (Fischel de Andrade and de Lima Madureira, 2021). Examples of livelihood impacts include livelihood shifts among Kenyan pastoralists to camel husbandry, resulting from household inequalities in assets and changes in relation to weakening of social norms of reciprocity and social cohesion (Volpato and King, 2019).

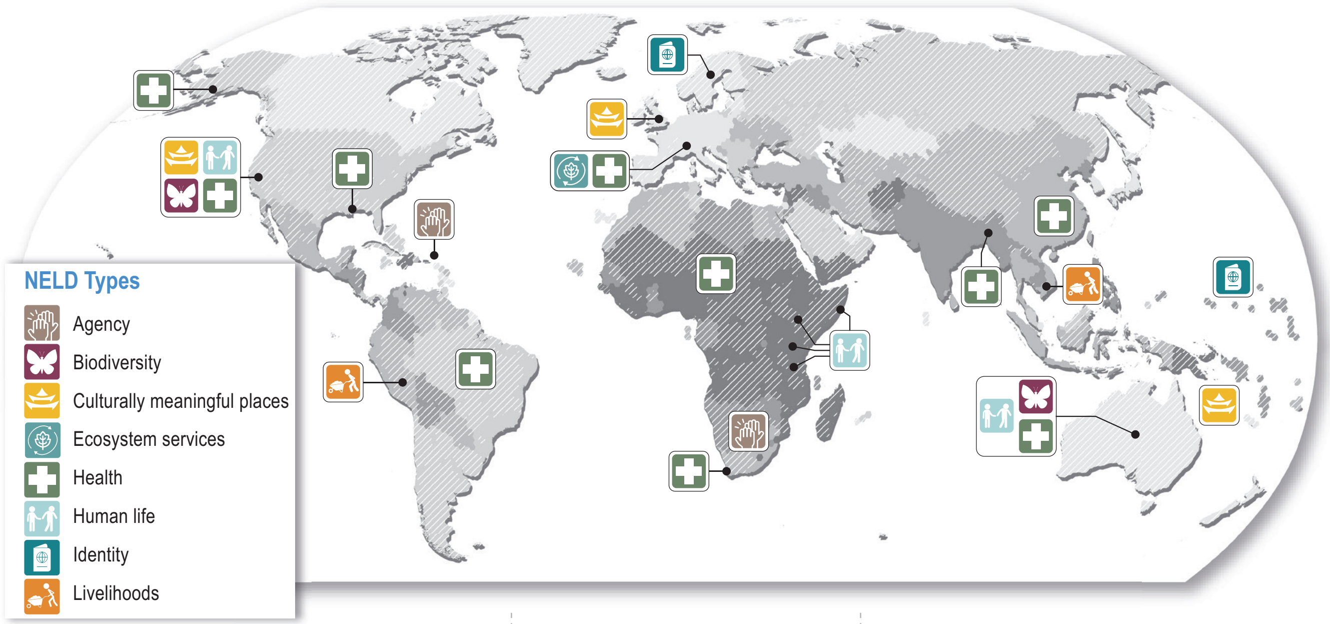
Extreme climatic events pose serious disruptions to local livelihoods and asset bases, requiring people to reconstruct, transform and diversify livelihoods (Uddin et al., 2021). Examples of livelihood shifts across Asia and Southeast Asia (e.g., Bangladesh, India, Philippines, Vietnam) include rural communities in coastal areas, urban settlements that are experiencing economic losses (*high confidence*) from, for example, crop failure and reduced access to fish, which contribute to non-economic losses associated with involuntary migration (Ghosh, 2018) and the malnutrition of children (Siddiqi et al., 2011). For Bangladesh, Chiba et al. (2017) show a connection between mental stress and impacts to the fundamental capacity to sustain livelihoods, such as food and a place to live, due to severe damage to houses, homesteads, properties, livestock and crops, loss of family members and relatives, and anxiousness about securing employment and income in the future. In Bangladesh coastal communities experienced losses in livelihood assets due to Cyclones Sidr and Aila (Uddin et al., 2021) and a significant number of cyclone victims were displaced from their homes by severe cyclones. People have had to change their occupations—both intra- and intersectorally—and are confronted by increased consumption and social costs. The study uncovered differences in impacts between occupations, such as farming and fishing; fishers changed their occupation post-disaster. The study also showed evidence that local people are learning to live with change and uncertainty by nurturing and combining various types of knowledge and social memory, generating diversified livelihood options and self-organising to enhance their resilience to future extreme weather events. In Bangladesh, Ahmed et al. (2019) found cyclones, riverbank erosion, salinity intrusion and floods negatively impacted people's lives by reducing their livelihood options. Their study found that when there are limited adaptation strategies, many people turn to 'illegal livelihoods' included using fine mesh nets to collect shrimp fry in the rivers, as well as logging in the Sundarbans. These people include the poorest and vulnerable, and law enforcement only exacerbates their vulnerability. Escarcha et al. (2020), studied impacts of typhoons, floods and droughts on crop production and effects on livelihoods of cash crop focused on rural villages in the Philippines. Their preliminary observations show a shift from crop to livestock production as a buffer activity to recover from crop losses. Farmers changed their farming activities as a multi-adaptive response driven by past experiences of climatic changes, farmers' social relations, household capacity and resources available.

In Central Asia, the Sahel and South Asia, three global poverty hotspots, change impacts were shown to undermine traditional knowledge about livelihoods in ways that jeopardise future culture cohesion and sense of place (Tucker et al., 2015). Acosta et al. (2016) identified loss to productive sites in the Philippines with landslides destroying agriculture, leaving many farmers without livelihoods. Similarly, Beckman and Nguyen (2016) in Vietnam identified an example where communal dams had been destroyed in floods leading to lack of irrigation for communal sites and local loss of farmland for farming communities. Chandra et al. (2017) identified the vicious cycle between declining agricultural production and conditions of soil erosion due to floods and droughts resulting in decreased crop fertility to productive sites with implications for decline in crop yields, loss of crops and of livelihood assets. Climate change-related extreme weather events, such as typhoons, floods, and droughts, can have detrimental impacts on crop production (*high confidence*) and in the Philippines and Pakistan have significantly affected the livelihoods of cash crop-focused rural villages (Escarcha et al., 2020; Jamshed et al., 2020b). There is an emerging shift from crop to livestock production as a buffer activity to recover from crop losses (Section 5.10.4; Jamshed et al., 2017; Escarcha et al., 2020). As with many examples of livelihood shifts, the viability of the shifts in the long term under climate change have yet to be assessed.

In Africa, many communities already experience drought- and flood-related disasters (*high confidence*) such as those that negatively impact livelihoods and assets in the Muzarabani district of Zimbabwe (Mavhura, 2017). In Muzarabani community has revived and developed new livelihood strategies to manage risks, including local informal safety nets, local farming practices and the traditional flood-proofing structures. Food security and agriculture productivity are examples of livelihood resources most at risk to climate hazards (see Figure 8.2) (*high confidence*). An illustration of such risks to cocoa farmers in Ghana includes increased incidences of crop pests and diseases, wilting of cocoa leaves, high mortality of cocoa seedlings which affected expansion and farm rehabilitation, and wilting of cherelles resulting in losses of crop yield. An illustration of livelihood shifts resulting from losses is of farmers shifting to cereals due to the unpredictable climatic patterns and the shortened duration of rainfall. Yet, insecurity with storage, supply chains and low returns from cereal production, coupled with land scarcity in the Western region, have resulted in a return to cocoa production (Asante et al., 2017).

Research from Australia shows complex linkages between the impacts of drought on livelihood income, health and cultural heritage, increasing risk of heat stroke, and possibly a link to suicide among male farmers (Alston, 2012; Hanigan et al., 2012; Marshall et al., 2019). The link between agricultural losses and suicides has also been noted in South Asia, including India (Carleton, 2017). Livelihoods are shifting with impacts to well-being, as noted by (Evans et al., 2016), who showed connections between loss of fishery productivity and impact on tourism sector livelihoods in the Great Barrier Reef region. In Europe, losses to Indigenous Peoples are associated with loss of well-being of Sami communities and has forced livelihood shifts from reindeer herding due to loss of ecosystems to support the animals (Persson et al., 2017; Jaakkola et al., 2018). Traditional pastoralist systems are also greatly impacted by cumulative dual challenges of encroachment of other land users and by climate change. Traditional Sami reindeer herding strategies are still practiced, but the rapidly changing environmental circumstances are forcing herders into uncharted territories where traditional strategies and the transmission of knowledge between

Non-economic loss and damage associated with climate hazards attributed to climate change with background map of global vulnerability



NELD	Climate hazard	Non-economic Loss and Damage	References
Health	Western Cape region in South Africa drought "Day Zero"	Loss of quality of life	Pascale et al., 2020; see also AR6 WGI Chapter 10, Section 10.6.2; M. Fanadzo,2021
Human life	East Africa drought 2017 (Tanzania, Ethopia, Keny and Somalia)	Loss of lives	Funk, C. et al. 2018: Haile et al., 2020
Culturally meaningful places, Human life, Biodiversity, Health	The 2011–2017 California drought	Loss of life, loss of quality of life, loss of culturally meaningful places and biodiversity	Seager et al.2015; Murray et al. 2021;.Greene 2021, Greene, 2018; Barreau et al., 2017. Hung et al, 2021; Garwood, et al. (n.d.)
Health	2015 Amazon forest fire in Brazil	Loss of quality of life	AR5 WGII Chapter 8, Box 8.6; Li et al., 2021
Identity	Wildfires Sweden 2018	Loss of cultural way of life	Krikken et al. 2021; Jaakkola et al., 2018
Human life, Biodiversity, Health	Australia bushfires, 2019-20	Loss of life, loss of quality of life, loss of biodiversity	van Oldenborgh et al. 2020; Celermajer et al., 2021; Nguyen et al., 2021; Godfree et al., 2021
Agency	Hurricane Maria "extreme rainfall" over Puerto Rico, 2017	Loss of safety networks and displacement	Patricola et al., 2018; Keellings and Hernández Ayala, 2019; Moleti et al., 2020; Salas-Wright et al., 2021
Livelihoods	Increased outburst flood hazard from Lake Palcacocha due to human-induced glacier retreat	Loss of livelihoods	Stuart-Smith et al., 2021; Bergmann et al., 2020; Drenkhan, 2019
Identity	Pacific sea level rise	Loss of Indigenous and local knowledge	Herring et al., 2014; Herring et al., 2015; Herring et al., 2015; McNamara et al., 2021
Culturally meaningful places	Great Barrier Reef mass bleaching, 2016	Loss of culturally meaningful places	Lewis and Mallela, 2018; Curnock et al., 2019
Health	East China's hottest spring, 2018	Loss of quality of life	Lu et al., 2021; Kinay et al. 2019
Health	Sahel drought	Loss of quality of life	AR6 WGII Chapter 8; Semde et al. 2021
Health	Alaska wildfires, July 2019	Loss of quality of life	Yu et al., 2021; Hahn et al., 2021
Health	Urban drought Dhaka, Bangladesh	Loss of quality of life	Singh et al., 2021; Ray and Shaw, 2019; Amjad 2019
Culturally meaningful places	Storm Desmond, 2018 UK	Loss of cultural heritage	Howard et al., 2017; Otto et al., 2017
Ecosystem services, Health	Unprecedented Europe heat, June-July 2019	Loss of ecosystem services and loss of quality of life	Ma et al., 2020; Kandic, 2020; Schuldt et al., 2020
Health	Louisiana floods, August 2016	Loss of quality of life	Wang et al., 2016; Zhang et al., 2021; Boullion et al., 2020; Keegan et al., 2018
Agency	Severe drought and poor harvests over southern Africa, 2016	Loss of agency	Funk, C. et al., 2018; Feeny and Chagutah, 2016; King-Okumu et al., 2021
Livelihoods	Flooding on the Lancang-Mekong River Basin, 2008–16	Loss of livelihoods	Yun, X. et al. 2020; Evers and Pathirana, 2018

Figure 8.10 | Examples of non-economic loss and damage associated with climate hazards attributed to climate change against a background of global vulnerability. Symbols with corresponding detail in the table show examples where non-economic losses have been documented. The figure is not exhaustive in terms of examples of extreme or slow-onset events or losses. It does not capture undocumented cases. It is an illustration of the relationship between unequivocal human-induced climate change and intangible losses (Adapted from Boyd et al., 2021).

generations may be of limited use. For example, rotational grazing is no longer possible as all pastures are being used, and changes in climate result in unpredictable weather patterns unknown to earlier generations (Axelsson-Linkowski et al., 2020). These examples show that there are complex factors underpinning the linking L&D and shifting livelihoods. Moreover, there are significant challenges to undertaking a shift to secure alternative livelihoods.

Linkages between losses, coping strategies and livelihood shifts in small islands (e.g., in the Pacific region, Kiribati and Tuvalu, and in the Caribbean, the Bahamas) shed light on impacted low-income households. For example, farmers have experienced extensive damage to homes and loss of infrastructure, and experience lack of migration opportunities (Curtain and Dornan, 2019). Evidence is growing that there is also significant loss of cultural heritage in resettlement (Barnett and O'neill, 2012), evidence from small islands' displaced communities suggests that resettlement can have impacts on sense of place, identity and social fabric, a theme highly relevant to loss, coping and adapting livelihoods, and not only restricted to small islands (McNamara et al., 2021b). Roberts (2015) identified loss of communal sites in Kiribati. It is predicted that, by 2050, up to 80% of the land on the island of Buariki and 50% of the land on Bikenibeu may be completely inundated and these effects will result in significant loss of livelihoods and displacement. Throughout the Caribbean, evidence indicates that there will be an overall reduction in the area of land suitable for crop cultivation, as the region's climate gets progressively warmer and as rainfall becomes more variable (Rhiney et al., 2016).

The multiple shocks of extreme events reduce crop yields, destroy homes, and lead to loss of infrastructure and displacement (*high confidence*). These are experienced in South and North America. For example, in Peru, glacial outbursts have led to loss of livelihoods (Drenkhan et al., 2019). People use a range of coping and adaptation strategies to deal with hazards where they live, such as shifting livelihood activities, inputs or production areas. However, traditional techniques are increasingly failing due to changing weather patterns. Across Peru, findings demonstrate that people use temporary and permanent migration among their many coping and adaptation strategies. Hazards related to water excess have been the key force in destroying homes and driving displacement in Peru. In contrast, studies demonstrate that water scarcity also threatens livelihoods and thereby influences migration in Peru. While non-climatic reasons for moving dominate migrants' motivations in many areas of Peru, water-related climatic drivers of migration are becoming increasingly relevant (Wrathall et al., 2014). Peru's smallholder farmers and urban poor are not responsible for the climate crisis, yet their lives and cultural heritage are being increasingly jeopardised by its effects, making improvements in governance an imperative for Peru (Bergmann et al., 2021). Another area of significance is coffee production in Brazil, where the majority of Brazilian coffee farms are operated by smallholders, producers with relatively small properties, who are mostly reliant on family labour (Koh et al., 2020). In the USA (e.g., New Orleans and Puerto Rico), people have lost livelihoods due to displaced households and destroyed homes, leading to loss of income, as well as loss of social networks and family networks and loss of cultural heritage. For example, impacts of Hurricane Katrina have led to people being displaced from their employment, many evacuees had to relocate to new areas, which disrupted their social networks and placed them in unfamiliar labour markets, resulting in mental health challenges (Palinkas, 2020). There has also been a 'climate gentrification' in parts of New Orleans (Aune et al., 2020). Many of those who returned to their pre-Katrina areas had to deal with extensive damage to their homes and to public infrastructure.

In summary, across regions there is an increasing number of examples of observed economic and NELD from climate change. Adaptation measures need to better incorporate actions to tackle the burgeoning negative social, psychological and well-being impacts of climate change (Barnett et al., 2016; Box 8.5). At present, losses from climate change are potentially growing faster than adaptation measures across the globe. It is still uncertain how economic and non-economic losses trigger successful or viable new climate-related livelihood transitions for the poor and people or groups in vulnerable situations in the future (see Sections 8.4.4; 8.4.5). In all likelihoods, economic losses from climate hazards (e.g., drought) will be compounded by many factors including COVID-19 and other vulnerability drivers. For instance, globally, small-scale coffee producers have been destabilised by COVID-19, but also because of a history of recurrent (climate) shocks and structural inequalities, and may have to shift into alternative livelihoods (Guido et al., 2020). Coastal communities in Vanuatu have been impacted in the immediate period after COVID-19 showing changes in village populations, loss of cash income and difficulties in accessing food, and have experienced shifting pressures on particular resources and habitats (Steenbergen et al., 2020). This trend poses real challenges to equity and sustainability.

In summary, this section has moved beyond the IPCC WGII AR5 in laying out structural elements of vulnerability and climate-related vulnerability hotspots globally, such as poverty, lack of access to basic services, gender inequality and undernourishment. The assessment provides new quantitative evidence about the global spatial distribution of systemic human vulnerability and therewith underscores that various hotspots of countries classified as having very high or high vulnerability emerge in regional clusters. In addition, the number of people living in very highly and highly vulnerable country contexts is significantly higher in some assessments, with even twice as many as the number of people living in countries classified as having low and very low vulnerability. The evidence suggests that statistically relevant differences in fatalities per hazard event are not just a product of the hazard event, but also strongly linked with the level of vulnerability of the region or community exposed. The assessment of non-economic losses has also received little attention in past IPCC Assessment Reports, therefore this section has provided new insights on how (next to measurable economic losses) non-economic losses and intangible losses emerge. These non-economic losses represent an important dimension of societal impacts of climate change that has not sufficiently captured so far within standard damage or post-disaster assessments. Finally, the section provides evidence about the existing adaptation gap in terms of differential vulnerabilities and various non-economic losses already experienced.

Box 8.5 | Western Cape Region in South Africa: drought challenges to equity and sustainability

Nature of the drought

Between 2015 and 2017, the Western Cape region experienced an unprecedented three consecutive years of below average rainfall, leading to acute water shortages, most prominently in the city of Cape Town (Sousa et al., 2018). Anthropogenic climate change made the drought five to six times more *likely* (Pascale et al., 2020; see also AR6 WGI Chapter 10, Section 10.6.2). The severity of the drought presented new challenges to the existing management and governance capacity to ensure equitable and sustainable water service delivery. The city's water supply infrastructure and demand management practice were unprepared for the 'rare and severe' event of three consecutive years of below average rainfall (Wolski, 2018; Muller, 2019). Despite a potential total storage volume of about 900,000 Ml of water (enough water for around a year and a half of normal usage, after taking evaporation into account), Cape Town's reservoirs fell from 97% full in 2014 to less than 20% in May 2018 (Ouweneel et al., 2020; Cole et al., 2021). The drought saw residents queue for water as restrictions were imposed together with threats of closure of water provision to households (Sorensen, 2017; Scheba and Millington, 2018). Poor communication in the early stages of the drought (Hellberg, 2020) and a lack of trust in the administration contributed to a near-panic situation at the threat of 'Day Zero' as dams almost ran dry in the first half of 2018 (Enqvist and Ziervogel, 2019; Simpson et al., 2020c). 'Day Zero' was avoided largely through public response, water demand management and the 2018 winter rains (Sorensen, 2017; Booysen et al., 2019a; Muller, 2019; Rodina, 2019b; Matikinca et al., 2020). At a household level, responses to the drought showed everyday residents can display unprecedented degrees of resilience (Sorensen, 2017), including behavioural and attitudinal shifts and technological innovation across the full socioeconomic spectrum (Ouweneel et al., 2020). But the private nature of some of these responses extended existing inequality in water access through privileged forms of 'gated adaptation' by elites which conventional water governance arrangements were unprepared for (Simpson et al., 2019b; Simpson et al., 2020a).

These 'climate gating' actions, such as drilling boreholes, secured water access for high-income households and companies, but excluded a large proportion of Cape Town's population who could not afford such private technologies (Simpson et al., 2019a; Simpson et al., 2020b). These responses were unanticipated by the city administration and compounded fiscal challenges faced by the municipality which could no longer use revenues from high-consumption households to cross-subsidise water for low-income households (Simpson et al., 2020a). This shift threatened to undermine the sustainability of the municipal fiscus and general water access (Box 9.8; Simpson et al., 2019a; Simpson et al., 2020a). In order to recover losses, municipal water tariffs for consumers were raised by 26% in 2018 (Muller, 2018; Simpson et al., 2019a). In addition to a decline in tourism, median estimations of the overall economic impact of the drought indicate loss of 27.6 billion South African Rand (USD 1.7 billion) translating into 64,810 job losses in the Western Cape, with Cape Town accounting for approximately half of those job losses (DEDAT, 2018). This had a disproportionate impact on unskilled and semi-skilled workers, particularly for those from low- and middle-income households (DEDAT, 2018). The drought also exacerbated the potential for sanitation health risks of the urban poor where tens of thousands of people lack access to safely managed sanitation facilities (Enqvist and Ziervogel, 2019).

The Day Zero Disaster Plan included prioritising and protecting the poor and most vulnerable communities where critical infrastructure and facilities and vulnerable and informal residential areas would remain connected while higher-income residential areas would be cut off (Cole et al., 2021). Yet it is important to recognise that pre-existing deficiencies in service delivery meant water access for the urban poor did not change as significantly during the drought, particularly those in informal settlements who collect water from standpipes (Enqvist and Ziervogel, 2019; Matikinca et al., 2020). For these communities, the negative economic impact of the drought was compounded by the unintended consequences of demand management regulation emanating from the drought response. South Africa ostensibly ensures a constitutional right to water, regardless of ability to pay (Rodina, 2016), 58). Since 2018, however, as a consequence of new water tariffs instituted during the drought, Cape Town residents now have had to 'prove their poverty' in order to register as indigent households and access their water right (Scheba and Millington, 2018). Further, since 2007 and with increasing effect during the drought, the municipality has installed approximately 250,000 water management devices as a credit control and, during the drought, also a consumption control measure. As these have been largely installed in low-income homes, this control measure disproportionately affected poor households (Scheba and Millington, 2018; Enqvist and Ziervogel, 2019).

Lessons from the drought

The effect of communication at different stages in the drought highlights how critical information needs to be provided in a format and language that empowers people to act appropriately and collaboratively (Muller, 2019; Rodina, 2019b; Rodina, 2019a). Getting political decisions made in a timely fashion and with public support is a long-standing challenge for managers of urban water supplies (Muller, 2017; Muller, 2019). In Cape Town this was further challenged by dependence on a malfunctioning national department for water supply planning, poor coordination between the spheres of government—city, provincial and national governments—and poor collaboration between political representatives, technical experts and strategic managers (Madonsela et al., 2019; Nhamo and Agyepong, 2019; Rodina, 2019a; Ziervogel, 2019b). This highlights the need to strengthen partnerships and collaboration across sectors and scales

Box 8.5 (continued)

of governance (Ziervogel, 2019a), including the adoption of a 'whole-of-society' approach that recognises the contributions of non-state actors as adopted in the Cape Town Resilience Strategy (CoCT, 2019; Simpson et al., 2020a). Experienced yet inflexible water management initially operated at a distance from politicians and their citizens. There was limited knowledge and capacity in how various municipal departments thought about risk, exposure and vulnerability of Cape Town's highly differentiated population (Mukheibir and Ziervogel, 2007; Pasquini et al., 2015; Madonsela et al., 2019). In the later stages of the drought, Cape Town's water management department was able to work collaboratively across different departments and with politicians to implement responses.

The Cape Town case highlights how disaster planning for slow-onset city-wide shocks will be become increasingly important to safeguard equity and sustainability across African cities (Cole et al., 2021). It demonstrates the importance of integrating state and non-state responses to climate change in municipal adaptation and disaster planning (Booysen et al., 2019a; Booysen et al., 2019b; Simpson et al., 2020a), particularly for responses with unintended consequences. Further, water tariff models need to be flexible enough and have built-in redundancies in order to prioritise the needs of the urban poor and ensure climate responses do not disproportionately affect low-income groups and deepen existing inequalities (Scheba and Millington, 2018; Enqvist and Ziervogel, 2019; Simpson et al., 2019b). Systems and relationships of mutual accountability can also build more effective water management between spheres of government and enhance horizontal collaboration between municipal departments and non-state entities (Ziervogel, 2019b; Ziervogel, 2019a).

8.4 Future Vulnerabilities, Risks and Livelihood Challenges and Consequences for Equity and Sustainability

Future climate vulnerability and risks to livelihood security are significantly influenced by present and past development trends, equity and sustainability. Consequently, observed impacts covered in previous sections provide essential insight for enhancing future adaptation and risk reduction. Since the AR5, new research approaches incorporate past lessons to project and assess climate change vulnerability and socioeconomic conditions into the future. Scenario tools and methods are a powerful approach for integrated assessments of emissions pathways, associated warming and development contexts, helpful in guiding analysis of adaptation policy and planning (Berkhout et al., 2014; Birkmann et al., 2021a). Both quantitative and qualitative scenario approaches that assess future vulnerability and risks, as well as livelihood challenges at global, national and local scales, allow experts, planners, decision makers and affected people to articulate and visualise development futures. These approaches can complement emissions pathway scenarios.

8.4.1 Future Exposure, Climate Change Vulnerability and Poverty at the Global Scale

The SSPs scenarios orient climate models around possible development pathways that produce future exposure patterns, risk probabilities and vulnerability for future populations (O'Neill et al., 2014; O'Neill et al., 2017a). While the likelihood of any given scenario actually occurring is highly uncertain, they have the advantage of pairing with computational models to generate robust projections about risk profiles in possible futures, and therefore assess the relative influence of different drivers of change. In this way, scenario tools generate pictures of future vulnerability and adaptation pathways, and often have both an analytic and normative function. The decision-making context will determine which specific scenario approach is most appropriate (Rozenberg et al., 2014). Scenarios are limited by stakeholders' imaginations and, as such, new emergent challenges, such as the COVID-19 pandemic, are difficult to anticipate in scenario planning. Nevertheless, recent studies and forecasts of the impact of COVID-19 on poverty conclude that in the near- and medium-term future major portions of the newly poor will emerge in sub-Saharan Africa and South Asia (Laborde et al., 2020b; Sumner et al., 2020). Since these countries are already characterised by high levels of absolute poverty and vulnerability to climate change, it is *likely* that these regions will face more severe challenges in overcoming vulnerability and will be confronted with a growing adaptation gap. Thus, the implication for scenario planning is that single crises or events, such as the COVID-19 pandemic, might not significantly alter existing vulnerabilities, but rather reinforce them.

8.4.1.1 Exposure and Vulnerability under Different Scenarios and Alternative Development Pathways

At the international and national level, the SSPs (O'Neill et al., 2017a) have been developed to outline various development pathways, associated emissions and levels of warming, but also different possible development profiles (i.e., levels of economic growth, poverty, inequality, demographic change, etc.) that are highly relevant for adaptation.

Studies using the SSPs to understand multidimensional poverty are few but growing, and underscore that the impacts of climate change on poverty are extremely sensitive to different levels of warming (Byers et al., 2018). Multi-sector risks approximately double between 1.5°C and 2°C global mean temperature (GMT) change, and double again in a +3°C world. Comparing a +1.5°C world pursuing sustainable development (SSP1) to a high-poverty and high-inequality +3°C world (SSP3), Byers et al. (2018) project substantial increases in populations exposed to drought, water stress, heat stress and habitat degradation (see in detail Byers et al., 2018). While in a +1.5°C world exposed populations increase by 7–17%, the increase within a +3°C plus world is 27–51% (Byers et al., 2018; Frame et al., 2018). Populations in Asia and Africa account for more than 80% of the global population

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exposed to these phenomena, and within South Asia and the Sahel, up to 90% of populations are exposed. Scenario tools help us to understand the burden of increasing multidimensional poverty, and potential for poverty traps, if mitigation and adaptation measures are not taken rapidly and effectively implemented.

At the national and sub-national levels, studies on development and risk scenarios capture specific challenges, for example, urban growth, demographic change, human health and ageing (e.g., Dong et al., 2015; Chapman et al., 2019). In this regard, local scenarios of human vulnerability can inform future strategies for adapting to hazards such as heatwaves in cities under different socioeconomic development strategies. These scenario approaches allow us to focus on changes in climatic and societal conditions as well as urban transformations. This provides a more comprehensive basis for defining adaptation goals (see Fekete, 2019; Birkmann et al., 2021b). Costs and benefits of different adaptation measures can be assessed against different future scenarios of climatic and societal change.

Contrasting with 'top-down' SSP scenarios, (Berkhout et al., 2014) outline how mesoscale and 'bottom-up' scenarios have been developed to inform spatial planning, for example, in the Netherlands. Increasing computational power has opened possibilities for large-scale 'bottom-up' simulations of people's livelihoods in the context of evolving climate change impacts, such as the migration decisions of farmers facing drought in Mexico over the coming century (Bell et al., 2019) and livelihood decisions of people facing coastal flooding in Bangladesh to the year 2100 (Bell et al., 2021). Such 'bottom-up' scenarios can generate projections about future outcomes, inform mapping and assess future vulnerability, with special emphasis on livelihoods of the poor. Researchers conclude that results of respective scenarios that aim to inform adaptation and risk reduction policies in the context of climate change have to match the frames of the stakeholder (Berkhout et al., 2014; Conway et al., 2019). Scenarios that assess potential future vulnerabilities and future capacities for adaptation require more attention, since many approaches for projecting future climate risk still largely overlook non-climatic drivers that determine future vulnerability and exposure (Windfeld et al., 2019).

8.4.2 The Influence of Future Climate Change Impacts on Future Response Capacities

The influence of climate change also impacts the future response capacities of people and nations to deal with future climate change and climate hazards. Recent studies (e.g., Mysiak et al., 2016) conclude that climate change can increase the severity and intensity of crises or even trigger disasters, particularly floods, storms, forest and wildfires, and droughts. These have undermined decade-long poverty reduction efforts, particularly in low-income and at-risk countries (Djalante, 2019). Climate-influenced (disaster) risks are getting more complex and systemic (UNDRR, 2019). The magnitude of global annual average economic losses from natural and climate-induced hazards to the built environment alone are estimated in the United Nations Office for Disaster Risk Reduction (UNDRR) Global Assessment Report (2015) as being comparable with the GDP of the 36th largest economy in the world at that time—the Philippines (in 2015) (UNISDR, 2015; Mysiak et al., 2016). In addition, a World Bank study concludes that losses of human well-being are higher than the overserved economic losses from natural hazards (Hallegatte et al., 2017). In this regard, it is *likely* that future impacts of climate change, particularly under increasing levels of global warming (above 1.5°C) will also increase non-economic losses (see Section 8.3.2.3) and losses of human well-being that are particularly relevant to most vulnerable groups and the poor.

Furthermore, the expected future increase in the number of people exposed to climate hazards, such as sea level rise and coastal flooding, is not only determined by changing hazard patterns, but also by regional processes of migration and urbanisation for example in Asia and Africa, including an increasing number of urban poor living in low-elevation coastal zones (United Nations, 2018). This can increase again the probability that more people require assistance and support for buffering these effects of climate-related hazards, for example, in coastal zones. Historical urbanisation processes, in coastal cities in Asia (e.g., in China, Vietnam, etc.) and Africa (e.g., in Nigeria) have increased the exposure of people to climate hazards, such as sea level rise, which by 2100 under Relative Concentration Pathway (RCP) 8.5 will globally threaten 630 million people, largely in coastal cities (Kulp and Strauss, 2019).

In addition, Smirnov et al. (2016) conclude that worldwide the number of people exposed to extreme droughts will increase under both the RCP4.5 and the RCP8.5 particularly at the end of the century. The authors assess that under RCP4.5 the average monthly global population exposed to drought will increase between the periods 2008–2017 and 2081–2100 from a mean of 80 million to 212 million, and under RCP8.5 from about 90 million to approximately 472 million people. The research findings underscore that there is a high probability that exposure to extreme droughts will increase, particularly in regions and countries already classified as highly vulnerable (e.g., Nigeria, Sudan, etc.) (Smirnov et al., 2016). Extreme droughts are expected to further erode coping and adaptive capacities of those already characterised by high levels of vulnerability (see Section 8.3.1). Building adaptive capacities for the most vulnerable groups in the future in these areas will be a challenge, since high levels of livelihood insecurity are coupled with high levels of structural vulnerability at national and regional scale (poverty, state fragility, etc.) making planned adaptation support very complex and difficult. Therefore, increasing adaptation gaps at different scales are anticipated in the future.

Increasing population exposure (e.g., due to urbanisation of coastal zones, etc.), coupled with higher frequencies and intensities of specific climate hazards are *likely* in connection with the existing adaptation gap (e.g., high levels of vulnerability) to compromise development and human security. Recent studies, such as that by Harrington (2018), conclude that the actual exposure and the physical individual recognition of some climate hazards, will be higher in low-income countries. The study of Harrington (2018) underscores that changes in extreme heat, for example, will be felt by the average citizen of a low-income country after 1.5°C of global warming and will not be felt by about 40% of people living in high-income nations until well after double the amount of global warming is reached (3°C increase). In this context, even if a city or place is exposed to heat stress, people experience it quite differently due to different levels of vulnerability and adaptive capacities, such as the ability to afford air conditioning (Barreca et al., 2016). That means well-off populations are better insulated from effects of global warming than poorer or more vulnerable groups, even if they are geographically living in the same exposure zone. These findings underscore that issues of climate justice need to be considered within the problem definition when designing adaptation strategies, and not solely at the end. Impacts of future climate hazards (heat stress, flooding, etc.) differ not only due to changes in frequency and intensity of the hazard itself, but also significantly in terms of the opportunities people have to respond and prepare for these hazards and climatic changes at present and in the future. However, extreme heat stress has also caused significant fatalities in countries classified as having low vulnerability, such as seen within the heat wave in Europe in 2003.

8.4.3 The Influence of Climate Change Responses on Projected Development Pathways

Responses to climate change can have dual effects on development pathways. On the one hand, mitigation and adaptation processes can create significant development opportunities. The potential of mitigation policies for job creation, in particular, has been highlighted (Healy and Barry, 2017). However, responses to climate change can also have detrimental effects on future development: mitigation policies, such as the building of hydro-electrical dams or the culture of biofuels can lead to communities' dislocation and populations' resettlement, particularly of disadvantaged groups within a society (de Sherbinin et al., 2011; Eriksen et al., 2021). Adaptation policies can also hinder some development processes: for example, the promotion of migration as an adaptation strategy can lead to communities being deprived of their workforce and resenting the departure of some of their members (Gemenne and Blocher, 2017), even though this may offer new livelihood opportunities. However, the migration consequences in the context of climate change are often more nuanced and different trade-offs and benefits occur (see Porst and Sakdapolrak, 2020). For example, remittances support family members but, at the same time, can also create imbalances in local markets (Melde et al., 2017). Evidence exists that some climate responses, such as small-scale agricultural livelihood adaptation strategies, have improved the ability of people to sustain their livelihood and to reduce poverty (Osbahr et al., 2010).

8.4.4 Social Tipping Points in the Context of Future Climate Change

Climate change has the potential to trigger major, sudden social transformations, yet there are no clear linear relationships between the magnitude of climate change impacts and the social changes they induce (Steffen et al., 2018). Evidence shows that major destabilising social transformations (e.g., forced migration) can occur in response to limited climate change impacts, even while major climate change impacts can be mitigated through the resilience of social, political and economic systems, and thus yield only minor social impacts.

In the context of climate change, 'tipping points' have been identified as critical thresholds at which a tiny perturbation can qualitatively alter the state or development of a system (Lenton et al., 2008; Lenton et al., 2019). The concept of tipping points is usually associated with large-scale components of the climate system that could be pushed past an irretrievable threshold as a result of human-induced climate change (Lenton et al., 2008), such as the deterioration of Antarctic ice sheets (Pattyn and Morlighem, 2020). Social tipping points refer to similar mechanisms of destabilisation resulting from impacts of climate change on human societies at multiple scales and the societal context conditions in which these impacts occur. They are reached when climate change impacts force destabilising social transformations from one state to another (Lenton et al., 2019): from sporadic losses due to climate change to chronic losses and impoverishment, from peace to violence, from a democracy to an authoritarian regime, from adequate food provisioning to famine, or into forced migration. For example, small variations in the rainfall or temperature can jeopardise livelihoods that are dependent upon subsistence agriculture, which can lead to migration or tensions around resources (see Figure 8.11). Social tipping points can also occur when intangible elements that ensure the survival of individuals and communities are eroded or removed. This is the case, for example, when the social fabric of a community falls apart. The Millennium drought in Australia led to higher rates of male suicide, especially among farmers, and droughts in Ghana led to similar outcome when people were forced to drink from the same water source as their animals, which they perceived as robbing them off their human dignity (Bryant and Garnham, 2015; Tschakert et al., 2019).

In socio-ecological systems, tipping points occur when a (small quantitative) change inevitably triggers a nonlinear change in the corresponding social component of the socio-ecological systems, driven by a self-reinforcing positive feedback mechanism, that inevitably and often irreversibly leads to a qualitatively different state of the social system (Milkoreit et al., 2018).

In recent years, significant research efforts have been made to identify early warning signals for social tipping points (Barrett and Dannenberg, 2014; Bentley et al., 2014; Lenton et al., 2019). While some identify early warning signals through time series (Scheffer et al., 2012), others see them in interaction networks and individual thresholds (Barrett and Dannenberg, 2014; McLeman, 2018). Empirical research conducted in a transboundary contentious region—the Jordan river valley—showed that there were significant local and regional differences in the identification of social tipping points (Rodriguez Lopez et al., 2019).

Empirical evidence shows that social tipping points can be triggered long before climate tipping points are reached. For example, recent research in West Africa shows that migration decisions are often based on the perceptions of environmental changes by local populations rather than on the actual observed changes (De Longueville et al., 2020). The migration of some members of a community can also trigger the migration of the whole group, as the migration of some members can have a strong impact on the community (Gemenne and Blocher, 2017). In other contexts, the expectation of a climate impact can trigger social or political shifts: for example, the expectation of lower snow cover levers can reduce or stop investments in ski resorts. Some planned relocations of populations are already underway in anticipation of future climate impacts (de Sherbinin et al., 2011), while the government of Indonesia decided in 2019 to move its capital city, Jakarta, in anticipation of future floods.

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A social tipping point is reached when climate impacts push a society towards a state of instability

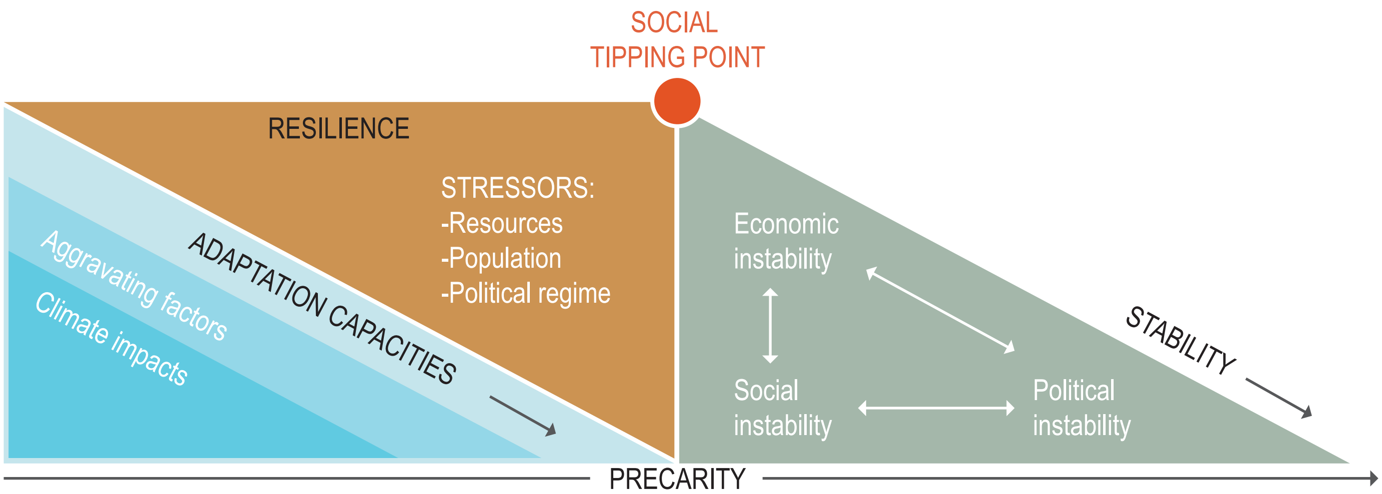

Figure 8.11 | A social tipping point is reached when climate impacts push a society towards a state of instability. Those climate impacts are typically aggravated by economic, social and political stressors that reduce adaptive capacity and overwhelm its resilience. Once a social tipping point is reached, a society may experience mutually reinforcing states of economic, social and political instability, leading to cascading disruptions such as livelihood insecurity, migration and displacement, food insecurity, impoverishment, civil and political conflict, and change of political regimes.

Shifting livelihoods is a typical adaptation strategy but can also reflect a social tipping point if this shift affects the community as a whole. Therefore, social tipping points should not be confused with the carrying capacity of a community. While the carrying capacity of a community is a fixed, predetermined limit, social tipping points are dynamic and constantly evolving under the influence of different social and political factors, such as solidarity networks or governance mechanisms. The carrying capacity of a community can evolve over time, but remains a static concept, unlike social tipping points. Social tipping points have also been applied to adaptation, through the concept of adaptation tipping points, which indicate how much pressure a socio-environmental system is able to absorb (Ahmed et al., 2018). Beyond the adaptation tipping point, the efficiency of adaptation responses will be limited, and can even transform into maladaptive options.

8.4.5 Projected Risks for Livelihoods and Consequences for Equity and Sustainability

8.4.5.1 Projected Risks for Livelihoods

There is *robust evidence* with *high agreement* that future climate change impacts will have severe consequences for poor households, particularly those situated in areas highly exposed to actual or future climate hazards, such as low-lying coastal communities (see also Cross-Chapter Paper 1), drylands (see also Cross-Chapter Paper 3) or remote mountain (see also Cross-Chapter Paper 5) settlements with low levels of connectivity to markets, poor infrastructure and high dependence upon poor quality natural capital (Barbier and Hochard, 2018; Gioli et al., 2019). While livelihoods operate in a dynamic context characterised by multiple interacting structures and processes, climate change can act as a risk multiplier. When current livelihood activities become untenable as a result of both long trends and short-term shocks and climate hazards (e.g., droughts, floods), shifting livelihoods is a common response and, in many cases, can be unavoidable due to the negative consequences of these climate hazards on specific livelihood capitals (see Section 8.5). Such shifts can involve a change in livelihood activities (e.g., continuing in agriculture but growing different kinds of crops), or a change to broader livelihood strategies (e.g., diversifying into handicrafts or paid employment, specialising in one particular activity, or migrating, seasonally or permanently, in search of other livelihood opportunities) or even an entire change of the livelihood activity, for example, abandoning agriculture altogether (McLeman and Smit, 2006; Black et al., 2011). Shifting livelihoods can therefore involve mobility or take place *in situ*. Some of these shifts also lead to social tipping points.

8.4.5.1.1 Proactive and reactive livelihood shifts and their relevance for future risks due to climate change

Livelihood shifts may also take place proactively as new opportunities emerge and reduce climate impacts by providing buffers of financial capital. For example, Hirons (2014) assesses artisanal and small-scale mining as an emerging livelihood opportunity in Ghana. Evidence challenges the popular assertion around the idea of wealth seeking for short-term profit and reveals an alternative scenario whereby artisanal and small-scale mining can be a poverty-driven activity, particularly in areas in which agricultural employment has not delivered sufficient income or where crops are highly exposed and sensitive to climate change impacts. Income from new livelihood activities can support recovery following specific events (major flooding or drought) linked to climate hazards and climate change. Livelihood shifts therefore take place in a highly dynamic and heterogeneous context. Another example comes from the Small Lake Chad, Republic of Chad studied by (Okpara et al., 2016a). Fluctuating water levels linked to seasonal flood pulses and droughts were shown to link closely to livelihood dynamics.

Lake drying led to new adaptive behaviours based on seasonality (e.g., migration of herders to different areas of the lake shore to access water resources, in line with more predictable seasonal changes), as well as linking to opportunism supported by climate change impacts. For example, during times of lake flooding, new opportunities for fishing opened for people that were otherwise operating primarily as pastoral or agricultural households. However, these kinds of livelihood shifts remain largely reactive and can bring negative as well as positive impacts. In the Lake Chad case, it resulted in social clashes between different groups, while in other examples from Tanzania, livelihood shifts towards extensification of farming led to deforestation (Suckall et al., 2014), which could constitute a maladaptive shift. Such findings have important implications for the types of government and institutional support that can enable livelihood shifts and highlight the need to consider trade-offs for climate change mitigation, as well as with other adaptation options (see Section 8.6).

8.4.5.2 Future risks, vulnerabilities, differentiated inequalities and livelihood shifts

Overall, there is *high agreement* that future climate change impacts are going to worsen poverty and exacerbate inequalities within and between nations, with projections that by 2030 these will increase significantly (Olsson et al., 2014; Hallegatte and Rozenberg, 2017; Roy et al., 2018). In addition, the COVID-19 pandemic and consequences linked to measures to reduce the spreading of the virus are *likely* to increase poverty, particularly in regions already facing high levels of vulnerability and poverty (Laborde et al., 2020b; Sumner et al., 2020).

Key risks due to future climate change, exposure and vulnerability are difficult to assess and are based on evidence from the past and *likely* future vulnerabilities and livelihood challenges. The assessment of Representative Key Risks (see Section 16.5.2.3.4) underscores that risks to living standards are potentially severe as measured by the magnitude of impacts in comparison to historical events or as inferred from the number of people currently vulnerable (see in detail Chapter 16). Table 8.4 provides an overview of what is known in the literature assessed about future risks, inequalities and particularly future vulnerabilities, including potential challenges for climate justice and adaptation barriers. For example, barriers for gender, ethnicity and class have been addressed for a long time yet need substantive intervention. Gender, along with many other structural inequalities (Table 8.4) that are deeply rooted, pose future threats to people and groups in vulnerable situations from, for example, the loss of land or assets, exposure to extreme events and so on. These people will also *likely* be highly exposed to future climate risks unless there are significant and new avenues for action on climate change now. For example, recent studies suggest that the total population of all countries classified

Table 8.4 | Summary of interlocking categories differentiation future risks, vulnerabilities, inequality and adaptation

Future risks	Inequalities	Future vulnerabilities, future livelihood, future exposure (examples)	References
Increasing risk of displacement and damage to women and girls in floods	Gender inequality leaves women and girls hidden, forgotten and exposed, resulting in displacement impacts and limited resources, including social capital and increasing risk of human trafficking.	Increasing future vulnerability of women and girls due to high hazard exposure; gender differentiated vulnerability to urban flooding (in India); increasing risk of human trafficking associated with exposure to future extreme events.	(Singh, 2020; CCB GENDER in Chapter 18)
Increasing risks of exacerbating inequalities and tensions	Differentiation based on ethnicity and race leads to groups in society being less visible, with fewer rights, particularly for livelihoods that expose them to extremes. Unequal access to adaptation opportunities and benefits.	Increasing future vulnerability of Indigenous Peoples due to exposure to extreme events. Communities of colour are *likely* to be exposed to increased climate change impacts, e.g., differentiated health impacts on black and Hispanic communities heat-related mortality rates and poverty for neighbourhoods in New York City.	Section 8.3; (Hsu et al., 2021; Section 8.3)
Increasing risk of loss of homes and assets in the case of floods	Class differences in exposure and awareness of flood risks. Lower caste disproportionately impacted by climate change.	Increasing differentiated exposure among classes to events such as flooding.	(Jones and Boyd, 2011; Fielding, 2018)
Risks to loss of lives in cases where there is no agency	Religious beliefs impact experience of climate change.	Increasing vulnerability to climate change among different religious groups.	(Schuman et al., 2018)
Risk of premature mortality, risk of loss of livelihoods in employment	Age and ageing populations. Elderly and young are disproportionately impacted by climate change, e.g., heatwave in France 2003 and Japan 2018. Youth underemployed or in vulnerable livelihoods could be vulnerable to climate-related risks, which adversely affects the economy.	Increasing future vulnerability among elderly, underage youth and children vulnerable to increasing risks of health impacts of pollutants, floods or heatwaves.	(Hsu et al., 2021; Section 8.3)
Risks to mobility in a climate extreme	People with disabilities, for instance; evidence emerging in the disaster risk reduction and humanitarian sector.	Increasing risks to people with disabilities, who are disadvantaged when exposed to extreme events.	(King et al., 2019)
Risks of isolation for communities remote from centres of power	Geographical exposure. The location of people and societies within a particular territory is a determinant of inequality e.g., disruptions to food supplies to the Caribbean when there are climate extreme events.	Increasing risk and exposure among communities remote from urban centres, far from resources and exposed to climate impacts.	Section 8.3; Cross-Chapter Box GENDER in Chapter 18
Risks of food insecurity	Differentiation of asset/ownership/access among groups where status is unclear.	Increasing risks to tenurial landless. If tenurial status is unclear, groups may experience loss of land and displacement.	Section 8.2; Cross-Chapter Box GENDER in Chapter 18.

as most highly vulnerable is projected to grow significantly. A study using five vulnerability categories globally concludes that the total population of all countries with very high vulnerability (see Figure 8.6) is projected to increase from 2019 numbers approximately by 102% by 2050 (i.e., roughly double) and 257% by 2100, while the population of all countries with very low vulnerability is projected to decrease by 9% by 2050 and 17% by 2100 (based on UN medium probabilistic projections). Another study estimates that the total population of all countries classified at most vulnerable (top two categories; using seven vulnerability categories globally) is predicted to increase by 82% by 2050 and 192% by 2100. In contrast the population of all countries classified as least vulnerable (bottom two categories) is projected to only increase by 9% by 2050 and 1% by 2100 (see in detail UN-DESA, 2019; Birkmann et al., 2021a; Birkmann et al., 2022).

That means that, based on current population growth estimates and if vulnerability levels are not reduced significantly, more people will be living in more vulnerable context conditions in the future compared to those living in less vulnerable contexts. This is independent of the development of climatic hazard exposure. If significant reductions of vulnerability are achieved, this projection will change. However, the vulnerability and poverty of some regions and countries, such as Afghanistan or Haiti, has proved over decades to be persistent. Consequently, the estimated future population growth is another factor that points towards the urgent need to reduce vulnerability and to narrow the adaptation gap.

While future adaptation options can also encompass measures or tools that emerge in future, most of the future adaptation options and their relevance for reducing vulnerability, poverty and inequality are known. Evidence exists that the importance of social networks that organise social protection and leverage resources in terms of reducing risks to climate change is increasing, particularly for most vulnerable people or groups in countries that have limited social security measures in place.

8.4.5.3 Future Limits to Adaptation

Local perceptions of losses from adverse effects of climate variability and change can help to assess the magnitude of impacts that individuals and communities have not been able to cope with or adapt to (James et al., 2014; Barnett et al., 2016; McNamara and Jackson, 2019 McNamara et al. 2021, Mecheler et al. 2020).

The IPCC Special Report on a 1.5°C warming world shows with *high confidence* that for the Arctic systems, if average temperature increase exceeds 1.5°C by the end of the century limits to adaptation and residual impacts will be exceeded, compromising people's livelihoods (Ford et al., 2015; O'Neill et al., 2017b; Roy et al., 2018; Hoegh-Guldberg et al., 2019a). The loss and degradation of the Amazon forest with global warming temperatures beyond 1.5°C is another clear example of irreversible loss, with significant impact to people's livelihoods today and in the future (Hoegh-Guldberg et al., 2018; Roy et al., 2018). Moreover, the L&D from climate change impacts are also felt heavily by women, children and elderly given the intersectionality with socioeconomic and gender inequalities (Li et al., 2016; Roy et al., 2018). For instance, gender and wealth inequality offers challenges to scale up the Maasai pastoralist community autonomous adaptive practices (Wangui and Smucker, 2018). This study found that most female-headed and poorest households could not access the land, water for irrigation and financial assets required to access adaptive practices that are available in the wider community. Consequently, future impacts of climate change are *likely* to increase rather than decrease inequality based on already observed impacts on adaptive capacities that constrain future adaptation options, particularly for the poor (Roy et al., 2018).

8.4.5.4 Future Livelihood Challenges in the Context of Risks and Adaptation Limits

The climate change risks in this section are addressed through the lens of livelihoods, human, food, water and ecosystem security, building on key impacts and risks since AR5 (Oppenheimer et al., 2014) and key findings from SR1.5°C (Hoegh-Guldberg et al., 2018; Roy et al., 2018), SROCC (IPCC, 2019b), and SRCCL (IPCC, 2019a). The AR5 WGII risk tables (IPCC, 2014b), updated in SR1.5°C (Roy et al., 2018) offer an interesting entry point as they show *high confidence* on key observed impacts and limits to the adaptation of natural and social systems that are compounded by the effects of poverty and inequality on water scarcity, ecosystem alteration and degradation, coastal cities in relation to sea level rise, cyclones and coastal erosion, food systems and human health (Hoegh-Guldberg et al., 2018; Roy et al., 2018). As a consequence, climate change risks pose substantially negative impacts on climate-sensitive livelihoods of smallholder farmers, fisheries communities, urban poor, Indigenous Peoples and informal settlements, with limits to adaptation evidenced by the loss of income, ecosystems and health, and increasing migration (Roy et al., 2018). The compounded effects of socioeconomic development patterns and climate change impacts are worst in climate-sensitive ecosystems in the Arctic and SIDS (Roy et al., 2018). The future risks to these climate-sensitive ecosystems and livelihoods are potentially severe given their current high exposure to climate hazards, and high number of vulnerable of people exposed for example in the SIDS (see also Chapter 16; Ahmadalipour et al., 2019; Liu and Chen, 2021). Residual losses then may be unavoidable for some ecosystems and livelihoods affecting the vulnerable groups of people and countries as consequences of structural poverty, socioeconomic, gender and ethnic inequalities, that marginalise and exclude and limit the development of adaptive capacity for future changes (Olsson et al., 2014; Roy et al., 2018).

In SIDS, key risks are represented by losses of livelihoods of coastal settlements, ecosystem services, infrastructure and economic stability, exhibiting limits to adaptation in the face of local people's coping strategies capacity (Hoegh-Guldberg et al., 2019a). There is *high confidence* that sea level rise in SIDS combined with extreme flooding events will threaten the future livelihoods of coastal communities (Hoegh-Guldberg et al., 2018; Roy et al., 2018).

In the Global South, the increasing heat associated with warming global temperature represents an important risk due to losses in labour productivity, crop failures and livelihood security. These involve economic losses and health effects, as well as increasing deaths that are anticipated to have significant implications for poverty, inequality and equity (Carleton, 2017; Roy et al., 2018). The increasing temperature, droughts and excessive rain lead to successive crop failures and reduced productivity that are affecting children's growth and health in developing countries (Hanna and Oliva, 2016). Likewise, the expected global temperature increase by the end of the century will have devastating health consequences for children, associated with sea level rise, heatwaves, affecting the incidence of malaria and dengue, and malnutrition, especially in Asian (Ghosh et al., 2018) and African countries, such as Chad, Mali, Niger and Somalia (Hanna and Oliva, 2016; Ghosh et al., 2018; Clark et al., 2020).

The incidence of floods also increases the occurrence of diseases (e.g., diarrhoea and respiratory infections) and undernutrition in children living in informal settlements and slums in Asia (Ghosh, 2018) and Africa (Clark et al., 2020). Women and children are currently bearing the worst impacts of climate hazards, and are unable to move due to assigned gender roles to avoid flooding risks in highly vulnerable slums in Bangladesh. This results in poor living conditions and causes the women emotional distress (Ayeb-Karlsson et al., 2020). This region experienced severe floods associated with death, injury, infectious disease, mental and emotional stress and cultural disruptions—dimensions of non-economic losses that are often not accounted for in disaster relief policies (Chiba et al., 2017) and these greatly influence the ability to build adaptive capacities for future hazards (Roy et al., 2018). In the same way, risks to female-headed households that have insecure tenure rights are greater. This group was the most affected by flooding in 2018 in Dar es Salaam, Tanzania, costing 3–4% of the country's GDP and affecting 4.5 million people (Erman et al., 2019).

In the Himalayas (part of the Hindu Kush Himalaya, HKH) temperature warming is expected to increase up to 2°C by 2050 (*high confidence*), increasing flooding and bringing larger risks to food and water security for mountain communities that are already highly vulnerable given limited livelihood options and supporting infrastructure in these regions (Mishra et al., 2017). In Nepal, agriculture-orientated livelihoods are reported to be negatively affected by an increase in landslide frequency (92.6%) and intensity (97.3%) over a 20 years period (1996–2016) (van Der Geest and Schindler, 2016). The catastrophic landslide in 2014 caused material losses associated with loss of crops and land to poor households that were 14 times greater than their annual gains. The NELD losses were emotional distress and fear of new event occurrence, showing that poorest households may not fully recover following an extreme event. This example is indicative of the representative future climate risks to these populations. Livelihood diversification is commonly adopted by poor households and smallholders in Nepal to reduce the impacts of extreme rainfall and landslides. However, there are limits to these strategies given poor household infrastructure that challenge risk reduction, as a result, it is expected that migration to neighbouring countries as Bhutan or India will increase (van Der Geest and Schindler, 2016).

Expected future risks to vulnerable communities and Indigenous Peoples include losses across a range of impacts. A larger household comparative analysis across mountain regions in Africa, Asia and Southeast Asia shows that more than 60% of the population reported losses from residual impacts concerning droughts, floods, cyclones, sea level rise, glacier retreat and desertification, despite autonomous adaptation involving changing food consumption and formal aid from the government (Warner and Van der Geest, 2013). Among Indigenous Peoples in the Global South, for example in the Brazilian Amazon, Australia and Botswana, locally autonomous adaptive measures were not sufficient to avoid significant losses (some irreversible in case of lost habitats). The barriers and insufficient adaptive capacities are also intrinsically linked to historical marginalisation and vulnerability of the population in these countries (Maru et al., 2014).

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In the Arctic, warming temperature and sea level rise constitute key risks to the loss of identity and culture of Indigenous People. This is associated with migration and relocation due to livelihood deterioration resulting from coastal erosion, permafrost thaw and reduced fisheries productivity (Roberts and Andrei, 2015; Roy et al., 2018). These risks and losses often encompass various non-economic losses, such as the loss of identity, that cannot be replaced or economically compensated (see also Section 8.3.5).

Likewise, in the Amazon basin, climate change hazards of severe droughts and floods (*high confidence*) (Cox et al., 2004; IPCC, 2019a) are revealing limits to adaptation among the majority of riverine communities and smallholder farmers with residual impacts associated with losses of income, fisheries and agricultural productivity, as well as affecting non-economic livelihood dimensions, such as the ability to attend school and losses of place and identity through forced migration (Maru et al., 2014; Pinho et al., 2015; Lapola et al., 2018). Furthermore, the expansion of the agricultural frontier and construction of large dams to supply energy needs in the Amazon basin are amplifying the vulnerabilities and reducing future adaptive capacities of smallholders and the fisheries communities to climate risk (Bro et al., 2018; Castro-Diaz et al., 2018). It is expected that a global temperature warming level of 2°C by 2050 in the Amazon will lead to a significant reduction of water flow in major rivers leading to further food and water insecurity (Betts et al., 2018). This is affecting forest- and river-dependent livelihoods in the region (Box 8.6; Lapola et al., 2018).

The glacier retreat associated with the increase in global warming temperature has also shown losses that are permanent and related to a sense of belonging and cultural heritage for glacier countries. The most negative livelihood impacts are experienced by poor households in the Peruvian Andes and Himalayas (Jurt et al., 2015). The risks for smallholder livelihoods in glaciated regions are expected to increase as the shrinking glaciers result in increased water competition, crop failure and extreme flooding (Kraaijenbrink et al., 2017). For example, in Bhutan adaptive measures such as changing crops, developing irrigation channels and sharing water among community members are still insufficient to avoid L&D associated with the dramatically reduced water availability (Kusters and Wangdi, 2013; Warner and Van der Geest, 2013). In high-mountain regions, the intersections of agro-pastoralist marginalisation, difficulty of access and ecological sensitivity contribute to residual impacts associated with extreme climate hazards, which can lead to irreversible losses and challenge poverty reduction efforts (Mishra et al., 2019).

In semiarid West Africa, longer-term local adaptation is in place to help poor households deal with severe droughts. This involves reducing household and cattle water consumption, planting drought-tolerant crops and adopting integrated crop–livestock production for efficiency, with migration being either seasonal and or permanent. These measures are mostly effective (van der Geest et al., 2019). Likewise, in Ethiopia, Northern Kenya and Senegal, adaptation has advanced with external government and non-government organisation (NGO) support (Schäfer et al., 2019). This includes technological innovations and insurance for households (Schäfer et al., 2019), but is not enough to prevent losses in already impoverished households (Schäfer et al., 2019).

There is *robust evidence* that future risks to climate-sensitive livelihoods, such as agriculture, livestock and fisheries are amplified by gender, age, wealth inequalities (Wangui and Smucker, 2018), ethical background and geography (Piggott-McKellar et al., 2020; Thomas and Benjamin, 2020), as well as by ecological thresholds that challenge autonomous adaptation among vulnerable disadvantaged communities mostly in the Global South (Roy et al., 2018; Mechler et al., 2020).

The assessment also points towards the fact that there are strong linkages between national-level vulnerability (e.g., Figure 8.6) and individual vulnerability at household or livelihood scale. Various disadvantaged and marginalised groups or communities within a society are significantly constrained in terms of the ability to build adaptive capacities for future climate change threats due to limited access to resources or government support for planned adaptation. Consequently, these linkages between regional, national and local vulnerability need more attention in research and practical adaptation strategies (vertical integration).

The next section discusses how risks emerge as a result of the failure in adaptation or failure to implement it, with particular attention to risks that are impossible to adapt to and lead to inevitable L&D among poor households, livelihoods and countries.

8.4.5.5 Maladaptation as a Projected Future Risk Particularly for the Poor and Marginalised

There is increasing evidence that maladaptation can lead to future risks to socio-ecological security. Adaptation measures focusing on short-term action can lead to adverse longer-term impacts to livelihoods and failures to address transboundary scales to avoid negative consequences for social and ecological systems (Warner and Van der Geest, 2013; Roy et al., 2018; Mechler et al., 2019a; see also Section 5.13.3). Hence, maladaptation can intensify and even accelerate future risks as a result of climate change mitigation and adaptation policies when responses to climate change hazards are embedded within business-as-usual development approaches (Work et al., 2019). For instance, in Cambodia, the conventional development strategies intertwined with climate change mitigation and adaptation initiatives are increasing the probability of maladaptive outcomes in the context of high informality, and conflicts among poor farmers exposed and vulnerable to flooding (Work et al., 2019). The potential for maladaptation emerges from the vulnerability of precarious living conditions of informal poor farmers, not accounted for in climate mitigation and adaptation strategies for irrigation, protected areas

Box 8.6 | Social dimensions of the Amazonia forest fires and future risks

The Amazon ecosystem, together with the Arctic, is listed as the first of five IPCC Reasons for Concern due to climate change, given the *high confidence* level that different temperature warming and GHG emissions will pose significant risks that threaten these unique ecosystems (O'Neill et al., 2017b; Roy et al., 2018). In addition to the scientific evidence, a resurgence of cross-national collective expressions about the fate of the Amazon forest, Indigenous Peoples and traditional communities, in the context of an unprecedented climate crisis and sustainable future, have gained pronounced importance. On 19 August 2019, the skies of Sao Paulo State were dark by 3 pm due to the formation of a 'smoke corridor' associated with the extensive burning of the Amazon forest (Seymour and Harris, 2019). The fire outbreaks were a consequence of multiple factors related to political, social, economic and environmental scenarios concomitant with the weakening of environmental governance, such as control and monitoring of deforestation and fire incidences programmes (Escobar, 2019; Seymour and Harris, 2019). The deforestation rate and incidences of fire are both increasing in the Amazon of Brazil, Colombia and Peru (Seymour and Harris, 2019). Accordingly, 2019 registered an increase of 60% in the cumulative fire count in Brazil, Bolivia and Peru in comparison with the same period in 2018, and a 12% increase in comparison with the same period in an extremely dry year in 2016 (GFED, 2019). In this context, looking at this case study through the lenses of poverty, inequality and the SDGs, it addresses the compound effect of climate and land use change in the Amazon forest fires and its cascading impacts and risks on the social domain in the region. There is evidence that both climate and land use change impacts and risks are disproportionately borne by poor and vulnerable ethnic groups, remote rural communities and poor urban households in the Amazon (Pinho et al., 2015; Brondízio et al., 2016; Mansur et al., 2016; Pinho, 2016).

Fires are not a natural phenomenon in the Amazon region (Bush et al., 2004; McMichael et al., 2012); they are used for food security, hunting and religious rituals by Indigenous Peoples and traditional communities (Hecht, 2006; Carmenta et al., 2019; da Cunha, 2020), and also as a widespread technique for land clearing for small- and large-scale farms for agriculture (Morello et al., 2019). The dramatically increased forest burning observed in the Amazon recently are the result of illegal land grabbing, the small-a and large-scale cattle ranching sector and agribusiness practices coupled with loosening of land tenure policies and decision makers' neglect of deforestation and burning monitoring data (Nobre et al., 2016; Lovejoy and Nobre, 2018; Leal Filho et al., 2020a). The fire outbreaks intensified substantially to the point that, in August 2019, there were approximately 3500 fires in 148 Indigenous territories (DETER and INPE, 2019; ISA, 2019). Although most of the burning in the Legal Amazon in Brazil occurred on private land of medium and larger sizes (about 67%),

Box 8.6 (continued)

around 33% was observed within Indigenous territories and protected areas called conservation units (UCs) (DETER and INPE, 2019; ISA, 2019). In 2019, 40% of the deforestation occurred in public forests, which encompasses undesignated forest lands, Indigenous territories and UCs. This deforestation came accompanied by fires: 18% of the 2019 fires occurred on undesignated lands, 7% on Indigenous territories and 6% on UCs, where many traditional populations live (Alencar et al., 2020). During 2019, 46% of the deforestation and 52% of the fires occurred on private rural properties and settlements, respectively, where legal accountability for these crimes is possible. The 2020 deforestation rate increased by 47% and 9.5% compared to 2018 and 2019, respectively, and was the highest in the decade (Silveira et al., 2020). The clear-cut inside indigenous territories more than doubled from 2018 to 2019 (Brasilis, 2021) and, despite it decreasing from the 2019 rate, during 2020 it was the highest since 2008. On average, at least 50% of yearly active fires were within 5 km of deforested areas in the same year, reaching 74% during 2019 (Silveira et al., 2020). This means, that fires and deforestation have an increased threat to Indigenous populations (Oliveira et al., 2020), particularly during the year 2020 and currently in 2021, since COVID-19 and air pollution from agricultural burning greatly impacts respiratory health in the Amazon (Morello, 2021).

Health impacts, economic and non-economic losses

The health impacts and economic losses estimates are not homogeneously gathered for the entire Amazon basin countries, but some recent evidence associated with this knowledge gap shows the magnitude of the forest fire impacts, as well as where they spatially occur and who are the most affected by it. Fires associated with deforestation in the Amazon have been related to 1065–4714 deaths annually in South America (Reddington et al., 2015). The recent fires in the Amazon basin are directly affecting 24 million Amazonians with the worst impacts felt by children and the elderly (Machado-Silva et al., 2020), Indigenous Peoples and traditional communities (Fellows et al., 2020). Children under 5 years old and the elderly in rural areas are respectively 11 and 22 times more affected by the smoke from fire outbreaks and temperature increase in the Amazon (Machado-Silva et al., 2020).

In Acre State, the fire incidence coupled with extreme droughts in 2005 and 2010 led to an increase—from 1.2% to 27%—in hospitalisations of children (under 5 years) due to respiratory diseases (Smith et al., 2015). The same evidence was found among the rapidly deforested areas known as the 'Arc of Deforestation', with a dramatically higher number of respiratory diseases recorded, mainly in children under 5 years (do Carmo et al., 2013). There is also evidence for interlinked dynamics between deforestation, urbanisation and incidence of fire episodes providing an appropriate environment for *Anopheles darlingi* vector propagation and the increased incidence of malaria in the region (Hahn et al., 2014). In the 2005 drought, burning in Acre alone recorded 400,000 people affected and the loss of 300,000 ha of forest with direct costs of USD 50 million (Brown et al., 2006). In 2010, the fires during the drought were approximately 16 times larger than those in the meteorologically normal years (Campanharo et al., 2019). The estimated total economic loss in 2010 was about USD 243.36 ± 85.05 million, representing 9.07 ± 2.46% of Acre's GDP (Campanharo et al., 2019). The economic and non-economic losses associated with the impacts of climate change and future risks of fire outbreaks on native food crops (açai, guaraná), livelihoods, tourism, medicinal and spiritual sites, culture, migration patterns, place-based attachments, emotional and mental distress among the most affected and vulnerable population as Indigenous Peoples and traditional communities are still to be fully estimated for the region (Pinho et al., 2015; Brondízio et al., 2016). Also relevant is a trend of Amazonian forest fires spreading from the southern Brazilian Amazon to Bolivia and Peru, indicating that transboundary burning increases are systemic and will lead to extensive economic losses of wild crops, infrastructure and livelihoods, requiring a landscape level approach for deforestation and fire management and control (Kalamandeen et al., 2018).

Future vulnerabilities and risks for Indigenous Peoples and traditional communities

It is expected that by 2030 the incidence of extreme droughts in the Amazon will increase the costs of the health sector associated with treatment costs of respiratory diseases (20–50%) and malaria incidence (5–10%). This will also incur a high social cost as people will less able to carry out their livelihoods (Lapola et al., 2018). It is also expected that the droughts will accelerate and intensify rural (traditional communities and Indigenous Peoples) migration to urban centres where migrants living standards are expected to decrease once they will occupy marginal areas within larger urban centres (Lapola et al., 2018).

In terms of adaptation and risk reduction, priority should be given to strengthening multi-scale governance and partnerships among different private and public actors. Policies at national and sub-national levels are needed, such as control strategies to reduce deforestation and fire incidence, demarcating new Indigenous territories, payment for ecosystem services (REDD+) and investment in traceability for commodity production chains are needed (Morello et al., 2017; Scarano, 2017; Carmenta et al., 2019; Seymour and Harris, 2019). The increase in global temperature level up to 2°C will exacerbate food and water insecurity in the Amazon (Betts et al., 2018; Hoegh-Guldberg et al., 2018) (*medium confidence*). Thus, curbing fire incidence and deforestation rate will make it easier for Indigenous Peoples, traditional and vulnerable populations to reach the SDGs, especially in terms of reducing poverty (SDG1), improving food security (SDG2), improving well-being and health (SDG3) and protecting terrestrial ecosystem (SDG15) (Roy et al., 2018).

Table 8.5 | Categories of maladaptation as future risk and examples of outcomes and world regions based on literature assessment evidence.

Categories of risks to maladaptation	Examples of outcomes
Uncertainty (climate events)	Lack of knowledge of future climate extreme events hinder adaptation actions for the poor
Inequalities	Exclusion of rights and access, and benefits of adaptation
Sustainability	Further ecological degradation and biodiversity loss
Informality	Reinforced vulnerabilities of the poor and marginalised populations
Poverty	Increased vulnerabilities and risks of maladaptation
Scales (temporal and spatial)	Negative trade-offs across short- and longer-term decisions, as well as transboundary issues resulting in increased likelihood of maladaptation
Regional evidence	South Asia and Southeast Asia (Bangladesh, India, Indonesia, Maldives, Nepal and Thailand) (6) **
	Africa (Ethiopia, Ghana, Malawi) (3)
	Central America (1)
	Global South (2)
	Global (1)

Notes:
Confidence level ***medium* (5–9 papers).

management and reforestation projects funded by multilateral donors (Work et al., 2019). As a consequence, losses emerge despite actions to prevent adverse impacts, and maladaptation instead becomes a vector of increased vulnerability for poor and vulnerable communities (Mechler et al., 2019a).

The maladaptation outcome also emerges as a failure of adaptation. In Ghana, poor farmers, facing crop yield failure during severe droughts further exacerbated by water use for irrigation have diversified their livelihoods (e.g., selling firewood for charcoal production).This is a form of maladaptation that can further increase their vulnerability to climate risks, compromising food production, income generation and sustainability (Antwi-Agyei et al., 2018b). In Cambodia, governmental adaptation strategies focusing on reforestation and conservation measures are eroding local biodiversity, and crop irrigation strategies are compromising scarce water resources and also excluding poor farmers, who are susceptible to flooding, from decision making and benefits (Work et al., 2019). Likewise, in Ethiopia, efforts of adaptation programmes to address droughts contribute to current unsustainable development trajectories among pastoralist communities, resulting in charcoal production, overgrazing, migration, conflict with other groups and marginalisation of livelihoods (Magnan et al., 2016). In the Sudan, maladaptation outcomes for the poor population are linked to a dependency on a war economy and post-conflict power dynamics that are and will continue to affect sustainability and equity in the context of drought incidence (Young and Ismail, 2019).

In Bangladesh, an expensive coastal climate-resilient infrastructure project could potentially increase the vulnerability of urban poor as they will remain in areas that are highly susceptible to flooding brought by sea level rise (Magnan et al., 2016). In Central America, the lack of assessments of future climate variability on crop yield scenarios, coupled with lack of policymakers to incorporate autonomous local adaptation practices, could lead to an unsustainable trajectory for local communities and risk of maladaptation (Beveridge et al., 2018). In Bhutan, small-scale rice farmers have adopted water-sharing measures to avoid the impacts of reduced and uncertain precipitation levels associated with monsoons. However, these measures led to disruptions in social cohesion as conflicts over water sharing escalated (Mathew and Akter, 2015). In the same region, local governments prioritise the glacier retreat as a perceived risk to flooding from dams, but overlook the slow and gradual impact of the deficit in precipitation that is negatively affecting rice productivity (Mathew and Akter, 2015). In Burkina Faso, a region highly impacted by severe droughts, local communities have become less able to cope with droughts given a decline in cultural pastoralism and increased dependence on crops (van der Geest et al., 2019).

As seen, maladaptive responses to droughts, sea level rise and flooding are negatively affecting poor farmers, pastoralists, and rural and urban informal workers, increasing loss of crops, infrastructure, income, conflict and migration. Given the high risks of maladaptation to poor people this agenda should be given priority by development and planning sectors (Magnan et al., 2016). The categories in Table 8.5 also represent important future compounding and complex risks that can emerge due to maladaptation (*high confidence*).

8.4.5.6 Future Challenges for Vulnerability and Livelihood Security due to Adaptation Limits of People and Ecosystems

Communities and livelihoods with higher exposure to the risks posed by climate change and with lower adaptive capacity will experience a higher burden of L&D in comparison to others (Tschakert et al., 2017). In Asia (Indonesia) and the Arctic region, a decline in marine fisheries by approximately 3 million tonnes per degree of warming is expected to have severe negative regional impacts, especially on Indigenous People (Cheung et al., 2016).

It is projected that climate change impacts on the incidence of disasters will push 122 million additional people into extreme poverty with global temperature increase by 2030 (Hallegatte and Rozenberg, 2017; Hoegh-Guldberg et al., 2018; Jafino et al., 2020). It is also expected that around 330–396 million people will experience lower agricultural yields at warming beyond 1.5°C (Hoegh-Guldberg et al., 2018), most of them in South Asia and sub-Saharan Africa (Chapter 16; Roy et al., 2018; World Bank, 2019a). There is also *medium evidence* that tens to hundreds of millions of people that are dependent upon climate-sensitive livelihoods could out-migrate as a consequence of global temperature increasing, mostly in Africa, Asia and Latin America—posing additional risks to unsustainable urbanisation and group conflict (Chapter 16; Hoegh-Guldberg et al., 2018; Roy et al., 2018).

The multi-intersectionality of inequalities (socioeconomic, caste, ethnicity, among others) and marginalisation, result in differential capacity to avoid risks, which is particularly limited amongst the most vulnerable communities who are in, or at the brick of falling into, poverty traps, which then also affects future generations (Hallegatte and Rozenberg, 2017; Roy et al., 2018; Tschakert et al., 2019). For instance, the poorest communities in the Global South, who are dependent upon thriving ecosystems for health, food, water and energy, are disproportionately more exposed to temperature extremes and droughts, compromising food and water security (Byers et al., 2018). There are also inequalities associated with opportunities to adapt to risks that are unevenly distributed among global regions, with richer and more equal societies in the Global North presenting superior capacities than Global South communities, sectors, ecological systems and species, where the most detrimental climate change impacts are experienced (Hoegh-Guldberg et al., 2018; Roy et al., 2018). The climate-sensitive livelihoods of poor and vulnerable communities in the Global South, and the unprecedented ecosystems losses are examples of multiple limits of adaptation that emerge simultaneously and are also linked to the differential access to assets and resources, such as physical (propriety, income), social (health, age, education) cultural (shared community values and norms, ethnicity), ecological (linked to land use change and productivity) and institutional (market, policies and governance) (Roy et al., 2018; Hoegh-Guldberg et al., 2019a; Olsson et al., 2019). The adaptation limits emerge mostly in countries in Global South, and disproportionately affect specific groups, with high poverty incidence, that are constrained by inadequate financial resources and institutional instruments (Tian and Lemos, 2018; Volpato and King, 2019), including lack of understanding and preparedness of the risks posed by climate change (Ayeb-Karlsson et al., 2016; Maharjan et al., 2020).

In other situations, adaptation limits to household livelihoods emerge from ecological thresholds associated with global warming temperatures, such as deterioration of land and water resources, extinction of species and biodiversity that can lead to systemic crop failures, declining fisheries productivity and water availability and substantial risks to households' livelihoods (Roy et al., 2018). However, it is also important to note that limits are associated with development, technology and cultural norms and values that can change over time to enhance or reduce the capacity of systems to avoid limits (Adger et al., 2014; Roy et al., 2018). It could also include aspects of maintaining security of air or water quality, as well as equity, cultural cohesion and preservation of livelihoods (Adger et al., 2014; Tschakert et al., 2019). For soft limits, however, adaptation options could become available in the future through changing attitudes or values or as a result of innovation or other resources becoming available to most vulnerable and poor actors, households and countries. However, when compounded with lack of finance, and high costs associated with disasters, poverty and environmental degradation, soft limits could become hard ones in the future (see Figure 8.5; Gracia et al., 2018).

Table 8.6, built from SR1.5°C (Roy et al., 2018), illustrates how ecological thresholds and socioeconomic determinants are linked to soft and hard adaptation limits and what the potential and magnitude of livelihoods risks will be in the future. For instance, in the SR1.5°C (IPCC, 2018b) and Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) (IPCC, 2019b), hard limits are expected with global warming beyond 1.5°C associated with the loss of coral reefs, that will lead to substantial loss of income and livelihoods for coastal communities (Roy et al., 2018; Mechler et al., 2019b; Oppenheimer et al., 2019). The loss of coral reefs around the remote islands of Boigu in Australia is affecting low-lying communities facing financial, institutional (Evans et al., 2016) and cultural place-based attachment adaptation limits (McNamara et al., 2017). Another hard limit to adaptation with implications for income, and culture- and place-based livelihoods is related to the sensitivity of fish to global temperature increase, with losses in fish reproduction expected to be 10% (SSP1–1.9) to about 60% (SSP5–8.5), potentially cascading into severe risks for fisheries livelihoods (Dahlke et al., 2020). In West African fisheries, the loss of coastal ecosystems and productivity are estimated to require 5–10% of countries' GDP in adaptation costs (Zougmoré et al., 2016), incurring financial limits in poor countries to avoid socioeconomic risks. The SROCC (IPCC, 2019b) showed that scientific knowledge limitations can constrain management of coastlines, mainly in the context of lack of data, affecting most of the vulnerable and poor communities in the Global South (Perkins et al., 2015; Sutton-Grier et al., 2015; Wigand et al., 2017; Romañach et al., 2018). Hard and soft adaptation limits are challenging to define, given the rate and intensity of climate change hazards and the mitigation and adaptation options available, but also the level and rate of non-climatic stresses increasing vulnerabilities and undermining adaptive capacity of poorest members of society and sensitive ecosystems (*medium evidence, high agreement*) (Klein et al., 2014; Roy et al., 2018).

The recent evidence shows that adaptation limits can also be associated with financial and institutional mechanisms, and related to structural poverty and inequalities among rural farmers in India (Singh et al., 2019a) and among low-income countries (Tenzing, 2020), agro-pastoralist communities (Volpato and King, 2019), women (Balehey et al., 2018), informal slum settlements in Latin America (Núñez Collado and Wang, 2020) and informal workers in Southeast Asia (Balehey et al., 2018). For SIDS, multiple adaptation limits also emerge as a combination of political–institutional and cultural aspects (Robinson and Wren, 2020), such as preserving national identity and sovereignty in the context of migration in the Marshall Islands (Bordnera et al., 2020). A widespread narrative is that an increase in migration in SIDS, given sea level rise and global temperature increase by 2050, is inevitable, desirable and economically necessary. Many more people will be exposed to migration and affected by multiple forms of physiological and emotional stress (Bordnera et al., 2020). In the same way, the Mohawk community of Kanesatake, Canada, is faced with institutional and socio-political adaptation limits such as lack of land ownership rights, insurance and social institutions (Fayazi et al., 2020).

Table 8.6 | Synthesis of hard and soft limits to adaptation and risks to livelihoods, equity and sustainability adapted from Chapter 5 of SR1.5°C (Roy et al., 2018).

Determinant	Nature of barrier to livelihood adaptation	Magnitude + Indicator	Soft limit	Hard limit	Confidence level based on number of papers
Socioeconomic and human-geographical determinants					
Gender-based inequality or discrimination	Gender-based inequalities constrain women's access to resources, thus limiting ability to invest in adaptive capacity and heightening vulnerability.	World Bank: 62.151% [Employment in agriculture, female (% of female employment) (modelled International Labour Organization (ILO) estimate) – Low income, 2020]; 25.409% [Employment in agriculture, female (% of female employment) (modelled ILO estimate)].	X		****high* (≥ 10 papers)
Poverty and socioeconomic inequality	Poverty and lack of financial resources constrain ability to invest in livelihood diversification, resilience and adaptive capacity.	World Bank: 10% [Poverty headcount ratio at USD 1.90 d^{-1} (2011 PPP) (% of population)]; 26.498% [Employment in agriculture (% of total employment) (modelled ILO estimate)]; 58.783% [Employment in agriculture (% of total employment) (modelled ILO estimate) – Low income], Low-income countries, 2020.	X		****high* (≥ 10 papers)
Indigeneity and other cultural place-based attachments	Indigenous and other populations with strong cultural or economic attachments to place face barriers to adaptation due to non-economic losses associated with migration, urbanisation and some forms of livelihood transformation.	SIDS total population of around 65 million (UN-OHRLLS, 2015); 476 million indigenous people worldwide (World Bank, 2016).		X	****high* (≥ 10 papers)
Arctic hunting and fishing communities	Residents of arctic regions dependent on hunting and fishing livelihoods interrelated cultural and economic vulnerability due to risk crossing arctic ecosystem thresholds and tipping points.	Global arctic population, around 4 million (Larsen, 2015).	X	X	****high* (≥ 10 papers)
Urban slum and informal settlement populations	Residents of slums and informal urban settlements are particularly vulnerable due to limited infrastructure and limited employment opportunities.	33.331% [Population living in slums (% of urban population)], World, 2009; It is estimated that 50–57 million urban Africans (47% (44–50%) of the urban population analysed) were living in unimproved housing in 2015, mostly in sub-Saharan Africa (Tusting et al., 2019).	X		****high* (≥ 10 papers)
Ecological determinants					
Glacier retreat	Seasonal water scarcity and/or glacial lake outburst floods pose a serious threat for highly exposed and vulnerable smallholders in the Peruvian Andes (Drenkhan et al., 2019). Tibetan Plateau region will reach peak water between 2030 and 2050 (Yao et al., 2020).	The flow decrease of the Tibetan Plateau region will affect water availability for several countries, affecting a population of 1.7 billion people and a GDP of USD 12.7 trillion (Yao et al. 2019). In 2050, the number of people that will be living in water-scarce regions will increase to 2.7–3.2 billion (Luterbacher et al., 2020). As of 2010, 27% of global population (~1.9 billion people) lived in severely water-scarce areas (Luterbacher et al., 2020).	X	X	****high* (≥ 10 papers)
Loss of coral reefs	Loss of 70–90% of tropical coral reefs by mid-century under 1.5°C scenario (total loss under 2°C scenario) (see SR1.5°C, Hoegh-Guldberg et al., 2018, Sections 3.4.4; 3.5.2.1; Box 3.4; (Magnan et al., 2019); Roy et al., 2018, Section 5.2).	Coral reef fisheries-dependent and coastal livelihoods, sustain 6 million direct fishing jobs and more than USD 6 billion in revenues globally (Teh et al., 2013), often among disadvantaged populations (Hoegh-Guldberg et al., 2018). In tropical regions, there are 1.3 billion people living by coast and depending upon fisheries for food and livelihoods (Sale et al., 2014). In Africa and Asia over 400 million people are dependent upon protein intake from fisheries (Hoegh-Guldberg et al., 2019b). Approximately 850 million people live within 100 km of reefs and more than 275 million reside within 30 km, many of whom are likely to be highly dependent on coral reefs, especially those who look to these marine ecosystems for food and livelihoods (Burke et al., 2011).		X	****high* (≥ 10 papers)
Biodiversity loss	Terrestrial species on average lose 20–27% of their range at 1.5°C (significantly higher range losses projected for some species at 2°C) (see SR1.5°C, Hoegh-Guldberg et al., 2018, Section 3.4.3.2; de Coninck et al., 2018, Section 4.3.2). Tropical forests (vegetation shifts due mainly to drying), high-latitude and altitude ecosystems and Mediterranean-climate ecosystems (high vulnerability).	Forest-dependent livelihoods of 1.6 billion rural people (in 2012) are likely to be affected to risks of terrestrial forest and biodiversity loss (Newton et al., 2020).		X	***medium* (5–9 papers)

Determinant	Nature of barrier to livelihood adaptation	Magnitude + Indicator	Soft limit	Hard limit	Confidence level based on number of papers
Ocean acidification and warming	Large-scale changes in oceanic systems (temperature, acidification) inflict damage and losses on livelihoods, income, cultural identity and health for island and coastal-dependent communities at 1.5°C (potential for higher losses increases from 1.5°C to 2°C and above) (see SR1.5°C, (Hoegh-Guldberg et al., 2018); (de Coninck et al., 2018); (Roy et al., 2018).	500 million people who derive food, income, coastal protection and a range of other services from coral reefs (Hoegh-Guldberg et al., 2017).	X	X	***medium* (5–9 papers)
Sea level rise (SLR)	SLR and increased wave run up, combined with increased aridity and decreased freshwater availability, at 1.5°C warming potentially leaving several atoll islands uninhabitable (see IPCC SR1.5°C Hoegh-Guldberg et al., 2018, Box 3.5; de Coninck et al., 2018, Cross-Chapter Box 4.1). SLR is projected to affect human health and well-being, cultural and natural heritage, freshwater, biodiversity, agriculture and fisheries (IPCC, 2018b; WHO, 2018; IDMC, 2019; McMichael et al., 2020).	It is projected that ~316–411 million people in 2060 will be living in areas affected by SLR, with most in South and Southeast Asia and in Africa (Neumann et al., 2015; Oppenheimer et al., 2019). The number of people at risk of floods will increase from its current level of 1.2 billion to 1.6 billion by 2050 (Luterbacher et al., 2020). It is estimated that 6–8% of Latin America and the Caribbean's population, face high risk associated with coastal hazards (Oppenheimer et al., 2019).		X	****high* (≥ 10 papers)
Heat stress	It is expected that by 2070 over 30% of global poor population will be living outside the human thermal comfort, beyond adaptive capacity. This will also affect crop and livestock productivity (Xu et al., 2020).	Currently 30% of the global population is exposed to deadly heat waves and this percentage by 2100 is projected to increase to ~48% under a drastic mitigation scenario to ~74% under a scenario of growing emissions. (Mora et al., 2017). Heat stress contributes to deaths and health problems among the elderly and children. Specifically, heat stress is currently responsible for 38,000 annual deaths mostly among the elderly, and 48,000 from diarrhoea, 60,000 from malaria and 95,000 from childhood undernutrition (WHO, 2014a; Roy et al., 2018).		X	***medium* (5–9 papers)

New emerging considerations to ecological limits to adaptation associated with severe glacier retreat in the Peruvian Andes, is expected to reduce lake discharge by 2–11% (7–14%) by 2050 (2100). This will affect smallholders farmers, through crop yield failures and severely reduced hydropower capacity (Drenkhan et al., 2019). In addition, the study showed a very high risk of glacier lakes being affected by GLOFs under RCP8.5, posing serious threat to rural people's livelihoods (Drenkhan et al., 2019).

Table 8.6 represents different types of adaptation limits (soft or hard) that emerge over time, sometimes concomitantly, that are leading to severe risks to livelihoods in a high poverty, unequal and hotter future, especially among poor and vulnerable populations, and within those Indigenous People, women and children (see Section 16.5.2.3.4). The confidence statements are assessed through the evidence on papers as high (≥10 papers), medium (5–9 papers) and low (≤ 4 papers) to ensure traceability on the nature of livelihoods barriers and ecological thresholds associated with 'soft' or 'hard' limits to adaptation under a warming global world. The determinants of livelihood barriers are linked to *gender-based inequality or discrimination, poverty and inequality, indigeneity and cultural place attachment, artic hunting and fishing*, and *urban slum and informal settlements* incurring soft and hard limits to adaptation. The ecological thresholds assessed are associated with *glacier retreat, loss of coral reefs, biodiversity loss, ocean acidification and warming, sea level rise* and *heat stress* incurring hard limits to adaptation and severe risks to people's livelihoods. The severity of risks to livelihoods is assessed using a magnitude indicator of the current number of people exposed and vulnerable to climate-sensitive livelihoods. The supporting literature is listed in Table SM8.1.

8.4.5.7 Compounding Future Risks on Equity and Sustainability

The compounding future effects on equity and sustainability emerge when multiple stressors linked to environmental and/or climate change, together with underlying structural poverty, exclusion, marginalisation, and conflicts creating risks that need to be addressed simultaneously. Compounding risks of climate change received attention in AR5 (Oppenheimer et al., 2014). This included risks associated with compound hazards (O'Neill et al., 2017b) and their implications for future risk when repeated impacts erode human and ecosystem capacity, including through transboundary effects. In SRCCL (IPCC, 2019a), land degradation and climate change compounded to highly expose the livelihoods of the poor to climate hazards and caused food insecurity (*high confidence*), migration, conflict and loss of cultural heritage (*low confidence*) (Olsson et al., 2019).

The evidence of compounded risks emerges from specific climate and environmental hazards, as in relation to heatwaves, droughts, altered precipitation regimes and increasing aridity, cyclones, floods, hurricanes and wildfires (Table 8.7). Other evidence shows that the structural poverty and socioeconomic inequalities (Lusseau and Mancini, 2019), disability (Sun et al., 2017), corruption (Markkanen, 2019) and isolation (Reyer et al., 2017) (Table 8.7) compound to amplify climate risks among rural and urban poor, smallholder farms, coastal settlements,

Table 8.7 | Effects of compounded risks on the poor. Climate hazards: flooding, hurricanes, drought and heatwaves.

Dimensions of compounded risk effects on the poor	Equity	Sustainability
Poverty (9)**	✓	✓
Environmental (ecological change, soil degradation, fertility and aridity) and socioeconomic changes (8)**	✓	✓
Inequalities (4)*	✓	
Governance (3)*	✓	✓
Geographical (isolation) (1)	✓	✓
Population growth (3)*		✓
Diseases (3)*	✓	✓
Uncertainty (1)*		
Finance (1)*		
Informality urban (2)*	✓	✓
Disability (1)*	✓	
Climate-sensitive livelihoods (1)*		✓
Infrastructure (1)*		✓

Notes:
Confidence level: ****high* (≥10 papers); ***medium* (5–9 papers); **low* (≤4 papers).

with health impacts on children's development (Perera, 2017) and urban elderly (Sun et al., 2017). In Tanzania, a greater exposure of households to climate change impacts and risks is associated with increasing land value and variable tenure, compounded by declining farm yields, accelerating the negative effects among the population (Röschel et al., 2018). In India, extreme droughts and heatwaves compound extreme poverty and high dependence on agriculture for income and food production will affect crop productivity, income and food prices among smallholder farms (Singh and Leua, 2017). In Mozambique, soil degradation and fertility, compounded by incidence of droughts, increase the vulnerability of already poor smallholders who lack access to technological advances for crop yield management and drought-resistant crops (Kidane et al., 2019).

In the context of urbanisation, in fast growing cities in Asia, Africa and Latin America that are highly socially and economically unequal, the climate change impacts from events such as flooding and droughts, are amplified as water crises, mostly among the poor and marginalised population, challenging governance for risk reduction (Gore, 2015; Dodman et al., 2017; Jiang and O'Neill, 2017; Pelling et al., 2018; Solecki et al., 2018). In the Global South, over 880 million people are living in precarious and informal conditions without access to water and sanitation, mostly in sub-Saharan Africa and South Asia (see Chapter 6; Rosenzweig et al., 2018; Satterthwaite et al., 2018; Tusting et al., 2019). In rapidly urbanising sub-Saharan African countries, around 53 (50–57) million urban inhabitants (50% of urban population) and 595 (585–607) million rural inhabitants (82% of the rural population) were still living in unimproved housing in 2015 (Tusting et al., 2019).

L&D from climate extremes, such as fatalities or economic losses due to droughts or floods (see also Figure 8.6) also matter for future vulnerability and risk, since the poorest segments of society take longer to recover after shocks (Gupta and Sharma, 2006; van der Geest, 2018). In some cases, poor households might never be able to fully recover post-disaster, especially in the context of increasing global temperature increase (van der Geest, 2018). Another example of compounding effects of climate change to equity and sustainability is migration, which is underpinned by the underlying socioeconomic and political context of vulnerability (see Section 8.2).

In Latin America, compounding effects of climate change impacts (disasters) and armed conflict has contributed to forced migration to the point that in 2018 alone, 1.7 million people migrated due to extreme events, four times as many as the number of people leaving their homeland due to armed conflict (Serraglio and Schraven, 2019). In South America, migration within and between countries can stem from climate extremes, primarily felt by the poorest and marginalised (by gender, age, ethnicity) populations that might not be able to adapt to the fast pace and scale of changes at the local level (Maru et al., 2014; Pinho et al., 2015; Serraglio and Schraven, 2019). In mountain regions, intersections of people's marginalisation, difficulty in access and environmental sensitivity in the context of incidence of climate extremes have combined to reduce the ability of mountain agro-pastoralists to cope with climate extremes (Mishra et al., 2019). Mountain ecosystems are also highly susceptible to disasters and disturbances, which can lead to irreversible loss and challenge poverty reduction efforts (Mishra et al., 2019) Some risks associated with the degradation and loss of habitats and ecosystem services associated with land use changes and commodities in many countries have compounding impacts on equity and sustainability, associated with permanent losses to the livelihoods of poor and marginalised groups, such as Indigenous Peoples and traditional communities around the world (Roy et al., 2018). For instance, high deforestation rates and increased forest burning in many Amazonian countries are further exposing vulnerable Indigenous Peoples and traditional populations to health problems, crop failures and shortages of freshwater supply, especially in the context of extreme droughts and non-supportive governance (Leal Filho et al., 2020a; Walker et al., 2020).

Overall, there is increasing evidence that the compounding effects of climate hazards intertwined with dimensions of poverty, environmental degradation and inequalities, represent a key risk to equity and sustainability among poor and vulnerable populations (*medium evidence* and *high agreement*). Compounding risks—compared to compounding hazards—can also be significantly influenced by societal tipping points and by different factors of human vulnerability that determine underlying destabilisation processes of societies and communities exposed to climate change, including issues of governance.

8.5 Adaptation Options and Enabling Environments for Adaptation with a Particular Focus on the Poor, Different Livelihood Capitals and Vulnerable Groups

This section focuses on adaptation at household and community scales, including options, capacity and enabling environment, which include actions required towards building resilience. The emphasis is on the decision-making space and governance including the role of the state, private sector and other actors. Successful adaptation requires not only identifying adaptation options and assessing their costs and benefits, but also exploiting available mechanisms for expanding the adaptive capacity of human and natural systems (Klein et al., 2014). At the same time, developing suitable responses to hazards for communities and users of climate services is important in ensuring the success of adaptation measures. But despite this, knowledge about adaptation options, including possible actions that can be implemented to improve adaptation and reduce the impacts of climate change hazards, is still limited.

8.5.1 Adaptation Options to Climate Change Hazards Focusing on Vulnerable Groups

In light of the severe adverse consequences of climate change for the poorest populations, whose livelihoods are frequently dependent on vulnerable ecosystems, it is essential to enhance knowledge about sustainable and appropriate adaptation strategies and measures, as well as recognise and respond to limits to adaptation as reported in AR5 (Somorin, 2010; Noble et al., 2014; Connolly-Boutin and Smit, 2016). There is increasing evidence on the adaptation options that enhance the ability of different socio-ecological systems to become resilient in the long term in ways that do not exacerbate poverty and inequality, and on which adaptations may have little or no impact, or even adverse effects (maladaptation). Analysis of climate hazards can provide an indication of required adaptation strategies, however, most important is the focus on exposure and vulnerability. The novelty of the AR6 is the assessment of existing response capacities to cope and adapt to climate changes and associated hazards. There is increasing knowledge about the differential adaptation options within and across social groups and the influence of (enabling) conditions that enhance or limit these options.

From the analysis in the IPCC AR5, there is *high agreement* that engineered and technological adaptation options are still the most common adaptation responses. However, there is increased recognition of the value of ecosystem-based, institutional and social measures, including the provision of climate-linked safety nets for those who are most vulnerable (IPCC, 2014a). Climate adaptation measures are increasingly integrated within wider policy, development strategies and spatial planning frameworks. Such integration streamlines the adaptation planning and decision-making process and embeds climate-sensitive thinking in existing and new institutions and organisations across scales and levels.

In past decades, a number of categories of adaptation options have been identified and are discussed in Section 8.5. Adaptation options are categorised in various ways, such as in terms of grey and green adaptation or hard and soft measures (Depietri et al., 2013; Chambwera et al., 2014; Grimm et al., 2015). Grey measures refer, for example, to technological and engineering solutions to improve adaptation of infrastructures or to protect a specific land use or city from adverse consequences of climate hazards (OECD, 2018). Accordingly, ecosystem-based approaches, including natural infrastructure, can provide an effective complement or substitute for traditional built (or 'grey') infrastructure. For example, watershed restoration can protect sources of drinking water and reduce the need for subsequent treatment. Green measures often encompass ecosystem-based (or nature-based) approaches. These make use of the multiple services provided by ecosystems to improve resilience and adaptive capacity or to reduce risk. Soft adaptation measures include policy, legal, social, management and financial measures that can alter human behaviour and support adaptive governance, contributing to improved adaptation capacity, increased awareness, and change in values and actions on climate change issues.

Adaptation actions frequently include deliberate, coordinated, proactive policy decisions based on the awareness that conditions have changed or will change and that action is required to avert impacts or return to, maintain or achieve a desired state (Carter et al., 1994). Governance provides an important contextual framing, particularly in contexts where it is weak or contested (e.g., some of the Sahel zone). In these cases, it can mean that adaptation options stem largely from the local level. Adaptation processes can be categorised as individual, collective, proactive, reactive, autonomous, coordinated or natural (Chambwera et al., 2014). Apart from governments, other actors, organisations and institutions (including non-state agencies and private industry actors) also play an important part in adaptation processes, and consequently the discussion of enabling environments for sustainable or successful adaptation has to consider these different scales and actors. For example, while autonomous adaptations are mainly undertaken by private actors, triggered by climate change-induced market or welfare changes, planned adaptations can be carried out by both private and public actors. Natural adaptations appear within ecosystems as a reaction to climate change, as well as other factors, and incorporate innumerable possible actions that are context specific, ranging from managerial approaches to technological innovations and ecosystem-based approaches (Huq et al., 2004). Sanchez et al. (2017) draws attention to preconceived ideas about some adaptation measures that are either considered good or bad without proper evaluation. It is argued that the association 'hard-bad' and 'soft-good' is not necessarily true; the impacts of adaptation can only be established through a case-by-case assessment. The decision to select a more or less intensive adaptation measure should integrate all approaches, social, environmental, technical and economic, in a multi-criteria analysis. This analysis should value, *inter alia*, social and environmental sensitivity, benefits and drawbacks or trade-offs with climate, including all the adaptation options, among them the 'no action' alternative.

Adaptation frequently responds to an observed or anticipated 'trigger' for response, such as the looming loss of land to sea level rise (Barnett et al., 2014). Identifying adaptation needs stemming from climate risks and vulnerabilities provides a foundation for selecting a sequence of adaptation options that connect through time, a long-term adaptation pathway (Wise et al., 2014; Turnheim et al., 2015). National, sectoral or local adaptation plans are *likely* to include a number of measures that are implemented jointly from across various categories, including structural, institutional and social options. While structural or physical adaptation encompasses measures for the engineered built environment it also can encompass nature-based solutions, which include ecosystem-based protection measures, for example to buffer risks and hazard exposure to extreme weather events. The category of 'soft' adaptation measures—changes in societal values or practices—is often linked to issues of education, information and behavioural changes to support communities within specific adaptation processes to climate change and climate hazards. Institutional adaptation deals with adaptation actions and measures introduced through new legal frameworks, laws and regulations for new institutions or policies for risk reduction and adaptation. This category can also encompass the development of new organisations that have a mandate to support adaptation (Noble et al., 2014). The appropriateness and accessibility of adaptation options under these categories for supporting the poor and most vulnerable groups differs. In many cases large-scale structural measures are not affordable for many poor communities. Despite this important potential of Indigenous knowledge for disaster risk reduction of communities, it is often shunned by practitioners (Dube and Munsaka, 2018). It is further argued by practitioners that Indigenous knowledge lacks documentation, it is not found in all generational classes, it is contextualised to particular communities and the knowledge cannot be scientifically validated. However, there is also evidence that both local communities and disaster risk reduction practitioners can benefit from the Indigenous knowledge of communities (Dube and Munsaka, 2018).

In practice, adaptation refers to initiatives such as a policy, plan, project or decision that are designed to change and/or respond to something in the context of existing risks and hazards. For example, a farmer might adapt to drought by deciding to harvest their crop earlier; a municipality can decide to build a sea wall to adapt to increased flood risk.

The increasing complexity of adaptation practice means that institutional learning is an important component of effective adaptation (Noble et al., 2014). It is paramount that approaches to selecting adaptation options continue to emphasise incremental change to reduce impacts while achieving co-benefits. There is increasing evidence that transformative changes may be necessary in order to prepare for climate change impacts and adaptation options in the context of climate hazards (Noble et al., 2014). Transformation for some actors at some levels may equate with incremental change and transitions for other actors and scales. While attention to flexibility and safety margins is becoming more common in selecting adaptation options, many see the need for more urgent and transformative changes in our perception and paradigms about the nature of climate change, adaptation and their relationship to other natural and human systems.

In this context, there are many potential adaptation options available for a marginal change of existing agricultural and other livelihood systems, often variations of existing climate risk management. According to Howden et al. (2007), implementation of these options is *likely* to have substantial benefits under moderate climate change for some existing cropping systems. Apparently, there are limits to their effectiveness under more severe climate changes. Hence, more systemic changes in resource allocation need to be considered, such as targeted diversification of production systems and livelihoods. Howden et al. (2007) further argue that achieving increased adaptation action will necessitate integration of climate change-related issues with other risk factors, which implies integrating non-climatic factors, such as climate variability and market risk, and with other policy domains, such as sustainable development. An increasing number of research programmes seek to support adaptation to climate change through the engagement of large-scale transdisciplinary networks that span countries and continents (Cundill et al., 2019).

Based on analysis of different adaptation options, there is *high agreement* that the many barriers to effective adaptation will require a comprehensive and dynamic policy approach covering a range of geographical scales and multiple actors across scales, taking into consideration both climatic and non-climatic stress factors (Eriksen et al., 2015). For instance, from the agricultural perspective, this could imply the understanding by farmers of change in risk profiles to the establishment of efficient markets that facilitate response strategies. It is also important to note that science, too, has to adapt employing a range of approaches, based on the fact that multidisciplinary problems require multidisciplinary solutions. Towards enhancing resilience, a focus on integrated rather than disciplinary science alone could be of utmost importance as well as strengthening of the interface with key stakeholders, ranging from decision makers, practitioners, policymakers and scientists.

8.5.2 Enabling Environments for Adaptation in Different Socioeconomic Contexts

8.5.2.1 Factors that Support Enabling Environments for Adaptation

This section assesses the literature on components of the enabling environment for adaptation. The point of departure considers findings in both the SR1.5°C report, which notes that adaptation becomes increasingly difficult (and expensive) at temperatures that are more than 1.5°C warmer (IPCC, 2018a). In addition, (IPCC, 2014a) underscores that there is no one-size-fits-all approach to adaptation for all contexts, and that mitigation and adaptation must be pursued in tandem.

Climate change affects people inequitably, and everyone does not contribute equally to climate change. A range of economic and non-economic impacts can be experienced. This has led some researchers to call for a more central role for rights-based approaches to adaptation to help secure space for those marginalised from adaptation decision making and to prioritise access to resources and information for those most vulnerable to, or affected by, the social, cultural or economic consequences of climate change (Bee et al., 2013; Da Costa, 2014; Toussaint and Martinez Blanco, 2020; Box 8.7; Section 5.12). In terms of international law, the human rights obligations of states have been subject to multiple recommendations relating to climate change by United Nations treaty bodies in the reporting period. More broadly, rights-based approaches rely on the normative framework of human rights, requiring adaptation to be non-discriminatory, participatory, transparent and accountable in both formal (e.g., legal and regulatory) and informal (e.g., social or cultural norms) settings and at international, national and sub-national scales (Ensor et al., 2015; Arts, 2017). Sovacool et al. (2015) note that unless critical competing interests are

Box 8.7 | Addressing inequalities in national capabilities: common but differentiated responsibilities and respective capabilities relating to adaptation and the Paris Agreement

Common but differentiated responsibilities and respective capabilities (CBDR-RC) is a key principle within the United Nations Framework Convention on Climate Change (UNFCCC), and attempts to acknowledge countries' diverse development situations. The Convention and its Kyoto Protocol operationalised the principle by committing developed (Annex I) countries to absolute emission reduction or limitation targets and exempting developing countries from any binding reductions in emissions (Huggins and Karim, 2016; Pauw et al., 2019). In contrast, the Paris Agreement distinguishes between 'developed' and 'developing' countries instead of Annex I and non-Annex I countries and acknowledges significant asymmetries and inequalities, not only between developed and developing countries, but also between developed and developing countries themselves, both in terms of vulnerability to climate change impacts and capacity to mitigate the problems. The literature contains extensive analyses of CBDR-RC in relation to equity in mitigation efforts in the post-2020 regime (e.g., Michaelowa and Michaelowa, 2015; du Pont et al., 2017; Liu et al., 2017; Holz et al., 2018; Sælen et al., 2019), but little in relation to adaptation, particularly relating to how it plays out in the Paris Agreement.

The somewhat static interpretation of CBDR-RC prior to the Paris Conference of the Parties was overcome through the introduction of a qualification to the CBDR-RC principle: the phrase 'in the light of different national circumstances'. Without changing the original principle, the qualifier adds a dynamic element (Rajamani, 2016). Common but differentiated responsibilities and respective capabilities of parties are therefore recognised not to be 'tied to the annexes', but instead evolve alongside national circumstances (Maljean-Dubois, 2016; Voigt and Ferreira, 2016 p.301). The Paris Agreement also recognises context, considering differentiation in relation to each of the Durban pillars: mitigation, adaptation, finance, technology, capacity building and transparency (Rajamani and Guérin, 2017).

Article 7 of the Paris Agreement acknowledges adaptation as a 'global challenge faced by all', recognising, for the first time, a global aspiration of 'enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change'. It calls for a balance between mitigation and adaptation funding and emphasises the need to provide developing country parties, especially the most vulnerable, with '[c]ontinuous and enhanced international support' for adaptation. The basis for differentiation under Article 7 therefore relies mostly on diverse national circumstances, capabilities and vulnerabilities. LDCs, as well as SIDS, are assumed by the literature, to be part of this category (Maljean-Dubois, 2016).

The literature offers two main perspectives when evaluating the effectiveness of these provisions on adaptation in the context of the post-Paris climate change regime. One argument follows that the Paris Agreement gives priority attention to the most vulnerable parties and, unlike previous international agreements in the climate change regime, places adaptation on equal footing to mitigation (Magnan and Ribera, 2016; Pérez and Kallhauge, 2017; Morgan, 2018). Article 7 is interpreted here as a breakthrough, containing unprecedented provisions that give adaptation prominence and which elevate the importance of undertaking adequate action to cope with current and future climate change impacts. A second view argues that the Article 7 marks little departure from previous efforts to support adaptation efforts in developing countries (Doelle, 2016) or that it could have included stronger provisions, such as a quantitative goal with respect to adaptation needs and costs (Bodansky, 2016).

The literature nevertheless shows *high agreement* that other parts of the Paris Agreement do contain consequential provisions on adaptation and the operationalisation of the CBDR-RC principle. Those provisions covering financial support are arguably the most pertinent, as they replace the dichotomy between developing countries and developed countries with a trichotomy which also includes 'other Parties' (Maljean-Dubois, 2016). While provision of support from developed parties continues to be mandatory, these 'other parties', apparently developing country parties, are 'encouraged to provide or continue to provide such support voluntarily' (Article 9.2). Parties themselves determine whether they belong to this category. So far, several developing countries have made contributions to the Green Climate Fund, ranging from Indonesia and Mexico to Mongolia and Panama (Green Climate Fund, 2017). Expanding the donor base to these 'other parties' and breaking down the wall between donor and recipient countries marks a departure from previous practice, under which developing countries had no formal role in climate finance and support (Bodansky, 2016; Voigt and Ferreira, 2016).

addressed during planning, adaptations may fail to achieve the desired outcomes. This is increasingly seen at a political level within efforts to implement the Paris Agreement, in relation to the principle of 'common but differentiated responsibilities and respective capacities' (CBDR-RC) (Box 8.7).

The scale of analysis, baseline conditions prior to adaptation and scale of action matter too when assessing the key components of an enabling environment for adaptation. At a national scale, it is well established that low-income countries are less well positioned to manage climate change impacts, being variously attributed to a lack of institutional, economic or financial capacity to adapt effectively (Tol and Yohe, 2007; Barr et al., 2010). It can be particularly difficult to adapt to drought, for example, when it occurs in the pre-conditions of poor water supplies and sanitation (see Box 8.5; Section 8.3.2), and in a context of corruption, governance failure and a lack of accountability. Adaptation productivity in higher-income countries is further supported by better infrastructure and stronger institutions—low adaptation efficiency is linked to lower government spending, higher inequalities in income distribution and poor governance (Fankhauser and McDermott, 2014). At smaller scales, even within a single socioeconomic setting, different groups require different kinds of adaptation support and exhibit different vulnerabilities to climate change impacts. Huynh and Stringer (2018) found that households vulnerable to climate change impacts linked to sea level rise and flooding in Da Nang City and Ngu Hanh Son district, Vietnam, had limited access to human, natural, physical, financial and social assets, and lacked a diversified livelihood portfolio. An enabling environment for household-level adaptation would need to address these factors in this context. However, the same authors found that at district scale, different challenges persisted, including obstacles to multidirectional flows of climate information, poor vertical interplay both upward and downward, and a lack of citizen participation in the governance of climate change.

Acknowledging that context and scale matter, it is nevertheless possible to set out the core components of a generic enabling environment (Figure 8.12), linking them to the literature on climate change and recognising how they can support adaptation in different socioeconomic and environmental settings in which different emphases are required. This broad set of enablers requires different emphases according to the specific context, yet the interdependence between them is universally applicable.

The specific political economy of each country and its underpinning philosophies shape the national political context in which public policy supporting adaptation is developed and implemented. It further shapes the context for private adaptation. Public policy targeting climate change seeks to address market failures, amend policy distortions and offer incentives for private adaptation, as well as provide climate-resilient public goods, climate services and safety nets for the poor and vulnerable (Fankhauser, 2017). In some countries that have a more stable institutional context, such policies are more straightforward to develop and implement; while in countries with weaker institutions (e.g., those emerging from conflict), a larger role may be needed for regional economic commissions and transnational networks to support the governance of 'borderless climate risks' (Benzie and Persson, 2019), particularly where these countries also are most vulnerable to climate change (see also Figure 8.6). To support enabling conditions in highly vulnerable countries that are also characterised by state fragility (see Figure 8.8), funding and projects designed to support adaptation may need to be modified to effectively promote regional cooperation and transboundary adaptation. Nevertheless, such interventions can also reinforce particularly powerful agendas and fail to assist and empower those with the greatest need to adapt (Biermann et al., 2010; Burch et al., 2019) neglecting community voices and sovereignty (Schlosberg and Collins, 2014). It is therefore important that the relevance of people and community empowerment to effectively achieve vulnerability reduction and climate change adaptation is recognised.

It is also insufficient to consider countries as stand-alone entities, due to links such as those provided by international trade. Taking Europe as an example, the continent has strong links to major trade partners such as India, Indonesia, Nigeria and Vietnam, so failure to assist adaptation in other locations opens up important vulnerabilities through supply chains (Lung et al., 2017). Policies seeking to protect national interests alone (e.g., in terms of food security) are seen as causes of negative impacts at a global scale (Puma et al., 2015; Challinor et al., 2017), with those nations and individuals least able to adapt to evolving climate changes experiencing exacerbation of existing imbalances (Elbehri et al., 2015). LDCs are projected to suffer greater import losses in more connected networks (Puma et al., 2015). In the food sector, poorer net food buyers are anticipated to experience the worst impacts of climate change (Gitz et al., 2015).

Behind each policy are decisions about the magnitude of financial resource investments in specific adaptation actions, and their allocation between different sectors and groups in society, both spatially and temporally. The IPCC has estimated that limiting the rise in global average surface temperatures to 1.5°C would require between USD 1.6 trillion to USD 3.8 trillion of annual investment in supply-side energy systems (those that generate energy) between 2016 and 2050 (IPCC, 2018b). Resource allocations, however, are shaped by perceptions of the risks of climate change and the urgency of actions, as well as other motivational factors such as descriptive norms and perceived self-efficacy (van Valkengoed and Steg, 2019) and the underlying approaches taken to valuing human well-being (e.g., see work from Bhutan on Gross National Happiness and climate change actions (Kamei et al., 2021)).

An increase in finance mobilised, however, does not automatically equate to adaptation interventions on the ground, nor does it guarantee the effectiveness of those adaptations deployed (Berrang-Ford et al., 2021). Unintended negative consequences may arise due to lack of understanding of the drivers of vulnerability (such as gender inequality or inequitable access to natural resources), non-involvement of marginalised local groups, retrofitting adaptation into existing development agendas, and insufficiently defining adaptation success (Eriksen et al., 2021). A 2017 study estimated that less than 10% of climate finance committed from international, regional and national climate funds to developing countries between 2003 and 2016 went to locally focused projects, suggesting a need to rethink approaches if the most affected groups are to build sufficient resilience to the impacts of climate change (Soanes et al., 2017).

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Core components of an enabling environment for adaptation to climate change

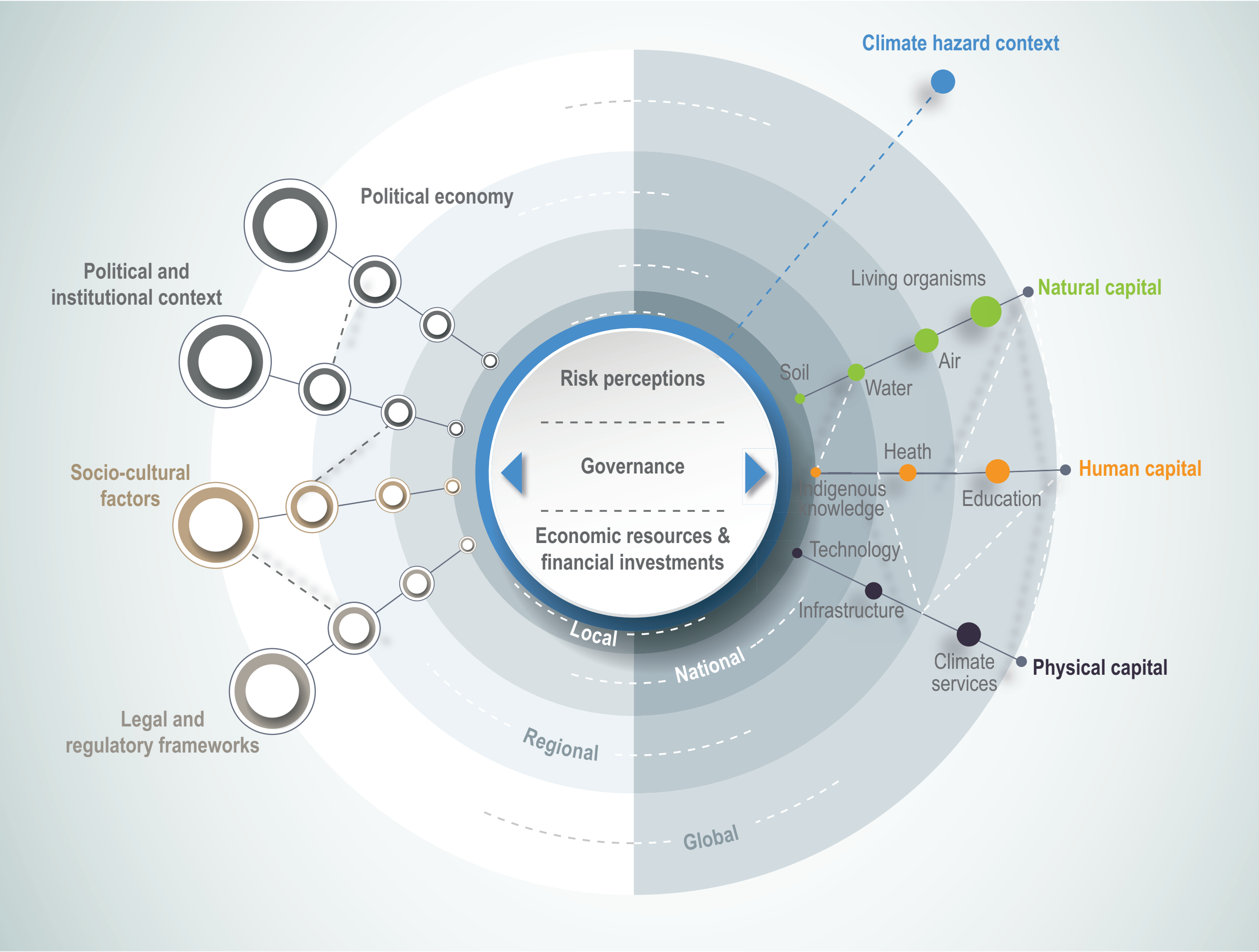

Figure 8.12 | Core components of the enabling environment for adaptation to climate change (key interactions are illustrated but there are overlaps, interactions and feedbacks both within and between each item; and different countries have different capacities and starting points in addressing these enablers and the interlinkages between them).

The literature shows with *high confidence* that the poorest groups in society often lose out, and require greater planned adaptation support, having less capacity to adapt than better off groups with easy access to assets (Barbier and Hochard, 2018; Ziervogel, 2019b; Box 8.5). Developing countries such as Burkina Faso, Mali and Zambia are not only among the most vulnerable to climate change, they are also the least able to mobilise the finance needed to adapt to its impacts (ND-GAIN, 2019). Women and girls are often most heavily burdened. When building adaptive capacity, these groups can require different support such that their knowledge, capacities and skills can be harnessed, in such a way that does not feminise responsibility and add to their burdens (Clissold et al., 2020; McNamara et al., 2021a).

There is broad support for the notion, enshrined in the Paris Agreement, that adaptation finance flowing to developing countries of the Global South should primarily benefit the most climate-vulnerable among them due to their limited technical capacity and financial capabilities, yet such countries are often insufficiently considered in funding decisions. There are nevertheless concerns regarding institutional fit: that foreign funding regimes may not map onto more recently developed administrative traditions, leading to dominance of governance models emanating from donors (Vink and Schouten, 2018). Research has found multilateral donors do not prioritise vulnerable developing countries at the project selection stage and they have received smaller allocations of adaptation finance from bilateral donors than less vulnerable countries (Saunders, 2019), leaving the poor vulnerable to climate impacts. The lack of climate finance flowing to LDCs and SIDs (currently 14% and 2% of the total, respectively) is compounded by access issues due to the inability of domestic institutions to meet specific fiduciary standards and other access requirements, insufficient human resource support and the inflexibility of current approaches, which are biased in favour of governments and against non-traditional actors, such as local enterprise and grassroots organisations (Shakya et al., 2021). Further, vulnerable developing countries shoulder additional financial burden, embodied in higher interest payments to service public and private debt, due to the increased cost of capital brought about by greater exposure to climate risks (Buhr et al., 2018). This has been further exacerbated by the recession and debt distress accompanying the COVID-19 pandemic (Kose et al., 2021). A range of reforms, including comprehensive debt relief by public creditors, green recovery bonds, debt-for-climate swaps and new SDG-aligned debt instruments may address unsustainable debt burdens, freeing up investment in climate adaptation and a green economic recovery (Volz et al., 2020; see Section 8.6.3.1).

Greater investment is also needed in the developed countries of the Global North. For example, the 2018 forest fires in Sweden, the 2019–2020 Australian bushfire season and the 2020 forest fire season along the US West Coast were unusually long and severe, resulting in unprecedented damage to natural habitats and human livelihoods and, relatedly, significant economic cost, particularly given interlinkages with other stressors such as COVID-19. While a range of drivers underpin annual fire seasons, including greater water withdrawal and years of fire suppression, early research indicates that climate change increases their likelihood due to long-term warming trends (van Oldenborgh et al., 2021a).

However, investing in poverty reduction does not necessarily lead to climate change adaptation and where adaptation does result, it does not always reduce vulnerability of the most marginalised, as documented in case studies from northeast Brazil (Nelson et al., 2016). Poverty also affects private adaptation options. For example, research from Portugal highlights the importance of private financial assets in helping older adults to adapt to extreme temperatures (Nunes, 2018).

Policies and investments that are adopted are embedded within the relevant legal and regulatory frameworks, which extend beyond national jurisdictions upward to the regional scale (such as the Southern Africa Development Community's Southern Africa Regional Framework of Climate Change Programmes, 2010) and international scale, for example, UNFCCC, the 2015 Paris Agreement, the Sendai Framework for Disaster Risk Reduction, the New Urban Agenda and the SDGs. Legal and regulatory concerns also extend downward to shape local- and city-scale adaptation efforts (e.g., Sao Paulo's municipal policy and new master plan). Nevertheless, only a minority of countries have dedicated legal frameworks supporting adaptation (Lesnikowski et al., 2017) and these often lack in both precision and obligation—largely because adaptation is a contested global public good but also because adaptation is commonly bundled in with mitigation commitments (Hall and Persson, 2018). Coherence, horizontally and vertically in both policy and law is often lacking. At the same time, bottom-up, private, autonomous adaptation efforts are being better tracked, with different actors motivated by growing experiences of local climate change impacts (Berrang-Ford et al., 2014). While the emergent polycentricity of adaptation governance is beginning to take shape, wherein both state and non-state actors share a common adaptation goal and interact coherently, yet often independently, to advance progress towards it (Morrison et al., 2019), understandings of how various centres of decision making with different degrees of autonomy support an enabling environment for adaptation, remain at a nascent stage. Multiple scales and forms of adaptation occur, with attributes such as self-organisation, appreciation of site-specific conditions, and the need for learning and experimentation, alongside building of trust, increasingly shown to be vital (Dorsch and Flachsland, 2017). Literature indicates that professional and learning networks are important groups supporting adaptation in cities and can help harness resources (Woodruff, 2018); while the research of (Hauge et al., 2019) in Norway underscores the importance of working across multiple disciplines and the inclusion of actors from different levels of authority in multi-level municipal networks. They found that these factors can help to identify specific adaptation actions as well support knowledge sharing within participating organisations, which in turn helps garner commitment to adaptation and its implementation. They also found that it is important to involve local leaders in polycentric adaptation networks.

Among the many institutions, actors and roles associated with successful adaptation, two play an increasingly important role: local governments and the private sector (Noble et al., 2014). These groups often define the flows of information and finance from the top down, as well as supporting the scaling up of community and household adaptation. In some countries, for example, in South America (Argentina, Brazil, Paraguay) vocational agricultural schools, often in remote rural locations, play a key part in knowledge-sharing activities that support adaptation. Similar valuable contributions are made by universities through their outreach activities, particularly those offering programmes in environmental and agricultural fields. Many actors face a lack of resources and capacity, particularly at the local level. Local institutions, including local governments, NGOs and civil society organisations, are hampered by ongoing challenges in gaining support from higher governance levels—from national government or the international community—particularly in developing countries. At the same time, private sector actors, from individual farmers and small/medium enterprises (SMEs) as well as large multinational businesses, will seek to protect and enhance their production systems, supply chains and markets by pursuing adaptation-related opportunities. Yet, while these goals will help expand adaptation activities, they may not align with government or community objectives and priorities without coordination and incentives, and in the process, can reinforce existing capacities, inequalities and power relations (Sovacool et al., 2015). Similarly, an enabling environment for businesses' adaptation is highly differentiated and often requires structural deficits (such as limited market access, finance and transport and communications infrastructure) to be tackled (Gannon et al., 2020).

The challenges of climate change have driven governments around the world to emphasise climate services as a route to enhance decision making and reduce climate-related risks, as well as inform adaptation, supporting calls for the right to information (Tall and Njinga, 2013). While there have been some efforts to evaluate the economic impact of climate services alongside other impacts (e.g, Tall et al., 2018), little is known about the institutional contexts in which investments in climate services have taken place, nor those groups that are most vulnerable or marginalised in relation to specific climate risks. Vincent et al. (2017) offer preliminary insights from Malawi, identifying that barriers to improved integration of climate services in national policy planning include factors relating to spatial and temporal scale, accessibility and timing of information provision, credibility and mismatches in time frames between planning cycles and climate projections. An understanding of the factors that enable climate service investment is important for the development of climate services at local, national and international levels (Vaughan et al., 2017) but this area of literature is not yet well developed.

Overall, adaptation entails financial (and non-financial) costs not just in implementing adaptation actions, but also in designing, facilitating and preparing for actions—costs to create and maintain an enabling environment (see also Section 8.2.2.3; Cross-Chapter Box LOSS in Chapter 17). Financial and economic investments target the whole range of other types of asset (natural capital, physical capital, human capital, social capital). AR5 reports that aggregate economic losses accelerate with increasing temperatures (IPCC, 2014a). Costs may be borne when gaining information (e.g., investments in climate services), while adjustment costs are incurred as adaptations take place. Nevertheless, to enable adaptation, investment is needed in various natural, human, physical and social assets, as considered below. The importance of investment in each of these different types of asset varies according to the scale and livelihood system in need of adaptation and the ways in which livelihood resilience is framed and power is distributed, within each specific setting (Carr, 2020).

8.5.2.2 Natural Capital

It is well established that climate change compounds the impacts of pressures that humans place on the environment (*high confidence*) and that environmental degradation can undermine options for adaptation and an enabling environment, with poor and natural resource-dependent groups most acutely affected (see e.g., Cross-Chapter Paper 3 for insights from deserts and semiarid areas). Sustainable management of natural capital contributes to building resilience and the natural ability of ecosystems to adapt to climate change (IPCC, 2014a; see also IPCC SROCC, Section 5.3.2, Bindoff et al., 2019). Some systems like mangroves (found in 123 countries, many of which are in the Developing World) offer a broad range of vital ecosystem services (Hamza et al., 2020). Mangroves provide regulating services by acting as a natural defence against sea level rise and storm surges; and by sequestering carbon in both the trees and sediments they capture. Provisioning services (e.g., fish, crabs, timber and fuelwood) from mangroves support livelihoods and livelihood adaptation options, especially for those with few other livelihood opportunities, while these systems also provide important habitat (breeding, spawning and nursery grounds for fish) and biodiversity, and offer cultural services in the forms of education, recreation and spiritual benefits (Quinn et al., 2017). As the frequency of events such as hurricanes, storms and typhoons rises with climate change, natural capital assets like mangroves become increasingly important in protecting coastlines and supporting adaptation. While not reducing the hazard itself, the mangroves reduce exposure and, in some cases, also vulnerability. The literature shows with *high confidence* that environmental assets support both climate change mitigation (at a large scale) and adaptation (at a smaller scale), particularly for the poorest groups in society, who directly depend upon natural capital for their subsistence (e.g., Angelsen et al., 2014). In turn, the legal and regulatory context and institutional set up determines who has access rights to different aspects of the natural resource base. This shows how different aspects of the enabling environment work in tandem to constitute one another.

In a market economy, human activities tend to exacerbate degradation of natural capital, despite its role in buffering climate change impacts, supporting mitigation and providing adaptation options. Economic agents base their decisions on market prices, even though market prices do not incorporate the costs of deteriorating natural capital because of externalities and other market failures, that is environmental degradation is not internalised (Bowen et al., 2012). At the same time, expanding populations, capitalism and consumption choices affect the condition of natural capital, alongside short-termism stemming from poverty, linked to the need for survival. All these factors therefore interact, with the aggregate effect of worsening the impacts of climate change, while also undermining future adaptation options, particularly for the poor. Adaptation policies should, but do not always, compensate for the prevalent market failures. For example, in Melanesia, sea walls have been built out of coral by local people in an attempt to reduce the impacts of rising sea levels, leading to outright destruction of some of the world's most productive and biodiverse coral reefs (Martin and Watson, 2016). Similarly, in the Congo Basin, farmers are adapting to increasingly variable rainfall by expanding their cropping activities into forested areas, releasing carbon into the atmosphere through forest clearance activities and threatening biodiversity. Agricultural land is also being degraded globally (see IPCC, 2019a), and this too closes down adaptation and livelihood options for the poorest, natural resource-dependent populations, while jeopardising food security, biodiversity and human health at wider scales. An enabling environment for adaptation therefore demands investment in sustaining natural capital at multiple scales, internalising the costs of degradation, as well as establishing the necessary legal and regulatory frameworks (and associated enforcement) to reduce its degradation (IPBES, 2018).

The literature increasingly shows that approaches such as nature-based solutions (NBS) and ecosystem-based adaptation (see Chapters 2; 6) can offer value for money in tackling climate change from both a mitigation and adaptation standpoint (Seddon et al., 2020). According to the Global Commission on Adaptation, a global investment of USD 1.8 trillion between 2020 and 2030 into adaptation measures such as early warning systems, climate-resilient infrastructure, improved dryland agriculture, mangrove protection, and resilient water resources can yield USD 7.1 trillion in total net benefits (Global Commission on Adaptation, 2019). NBS operate by harnessing natural processes, sometimes in combination with technological or engineered solutions. Examples encompass green public spaces and parks (Sahakian and Anantharaman, 2020), green infrastructure, such as urban forests and street trees (Richards and Edwards, 2017), which create shade and reduce urban heat island effects whereby urban areas are warmer than their surroundings (Depietri et al., 2013), and support human health and well-being by keeping people in cities more closely linked with nature (Gulsrud et al., 2018). NBS also encompasses blue infrastructure including constructed wetlands, bioswales, rain gardens and so forth, which can reduce flood risks (Haase, 2015). While the literature is generally positive about the ability of NBS to support climate risk reduction and deliver multiple other benefits (Connop et al., 2016), such as green job opportunities, improved provision of recreational space, cleaner air, habitat provision and increased property values (Emmanuel and Loconsole, 2015), more research is required to specifically assess and evaluate the conditions and contexts in which these kinds of

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potential benefits are realised and how they can be mainstreamed into policy (Frantzeskaki et al., 2019). Similarly, there is *limited evidence* on unintended consequences (e.g., methane production, creation of habitat for disease vectors, increased human–wildlife conflict) and how these can be avoided (Wolch et al., 2014).

8.5.2.3 Human Capital

Successful adaptation requires support to be directed towards human capital and socioeconomic capabilities and competences, in terms of education, knowledge, experience, health and well-being, and migration, enabling people to contribute meaningfully towards development (Bowen et al., 2012). At the same time, strong human capital and investment in actions that build human capacities to deal with climate change, can further enhance adaptation activities linked to other capitals, and contribute positively to overall disaster risk reduction.

Analyses of educational attainment distributions with datasets reaching back as far as 1970 show that improving educational attainment in people of working age has been the most consistent and significant driver of economic growth globally (Lutz et al., 2008), showing the importance of the right to education. Education has further supported sustainable development by fostering empowerment, yielding access to information (including on climate change) and has clear links to other aspects of human capital, including health and mortality (Samir and Lutz, 2017). There is *medium evidence* and *high agreement* that education reduces vulnerability and enhances adaptive capacity (Frankenberg et al., 2013; Sharma et al., 2013), with *high agreement* that climate change impacts can have negative effects on existing levels of human capital, with some development pathways affected more than others (Samir and Lutz, 2017). Education can help to shape people's risk perception and assessment, as well as affecting knowledge sharing and the development of problem-solving abilities (Striessnig et al., 2013).

At the same time, IKLK can inform adaptation actions (Apgar et al., 2018), but is poorly integrated into formal educational systems and, in some cases, is insufficient to adapt to new hazards that are emerging as a consequence of climate change. Education further feeds into livelihood options, with close relationships between people's earning capacities, the livelihood choices they can make and their levels of financial capital. It also supports food security (Lutz et al., 2004). There is *medium evidence* that climate change can undermine human capital and education. For example, studies have shown that higher temperatures reduce exam educational performance (Park, 2020), while extreme weather events such as snowstorms disrupt learning, yielding long-lasting and multidimensional effects (Maccini and Yang, 2009; Cho, 2017; Graff Zivin et al., 2018).

As well as studies examining formal education, a large body of research has focused on social learning and its role in building adaptive capacity through joint knowledge production and reflexivity. Foregrounding the need for continuous changes in response to emerging conditions, this literature identifies the potential of shared learning for co-constructing policy and practice responses to complex, multi-stakeholder environmental problems, and highlights both the necessity and challenge of including non-dominant values, knowledge and expertise in adaptation decision making, considering the role of power dynamics therein (Collins and Ison, 2009; Ensor and Harvey, 2015; Phuong et al., 2017; Apgar et al., 2018; Brymer et al., 2018; Fisher and Dodman, 2019). A growing body of evidence also links to organisational learning and adaptation. Organisations' adaptive behaviours, like those of households and individuals, do not operate in a vacuum, with organisations' behaviours shaped by policy and market conditions amongst other factors. Mudombi et al. (2017) highlight further barriers in their study in South Africa, linked to inadequate resourcing, political interference, governance shortcomings and knowledge/expertise gaps within organisations, alongside short time frames for implementing projects.

Adaptations that support human health and well-being require investments in physical assets and infrastructure linked to water and sanitation (see Chapter 4), particularly in rapidly urbanising areas in the Global South, alongside specific pro-poor investment strategies given disproportionate climate change impacts on women (see Cross-Chapter Box GENDER in Chapter 18), other marginalised groups and low-income households who lack access to healthcare. Climate change facilitates the spread of vector-borne diseases such as malaria, as well as illnesses such as meningitis (Rocklöv and Dubrow, 2020). Impacts on health are also experienced, through food insecurity resulting from climate change, including malnutrition, as well as through loss of livelihoods, making it more difficult to afford and to access health services. Health aspects are considered in-depth in Chapter 7, but we underscore the importance of a rights-based approach to adaptation in supporting the right to health and food in the context of inequality.

A key dimension of human capital is local understanding of climate risk, which includes knowledge systems outside Western scientific approaches. For millennia, local communities have relied heavily upon culturally accumulated Indigenous knowledge, participating in landscapes as stewards of their environment, engaged in profoundly detailed livelihood strategies that deal with natural hazards (Ajayi and Mafongoya, 2017). Indigenous knowledge systems are embedded in culture, and are passed from generation to generation in various ways: livelihoods, traditions, spiritual practices and oral tradition, cultural identity and historical memory. Indigenous knowledge is known or learnt from experience, or acquired through observation and practice, and handed down from generation to generation. It is acknowledged that Indigenous communities, particularly those in hazard-prone areas, have developed a profound understanding and knowledge of disaster prevention and mitigation, early warning, preparedness and response, and post-disaster recovery. Indigenous knowledge systems, themselves, are an indispensable dimension of capacity for adaptation, and where threatened represent a major risk to Indigenous communities. While still robust among Indigenous Peoples in many parts of Africa, Asia and Latin America, Indigenous knowledge is not well reflected or incorporated in assessments such as this, and stands in danger of being lost as its custodians are passing away.

Indigenous knowledge about natural hazards enables communities at risk to take steps to reduce climate risk. Indigenous knowledge systems are locally indispensable resources for adaptation to climate change, yet are often misunderstood and undervalued. Generally, Indigenous Peoples and other local groups hold relevant local-scale knowledge about environmental change, the impacts of those changes on ecosystems and livelihoods at local scales, and possible locally effective adaptive responses. However, it is important that IKLK is situated within knowledge from other scales in order to assess its broader relevance and applicability (Ahlborg and Nightingale, 2012). Some authors suggest including Indigenous knowledge in the IPCC assessment process should be of high priority, as it is becoming increasingly relevant for climate services (*high confidence*) (Strauss and Orlove, 2003; Crate and Nuttall, 2009; Crate, 2011). Their knowledge can draw attention to climate baselines and change, and identify adaptation priorities, such as plant and animal species that should be protected given local contextual environmental considerations. For example, using Indigenous knowledge in weather and climate prediction, local communities in different parts of Tanzania have been coping with, and adapting to, increased climate variability normally manifested in the form of increased frequency and magnitude of various exigencies, including droughts and floods, and outbreak of pests and diseases (Kijazi et al., 2013). Prediction of impending hazards has been an integral part of Indigenous Peoples' adaptation strategies. Various environmental and astronomical indicators are used to predict rainfall, including plant phenology, behaviour and movement of birds, animal and insects, in many parts of Tanzania (Kijazi et al., 2013).

There are efforts in developing adaptation plans that utilise local knowledge. Local knowledge-based adaptation is focused primarily on the use of traditional knowledge to increase adaptive capacity at the community level and less on integration (Mimura et al., 2014). Hence, there is need to increase effectiveness of policy processes that work towards integration of local and scientific knowledge (Nakashima et al., 2013; IPCC, 2014a).

8.5.2.4 Physical Capital

Ensuring sufficient investment in physical capital is vital to support development pathways at the national level, but for the poorest and most marginalised in society, physical capital represents an invaluable source of adaptation options (Hallegatte et al., 2019). Physical capital constitutes assets such as land, roads and other infrastructure (e.g., water supplies, electricity, mobile phone connectivity), housing and other buildings, as well as the materials and tools needed to make a living (e.g., farming, forestry and fishing equipment, transportation vehicles, technology). It can also help to foster a sense of place, and can support well-being. Climate change impacts on physical capital are often widespread, as well as economically and emotionally costly, particularly when communities are afflicted by hardship (inadequate levels of sustainable human development through access to essential public goods and services and access to income opportunities) (Abbott and Pollard, 2004).

Given the massive scale of investments required to build and sustain physical capital at the state level, it is imperative to ensure physical capital decisions consider climate resilience; not least because retrofitting and replacing are both highly costly. The World Bank estimates that adapting over the period 2010–2050 to a world that is 2°C warmer by 2050 will cost USD 70 billion to USD 100 billion per annum, with the infrastructure sector accounting for the largest share of costs (World Bank, 2010). At the same time, every USD 1 invested in preventive measures can save USD 5 of repairs (PRIF, 2013). While adequate financing and technical expertise are required, as well as foresight in planning and design and climate risk screening, successful adaptation relating to physical capital also demands legal and institutional enablers (e.g., development and enforcement of building codes and regulations; roll out of insurance options; planning restrictions to reduce construction in locations that are highly exposed to climate hazards, etc). In some situations, these are lacking. For example, low-lying LDCs, such as Bangladesh, as well as SIDS, regularly suffer from climate events such as floods, typhoons, cyclones, hurricanes and saline intrusion (see Chapter 15 on small islands). Hazards such as typhoons cause substantial damage and destruction, impede mobility, reduce connectivity, disrupt communications, food, water and energy supplies, and render people homeless and without the assets they rely on to make a living. In the absence of adequate legal and institutional enablers, as well as livelihood assets, the maintenance of physical capital is far more challenging, as the case of Cyclone Aila in Box 8.8 demonstrates.

Physical capital in the form of technology is increasingly supporting climate change adaptation, despite that innovations can be rolled out under high uncertainty, opening up new risks (e.g., hacking). Moreover, deployment of technology is closely tied to other forms of capital, especially human capital, and innovations cannot just be rolled out in the absence of suitable institutional and technical support and training. Similarly, access to finance is vital. Some technological adaptations require a pre-existing level of infrastructure and literacy, raising important questions about inequality (Taylor, 2018). Rotz et al. (2019) warn of automation impacts on rural labour, especially in places with high youth unemployment, while Taylor (2018) notes that social classes and gender are impacted differently by technological change, and failure to address underlying inequalities will shape who becomes vulnerable. Adequate testing of technologies in terms of their applicability to different contexts is also required, ensuring they do not become maladaptive when applied at scale.

Similarly, technology must always be grounded in an appreciation of the cultural context. Research in the European Arctic with the Indigenous Sami Peoples found that use of GPS technology on reindeer, together with supplementary feeding, offered useful adaptations for some herders. However, there are fears such technologies may, over time, reduce the skills, cultural knowledge and Indigenous adaptations of the Sami (Andersson and Keskitalo, 2017), as, for example, reindeer become tamer through supplementary feeding, affecting their range selection. Overall, technology and other adaptations should seek not to erode Sami culture's adaptive capacity (Vuojala-Magga et al., 2011; Risvoll and Hovelsrud, 2016), particularly because reindeer grazing as a land management practice can play a useful climate change mitigation role too. Reindeer grazing protects tundra from tree line and bush encroachment, while summer grazing increases surface albedo by delaying snowmelt (Jaakkola et al., 2018).

8.5.2.4.1 Socio-cultural Factors

Social and cultural factors are closely linked to values, beliefs and identities (Heimann and Mallick, 2016) and mediate the ways in which people respond to climate variability and change (Adger et al., 2013). There is *limited evidence* but *medium agreement* about the importance and role of social and cultural factors in shaping adaptation, in terms of

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Box 8.8 | Cyclone Aila in Bangladesh: impact, adaptation and way forward

Historically, southern coastal Bangladesh, where the 1970 Bhola Cyclone killed 500,000 people, has been considered among the most climate-vulnerable environments on Earth. However, in recent decades, extreme weather events, like Cyclone Aila, though still destructive and destabilising, have resulted in lower death tolls thanks to a concerted investment in flood mitigation infrastructure, a dense network of cyclone shelters and a robust early warning system (Chowdhury et al., 1993; Paul, 2009). Cyclone Aila struck the southwest coast of Bangladesh on 25 May 2009 with a wind speed of 120 km hour^{-1} (Islam and Hasan, 2016). With tidal surges of up to 6.5 m, occurring over dry pre-monsoon soils, 11 coastal districts and more than 3.9 million people were affected (United Nations, 2010), 190 people died and 7100 people suffered injuries (Saha, 2017).

Aila greatly damaged the region's physical capital, including 6000 km of roads and 17,000 km of embankments. The cyclone polluted and damaged sources of drinking water and destroyed 243,000 houses and thousands of schools (Mallick et al., 2017; Paul and Chatterjee, 2019). In Satkhira and Khulna districts alone, 165,000 houses were destroyed and households were forced to live on damaged embankments in makeshift shanties (UNDP, 2015). Many people had to live in these temporary shelters for years (Saha, 2017). Aila occurred during a high tide and the surge of saline water inundated not only the roads, embankments and houses but also vast areas of agricultural field and shrimp farms (Paul and Chatterjee, 2019) leaving many areas waterlogged for months (Abdullah et al., 2016; Mallick et al., 2017). The effect of saline water logging inside embankments caused further harm to houses, roads and culverts, adding more barriers to the post-disaster reconstruction activities (Roy, 2020). In the same area, tube-wells were damaged. Women had to travel up to 2 km every day to collect safe water, spending 30–90 minutes on this activity daily (Alam and Rahman, 2019). The distribution of costs across different socioeconomic groups was not always as expected. A study in Aila-affected Koyra sub-district of Khulna found that households with higher incomes were more vulnerable to Aila in both relative and absolute terms compared to middle- and low-income groups mainly due to damage to shrimp farming, which underpinned their livelihoods (Abdullah et al., 2016). This highlights how specialised livelihoods can leave people more vulnerable as they have fewer options. However, the same study found that the damage to physical capital such as fishing nets and boats was statistically significantly greater for middle- and low-income groups. Damage to houses was statistically significantly more among poorer households followed by middle- and higher-income groups.

A range of coping and adaptation actions were enacted in response to losses of and damage to physical capital (Table Box 8.8.1). Actions varied across the different affected areas and were taken by the households themselves, by the government and by NGOs.

Table Box 8.8.1 | Coping and adaptation actions enacted in the Cyclone Aila-affected area in response to losses of and damage to physical capital.

Coping and adaptation actions	Action group	References
Human migration—mostly forced due to loss of houses as well as other resources and livelihood activities	Households	(Abdullah et al., 2016; Mallick et al., 2017; Paul and Chatterjee, 2019)
Alternative livelihood activities such as crafts, and honey and wood collection from the Sundarbans, due to irreparable damage to fishing gear	Households	(Alam et al., 2015)
Saving money for house repairs or construction	Households	(Alam et al., 2015)
Underground storage of emergency items such as foods, matchbox, cooker and cooking fuel	Households	(Alam et al., 2015)
Selection of high land to build shelter along both sides of the embankments	Households	(Alam et al., 2015)
Tree plantation in the homestead periphery to protect the house from gusty winds and to use as a source of wood for house repair/construction	Households	(Alam et al., 2015)
Increasing height of the house plinth	Households	(Alam et al., 2015)
Changing of house roofing material from thatched to corrugated iron sheet or asbestos	Households	(Alam et al., 2015)
Informally allowing people to harvest Sundarbans forest wood without any charge so they could make makeshift houses	Forest Department	(Abdullah et al., 2016)
Rainwater harvesting using plastic or clay pots and artificial aquifer tube-wells for securing drinking water.	NGOs and households	(Sultana and Mallick, 2015)
Replacement of mud walls of houses with wood or bamboo sticks to enhance durability	NGOs and households	(Sultana and Mallick, 2015)
Making thick shelterbelts along coastal embankments	NGOs and households	(Rahman and Rahman, 2015)

The impacts of some of these adaptations, particularly engagement in new livelihood activities after Aila, were varied, with income of the affected households increasing in some cases and decreasing in others. In Koyra, the income of the poorest and middle-income households increased by 16% and 4%, respectively, while the income of richer households (many of whom lost physical capital assets that they used to pursue their livelihoods) decreased by 50% (Abdullah et al., 2016).

Box 8.8 (continued)

Research into adaptation projects led by various actors has shown that adaptations taken by the households and community themselves are effective only to address typical challenges (such as seasonal shifts in temperature or rainfall) but are less effective in addressing extreme events that have long-lasting impacts. This is mainly due to lack of adequate resources and institutional support (Alam et al., 2015). At the same time, some coping mechanisms are harmful in the longer term, for example, harvesting Sundarbans forest wood after Aila for reconstruction could have negative impacts on the forest.

As of 2017, many of the affected areas had not yet been able to recover from the effects of Aila (Paul and Chatterjee, 2019). A transformative approach needs to be taken not only to help them recover in livelihood terms, but also to support people's well-being. Suggestions of physical interventions that are needed include higher and stronger dykes, cyclone-resistant housing, active maintenance and strict policing of embankment use and good governance (Abdullah et al., 2016). Enabling formal institutions could help, for instance, by improving the climate resilience of physical capital (e.g., by developing and enforcing building codes for houses). Other institutional mechanisms could help to improve access to low interest credit, prevent maladaptation, improve enforcement of laws, and provide insurance. However, such institutional reforms need to be co-developed with local people and incorporate local cultural mechanisms (Islam and Nursey-Bray, 2017). Future adaptation strategies also need to consider the limits to autonomous adaptation (i.e. that without external intervention) and differential level of impacts and adaptive capacities among different groups of households in the Aila-affected areas. This example illustrates the importance of a more comprehensive approach to resilience building, and the need to better understand the interlinkages between the core components of an enabling environment for adaptation (see Figure 8.12).

both the need to adapt and the way it is presented and communicated, although evidence is somewhat mixed in terms of how experiences of weather affect opinions and perceptions of climate change (Howe et al., 2019). Research also highlights the importance of context in understanding relations between perceptions of risks and behaviour, arguing that power relations and other obstacles and opportunities play a vital role in shaping actions (Rufat et al., 2020). In general, nonetheless, adaptation is spurred when people perceive that there is an action they can take to make a difference (Kuruppu and Liverman, 2011; Mayer and Smith, 2019), although it cannot be assumed that action will be taken if the socio-cultural setting is not amenable and it contravenes the values underlying people's perceptions (Kwon et al., 2019). Research testing for the effect of beliefs on behavioural change from 48 countries highlighted the need for policy leaders to present climate change as solvable yet challenging, if fatalistic beliefs that act as barriers to adaptation were to be reduced (Mayer and Smith, 2019). This demonstrates how beliefs do not always reinforce actions, even when risks are perceived. Similarly, research from Burkina Faso working with the Fulbe ethnic group found that cultural norms restricted engagement in four of the most successful livelihood strategies that support adaptation to climate change (labour migration, working for development projects, gardening and female engagement in economic activities) (Nielsen and Reenberg, 2010). Cultural factors therefore play an important but under-researched role in adaptation.

Social factors in the context of adaptation, by contrast, are more widely studied. The literature on adaptation and the role of social capital as an enabler is diverse. There is *high confidence* that during disasters, social capital plays an important role in linking those who are affected to external supports and resources. On small islands, social networks can be dense and support adaptation (Petzold and Ratter, 2015), with traditional knowledge and societal cohesion helping small island communities to have self-belief and build resilience even in the absence of external interventions (Nunn and Kumar, 2018). Even the development of weak ties (e.g., one-way information transfer) can lead to the establishment of mutual collaboration relations that can be more easily drawn on in times of climate change-related shocks and stresses (Ingold, 2017), while collective shared disaster experiences can cause new social groups to emerge and spur action, linked to a perceived common fate (Ntontis et al., 2020). However, this can exacerbate inequalities and create new ones, with those who are more connected having enhanced access to, for example, shelters following storm evacuations or earthquakes (Rahill et al., 2014). In adapting to more incremental changes, social capital has been shown to increase shared local knowledge and awareness, support participatory processes and strengthen ties to corporate and political institutions, increasing their responsiveness to local concerns, as shown by examples from Aldrich et al. (2016). They describe how in Houma, Louisiana, located west of New Orleans, rising sea levels and hurricane risks have drawn on and built social capital at the community level. Having what was perceived locally as insufficient federal government support, residents, church groups and town council members collaborated to spur adaptation. Community mobilisation led to construction of self-funded levees and water projects to protect 200,000 residents from storm surges. Projects include marshland restoration, the elevation of existing housing, improved pumping systems and canal drainage, as well as buyouts and relocations of businesses and housing that has been repetitively damaged. Funds were raised from households through donations via a self-imposed sales tax. While this example paints a positive picture of the role of social capital and collective action in adaptation activities, it also raises questions about the coherence of actions across levels, again, highlighting a role for polycentric governance if risks of maladaptation are to be reduced. The danger in the example presented here is that should federal plans conflict with the community level work in the future, local efforts may have been in vain if installations have to be removed. This highlights the importance of careful evaluation of all adaptation options on an ongoing basis.

Further warnings about social capital as an adaptation enabler come from Acosta et al. (2016) who recognise that it may be detrimental to private adaptation in some cases. Their research in rural Ethiopia found that qualitative measures of trust predict contributions to public goods, supporting theories about collective action, but that the effects of social capital are not homogenous: it can be helpful in some contexts, but unhelpful, or even detrimental in others. This led them to highlight the need for policymakers to consider these potentially different outcomes. Other research, also from Ethiopia, suggested that households with more social capital are more specialised in their livelihood strategies. This could leave them more vulnerable to climate change impacts (as per the Cyclone Aila example where shrimp farmers were specialised and hit hardest by the cyclone's impacts), though social capital acts as a kind of informal insurance (Wuepper et al., 2018).

8.6 Climate Resilient Development for the Poor and Pro-poor Adaptation Finance: Ensuring Climate Justice and Sustainable Development

This section evaluates climate resilient development (CRD) focusing on potential synergies between adaptation and mitigation in different sectors, decision-making approaches and adaptation finance, especially for the poor. It examines whether climate change response options, meaning mitigation and adaptation, in different development sectors, create development synergies or trade-offs for low-income households and people living in poverty.

The link between development and climate change was not evaluated comprehensively until the first decades of the 21st century (Figure 8.13; Klein et al., 2005; Tol, 2005). Until recently mitigation and adaptation, the two primary approaches to climate action, have been dealt with separately in climate change science and policy (Landauer et al., 2015). Nevertheless, synergistic 'co-benefits' between mitigation and adaptation may be enhanced, and trade-offs reduced, through the holistic empirical evaluation of actions for climate change response (Runhaar et al., 2018). The synergistic effect of mitigation and adaptation has been documented for a few interventions across the globe, however, evidence-based quantification of the synergies and trade-offs are rare.

Where co-benefits have emphasised identifying mitigation–adaptation synergies, a key turn has been evaluating climate compatible development (CCD), 'development that minimises the harm caused by climate change impacts, while maximising the many human development opportunities presented by a low emission, more resilient future' (Mitchell and Maxwell, 2010). CCD calls for triple wins, resulting

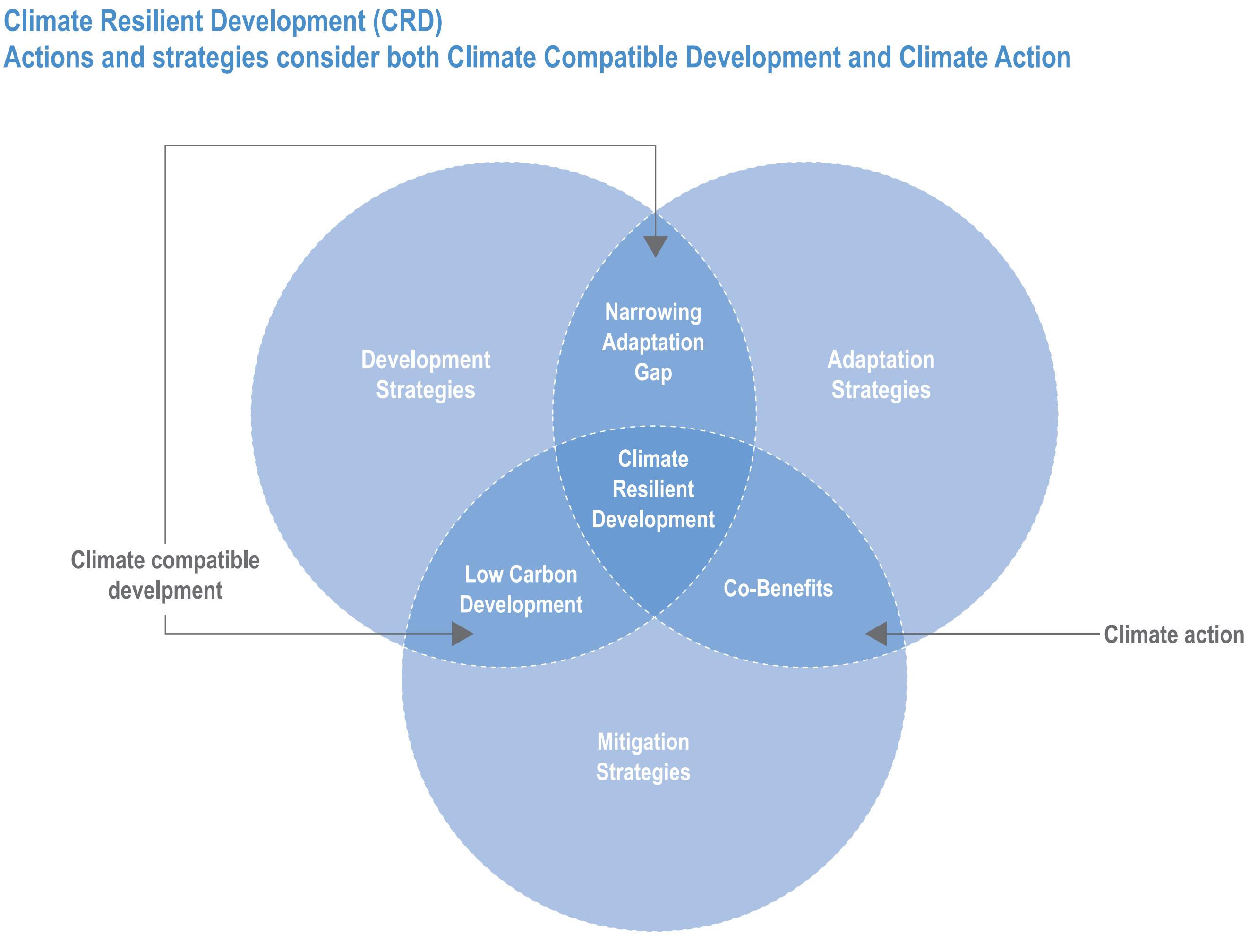

Figure 8.13 | Climate resilient development (CRD). Actions and strategies consider both climate compatible development (CCD) and climate action.

in synergies between mitigation–adaptation–development through single interventions (Figure 8.13; Ellis and Tschakert, 2019). CCD offers specific entry points for identifying ways on how to strengthen synergies between mitigation and adaptation, particularly within the context of low-income countries. Effective integration of emission reductions and accommodation actions for mitigation and adaptation can be win–win strategies, may be cost-efficient (Runhaar et al., 2018) and have the potential to create opportunities to foster sustainable development (Denton et al., 2014).

This assessment identifies and evaluates approaches to CRD 'that deliberately adopt mitigation and adaptation measures to secure a safe climate, meet basic needs, eliminate poverty and enable equitable, just and sustainable development'. The body of literature on the synergies and trade-offs between adaptation, mitigation, poverty, equity and sustainable development has grown steadily since the AR5 (IPCC, 2014a). The IPCC Special Report on the impacts of global warming of 1.5°C (IPCC, 2018c), suggests that 'Limiting warming to 1.5°C can be achieved synergistically with poverty alleviation and improved energy security and can provide large public health benefits through improved air quality, preventing millions of premature deaths.'

Implementing the integrative concept of CRD is expected to produce transformative benefits affecting the poorest populations primarily (Roy et al., 2018; Leal Filho et al., 2019). The risks of transformative actions to the poor are diminished when undertaken in the context of good governance at multiple levels, within existing top-down and bottom-up processes, and making use of available levers of policy, technology, education and financial/economic systems (Stringer et al., 2020).

8.6.1 Synergies and Trade-offs Between Adaptation and Mitigation in Different Sectors with Implications for Poverty, Livelihoods and Sustainable Development

8.6.1.1 Climate Resilient Development

CRD relies on identifying synergies between different strategies and actions in the field of climate change, primarily between mitigation actions with adaptation benefits (Locatelli et al., 2015), adaptation actions with mitigation benefits (Denton et al., 2014; Sánchez and Izzo, 2017), processes that promote both mitigation and adaptation measures, and policies and strategies that promote integrated mitigation and adaptation measures (Zhao et al., 2018). At the same time, adaptation and mitigation actions can be evaluated in terms of their co-benefits, the social, economic or other benefits of actions in addition to avoiding climate change impacts (Karlsson et al., 2020). The clearest co-benefits of mitigation are associated with economic development through low-carbon industrialisation (IPCC, 2014c; Jakob et al., 2014; Lu, 2017). Co-benefits can include contributing to economic growth, reducing competition for resources, improved integration of scientific input to policy development and implementation, or improving political participation and social licensing in large-scale

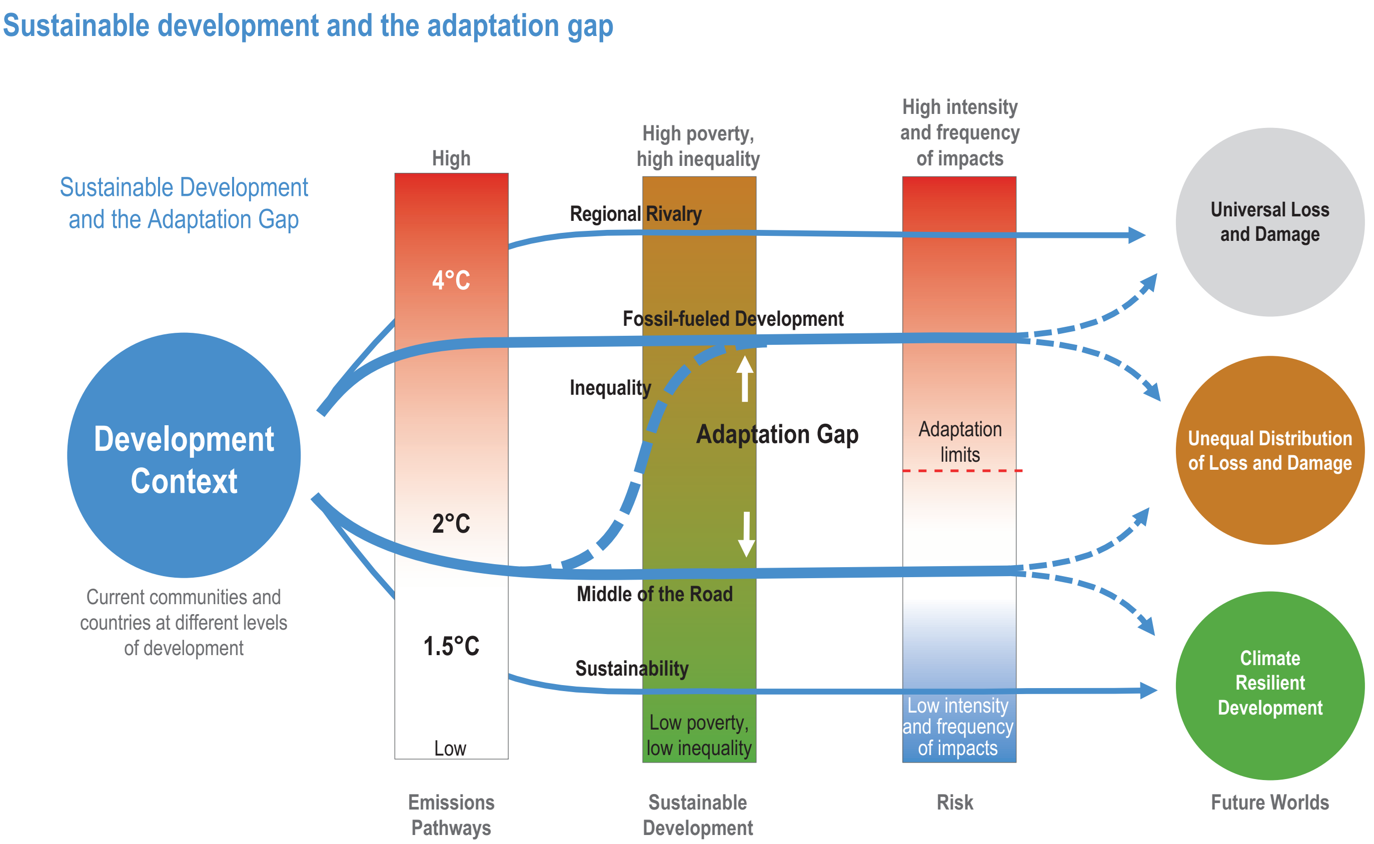

Figure 8.14 | Conceptual figure illustrating the link between sustainable development and the adaptation gap. Even if emissions are kept low, if poverty and inequality remain high, then impacts are expected to remain high and may overwhelm capacity for adaptation.

https://doi.org/10.1017/9781009325844.010

projects (e.g., hydropower) (Hennessey et al., 2017). Adaptation can support mitigation and contribute to co-benefits in various ways: ensuring development-based natural resource management (Denton et al., 2014; Suckall et al., 2015; Reang et al., 2021), integrating water resources management (Liang et al., 2016; Sharifi, 2021), practicing sustainable agriculture (Bustamante et al., 2014; Duguma et al., 2014a; Di Gregorio et al., 2017; Reang et al., 2021), ensuring the protection of ecosystem services (Pandey et al., 2017a; Baumber et al., 2019), conserving biodiversity (Di Gregorio et al., 2017; Loboguerrero et al., 2019; Smith et al., 2019) and managing bioenergy resource (Dovie, 2019).

The key challenge for CRD is addressing climate change from the perspective of development: addressing the fundamental development obstacles that limit capacity for adaptation. Where development is not sustainable, especially if it is not equitable, capacity for adapting is greatly reduced—a phenomenon known as the adaptation gap (Figure 8.14; Birkmann et al., 2021a; UNEP, 2021). Figure 8.14 depicts the effect of development trajectories (as described in the SSPs framework) on capacity for adaptation, a key determinant of eventual outcomes. Achieving CRD through coupling adaptation with equitable sustainable development under and low emissions profiles that limit warming to 1.5°C (i.e., sustainability scenario) is necessary to close the adaptation gap. Even if emissions are kept low and 1.5°C emissions targets are achieved, if poverty and inequality remain high, then impacts are expected to remain high and may overwhelm capacity for adaptation. High poverty and high inequality in a society (i.e., inequality scenario) reduce the likelihood that countries are able to manage risk and avoid residual impacts, such as also documented in the assessment above (see Sections 8.2; 8.3; 8.4). Unsustainable development trajectories reduce capacity for adaptation and may result in highly unequally distributed residual impacts from climate change. Even despite rapid, equitable development and modest emissions reductions efforts necessary to limit warming to 2°C (i.e., the middle of the road scenario), there is still risk of unequal distribution of impacts. Under all high emissions scenarios (>3°C warming), universal residual impacts are unavoidable.

Mitigation planning has not sufficiently considered poverty reduction policies, the basis for narrowing the adaptation gap (see also Figure 8.14). Many synergies between climate change mitigation and poverty reduction have been identified, although sometimes with *limited evidence*. The mitigation measures that have been most evaluated include clean development mechanisms (CDM), programmes aimed at reduction of emissions from deforestation and forest degradation (REDD+), voluntary carbon offsets and biofuel production. However, while these mitigation programmes stimulate economic growth, they may contribute to processes that trade-off against equitable development and threaten to further impoverish forest communities, such as large-scale land acquisitions (Carter et al., 2017; Schaafsma et al., 2021) and fortress conservation (see IPCC SR 1.5°C, Chapter 5 (Roy et al., 2018); and see also Chapter 6 of this report).

The IPCC Special Report on Climate Change and Land (IPCC, 2019a) states that agriculture, food production and deforestation are major drivers of climate change and calls for coordinated action to tackle climate change that can simultaneously improve land, food security and nutrition, and help to end hunger. There are five land challenges identified including climate change mitigation, adaptation, desertification, land degradation and food security. This report identified three major categories of climate response options that show promise for achieving mitigation and increasing capacity for adaptation while addressing poverty: SLM options, value chain management and risk management options (IPCC, 2019a). For example, programmes supporting no-till agriculture and residue retention allow small-scale farmers to participate in mitigation and adaptation activities, with long-term benefits to soil health and food, energy and water security (Wright et al., 2014). Likewise, the installation of a solar powered drip irrigation system simultaneously reduces emission, improves water security and increases farmers' income (Locatelli et al., 2015). Response options in terms of SLM options, and value chain and risk management involve interlinkages between land-based climate strategies, synergies and trade-offs (see Chapter 6). On the other hand, a key trade-off is the potential for maladaptation, where one adaptation intervention at one time, location or sector could increase the vulnerability at another time, location or sector, or increase the vulnerability of the target group to future climate change (*medium evidence, high agreement*) (Eriksen et al., 2011). A cause of increasing concern to adaptation planners is the understanding of maladaptation has changed subtly to recognise that it arises inadvertently, from poorly planned adaptation actions, but also from carefully deliberated decisions where wider considerations place greater emphasis on singular or short-term outcomes ahead of broader, longer-term threats, or discount, or fail to consider, the full range of interactions arising from the planned actions across scales (Eriksen et al., 2021). Research identifies the challenge of avoiding maladaptation as one of reducing long-term structural vulnerability. Accordingly, one can consider CCD and maladaptation as two sides of the same coin. Scholars of 'sustainable adaptation' define it as adaptation that contributes to socially and environmentally sustainable development pathways, which takes into account both social justice and environmental integrity (Eriksen et al., 2011). The parallels in maladaptation include the underlying drivers of vulnerability, namely socio-environmental processes such as conflict, marginalisation, economic restructuring, exploitation, institutional fragility and so forth (Antwi-Agyei et al., 2018b; Neef et al., 2018).

Harnessing opportunities for mitigation, adaptation and development in an effective manner may lead to 'triple wins' under CRD, though empirical evidence is extremely rare for such triple win strategies that address mitigation, adaptation and development in an effective manner (Tompkins et al., 2013). Integration of mitigation, adaptation and development is being initiated and operationalised through projects by several developing countries to achieve main national development priorities, such as poverty reduction, increased employment opportunities, energy security and transportation (Denton et al., 2014; Stringer et al., 2014). Important follow-on questions are pressing social questions about how trade-offs are deliberated, who wins and loses and who decides (see Section 8.4 and Ellis and Tschakert, 2019). Likewise, the efficiency, effectiveness and feasibility trade-offs of climate policies must be considered (i.e., can programmes in developing countries be economically efficient and provide opportunities to achieve sustainable development targets for developing countries?) (Dang et al., 2003). Moreover, questions about co-benefits must consider the benefit–cost ratio of mitigative versus adaptive action for assets saved from destruction by climate impacts, for example (Stadelmann et al., 2014). Implementing a mitigation or adaptation option may positively or negatively, directly or indirectly, affect the feasibility and effectiveness of other options, such as soil management leading to soil organic carbon (Locatelli et al., 2015; de Coninck et al., 2018). Farmers and local people are often also being encouraged to undertake mitigation and adaptation activities leading to long-term benefits, such as cultivation of no-till wheat with residue retention leading to low emissions along with saving energy and water (Wright et al., 2014).

Moreover, a regulatory structure for evaluation of mitigation and adaptation actions is required to understand the co-benefits of these two actions. For example, the choice of adaptation actions can be made according to their effectiveness per unit of money invested such as economic assets saved from destruction of climate change impacts and benefits can be evaluated in terms of economies, people and the environment, such as human lives and health protected rather than the emission reduction by mitigation strategies (Stadelmann et al., 2014).

8.6.1.2. Climate Resilient Development Synergies and Trade-offs by Sector

Some sectors—such as agriculture, forestry, energy—are found to have more potential for CRD synergies than others, although trade-offs are also identified. CSA, carbon-forestry programmes and the water–energy–climate nexus show trade-offs across levels and sectors with identified winners and losers (*high confidence*) (IPCC, 2018a). Mitigation can be designed to provide opportunities for enhanced adaptation with comparable co-benefits, even while adaptation portfolios can maximise co-benefits around sustainable resource management that reduce emissions (Dovie, 2019). Climate policy integration can be considered as the integration of multiple policy objectives, governance arrangements and policy processes of climate change mitigation and adaptation along with other policy domains (Di Gregorio et al., 2017), as well as sector policies integrating climate change adaptation and mitigation (England et al., 2018). Integrating climate policies may require balancing multiple sectoral goals, such as REDD+ projects, CSA, water sector strategies, national policies on climate change and national conservation plans (Duguma et al., 2014a). Within the scientific discourse, increasing attention is given to the question of the synergies and mismatches between mitigation and adaptation policies.

The assessed literature underscores that for synergies to be realised, mitigation and adaptation policies must be institutionally supported within a multi-level governance architecture (national to sub-national to municipal levels) with other priorities, and sustainable financing mechanisms identified within the country or via the international community (Dovie and Lwasa, 2017). Integrating and mainstreaming adaptation and mitigation across agencies within countries can bridge the divide between climate policy and sustainable development (Venema and Rehman, 2007).

The Paris Agreement recognised that the agreement will reflect equity and CBDR-RC of national circumstances, (Voigt and Ferreira, 2016) and should be broadened to include mitigation co-benefits (Dovie, 2019). Integrating adaptation with mitigation may possibly contribute to amending or reducing the discursive rift between climate policy and sustainable development (Venema and Rehman, 2007).

Integrated climate change actions or responses can be inefficient and infeasible in the absence of enabling conditions, including the policy conditions that reinforce unified climate action, and sustainable financial mechanisms for implementation of the programmes and policies (Duguma et al., 2014b). In the absence of strong coordination, integrating mitigation and adaptation may undermine the overall or individual objectives of either climate response (Kongsager, 2018). A lack of coordination in mitigation and adaptation may also exacerbate the threats of climate change to sustainable development (Ayers and Huq, 2009; Kongsager, 2018). Therefore, for successful integration of CRD, it is necessary to move beyond considering either adaptation or mitigation towards better understanding the linkages between adaptation and mitigation projects and policies at multiple levels of governance to identify potential trade-offs in projects and policies (Suckall et al., 2015) and to identify the enabling conditions for designing and implementing action leading to synergies (Denton et al., 2014; Kongsager, 2018).

Despite the potential effectiveness and efficiency of integrating mitigation and adaptation under a common CRD framework, gaps persist in our knowledge about the enabling conditions for synergies, due to the limited number of examples and even fewer evaluations. Potential benefits may be achieved by pursuing multi-level governance approaches, that means integrating decision making at the local level with coordination at other levels, by actors and agencies simultaneously pursuing multiple other priorities (see Section 8.5.2 Shaw et al., 2014). For example, pursuing climate-resilient land use pathways integrating climate policy within the land use sector requires a governance policy environment that combines multiple policy aims, including urban growth, soil conservation and water management alongside mitigation and adaptation. Facilitating climate-resilient land use pathways combining the aims of climate change adaptation, mitigation and sustainable development requires a governance environment with: (a) internal climate policy coherence between mitigation and adaptation objectives and policies, (b) external climate policy coherence between climate change and development objectives; (c) vertical policy integration that mainstreams climate change into sectoral policies and (d) overarching governance structures that facilitate horizontal policy integration for cross-sectoral coordination (Di Gregorio et al., 2017) as well as sector policies integrating climate change adaptation and mitigation (England et al., 2018).

Within sector policies and economic sectors (such as land use, transportation and technology), mitigation and adaptation have many positive, negative, direct and indirect linkages within and beyond the sector (Locatelli et al., 2015). The land use sector, for example, includes agriculture and forestry, and encompasses the management of a mosaic of interacting urban environments and ecosystems with a diversity of cultural and institutional attributes (Locatelli et al., 2015). The land use sector is key to climate adaptation, where policy coordination can enhance food production, regulate urban microclimates, affect water security and, in the case of mangroves, buffer the impacts of extreme climate events in coastal areas (Locatelli et al., 2015). City-level actions, such as zoning and planning that promotes green development and green and efficient energy use, can also be pivotal for reduction in emissions and improvement in resilience (UCLG, 2015). Urban planning and transport policies, such as means of transportation, are crucial to support a transition towards a low-carbon and resilient future (Ford et al., 2018), as public and private transport facilities are crucial for emission reduction.

CRD may require multi-sectoral coordination, including public–private partnerships (Campbell et al., 2018). In the food system, for example, under a CRD framework transformative actions may require (a) incentives for expanded private sector activities and/or public–private partnerships, (b) publicly backed credit and/or insurance, (c) public institutional support for strong local organisations and networking, (d) climate-informed weather advisories and early warning systems, (e) digital investments in technological transformation for agriculture (e.g., 'digital agriculture' and virtual markets), (f) investments in climate-resilient and low-emission practices and technologies (Duguma et al., 2014b), (g) prioritisation and pathways of change, (h) capacity and enabling policy and institutions are crucial with careful consideration of trade-offs between adaptation and mitigation, and amongst other SDGs for achieving SDG13 'urgent action to combat climate change and its impacts' (Campbell et al., 2018). Moreover, the risks of transformative actions to the farmers is addressed by strong good governance at multiple levels, combining top-down and bottom-up processes along with by a mix of levers that combine policy, technology, education and awareness raising, dietary shifts and financial/economic mechanisms, attending to multiple time dimensions (Stringer et al., 2020).

8.6.1.2.1 Agriculture and food production

Integrated CRD approaches in agriculture, such as CSA, can reduce trade-offs and exploit synergies with biodiversity and food security to reduce the risk of climate change (Di Gregorio et al., 2017; Loboguerrero et al., 2019). There are many technologies and approaches in agriculture that leverage synergies relevant for CRD, including agroecology (Pandey et al., 2017a; Saj et al., 2017), CSA, climate-smart landscapes, organic agriculture mitigating climate change, conservation agriculture, ecological intensification and sustainable intensifications, which in many cases aim to address both adaptation and mitigation to climate change simultaneously (Kongsager, 2018). From these approaches, a number of scalable agriculture technologies have emerged that simultaneously achieve mitigation and adaptation goals, such as reducing water consumption while maintaining grain yield, including alternate wetting and drying irrigation technology (Liang et al., 2016) and aerobic rice production (Wichelns, 2016). Likewise, a number of these approaches have been supported within international and national institutional frameworks (e.g., through incentives) to harness synergies (Kongsager et al., 2016).

CSA is discussed in the scientific literature as an approach that could transform agricultural production systems and food value chains in line with sustainable development and food security under climate change. However, concerns and criticisms have been raised, such as the insufficient consideration of access to entitlements within CSA and the question who wins and loses when applying CSA in different country contexts (see Karlsson et al., 2017; Sain et al., 2017). CSA has three main objectives: sustainably increase agricultural productivity and incomes, adapt and build resilience to climate change, and reduce and/or remove GHG emissions (FAO, 2017). Various CSA technologies are capable of improving crop yields, increasing net income, increasing input-use efficiencies and reducing emissions (Khatri-Chhetri et al., 2017). However, uptake and adoption of CSA by local farmers in poor developing countries remains a challenge (Palanisami et al., 2015) due to the difficulty of identifying and prioritising of technologies suiting local climate risks and accommodating the farming practices of locals (Dougill et al., 2017; Khatri-Chhetri et al., 2017). An analysis of CSA implementation in Mali, for example, identified major challenges to policymakers' efforts to adopt CSA, including difficulties identifying CSA options and portfolios, valuing them and prioritising investments (Andrieu et al., 2017).

Potential opportunities from CSA may also result from integration of 'technological packages' (Totin et al., 2018), which include new market structures, knowledge infrastructure and agriculture extension services, capacity-building programmes (Dougill et al., 2017; Totin et al., 2018) and institutional support for key enabling programmes, such as crop insurance, agro-advisories and rainwater harvesting (Khatri-Chhetri et al., 2017). CSA is able—if carefully designed—to achieve transformative 'triple wins' for climate and development when it is accompanied by new governance architectures that are socially inclusive and respectful of traditions and livelihoods, and accommodate traditional institutions that underpin the bargaining power of the poorest and most vulnerable groups (Karlsson et al., 2017).

Conservation agriculture (CA), another framework for achieving CRD, is based on three synergistic principles: (a) soil management to reduce soil physical disturbance and reduce its degradation, (b) crop management such as residue management to protect the soil top layers and (c) genetic management to increase agricultural systems' biodiversity and therefore their resilience (DeLonge and Basche, 2017). In the cereal systems of the Indo-Gangetic Plains, India, CA has increased crop yields, returns from crop cultivation and input-use efficiency, in spite of heat stress, while reducing GHGs emissions (Sapkota et al., 2015). However, challenges with CA are also documented in the scientific literature. For example, an evaluation of CA in Malawi noted that adoption of CA was challenged by weak integration of CA in agricultural policies, lack of institutional arrangements of promoters and farmers' experiences (Chinseu et al., 2019).

Locally appropriate agro-ecological practices have clear potential to increase the resilience of livelihoods and enhance adaptation to climate change at field and farm levels across a wide range of contexts, often with significant mitigation co-benefits (Sinclair et al., 2019). Relatedly, agroforestry systems are the intentional integration of trees and shrubs into crop and animal production systems to solve societal challenges including climate change (Raymond et al., 2017). For example, in the tropics, such systems offer viable opportunities to mitigate and adapt to climate change for farmers by transitioning to resilient farming systems and improving farm economy while securing environmental benefits for local and global communities (Swamy and Tewari, 2017). In Western Africa, the high plant functional diversity of agroforestry systems with a mix of trees and crops having different roles, such as shade provision, soil fertilization, fruit production or timber value, maximises benefits and allows alternative adaptation strategies (Tschora and Cherubini, 2020). In spite of various benefits of agroforestry, the expansion of existing areas of agroforestry and the establishment of new agroforestry systems has remained limited (Martineau et al., 2016), mainly due to a lack of institutional support, a lack of expert support to ensure adequate management, weak capacity for monitoring and regulation, and a lack of financial support (Hernández-Morcillo et al., 2018).

The enabling conditions for the expansion of agroforestry include training and expert support programmes for managers and sharing of best practices (Ashraf et al., 2015; Hernández-Morcillo et al., 2018; Tschora and Cherubini, 2020). Other scalable frameworks integrating food and agriculture within CRD include sustainable intensification (SI), which emphasises sustainable practices to safeguard sustainable use of natural resources and meet the growing demand for agricultural production, while building resilience (Thierfelder et al., 2018). Integrated agricultural systems aim to increase farm diversity and lower reliance on external inputs, enhancing nutrient cycling and increasing natural resource use efficiency (Smith et al., 2017), and may have the potential to enhance resilience against climate change impacts and risks (Gil et al., 2017). Policy frameworks that aim to integrate any of these approaches for climate action must account for the costs associated throughout the uptake and adoption process (Gil et al., 2017).

8.6.1.2.2 Livestock

As the consumption of animal protein and products rises along with global standards of living, CRD will require transformations in livestock-centred livelihoods. Livestock are a key contributor to global food security, especially in marginal lands where animal products are a unique source of energy, protein and micronutrients (FAO, 2017; IPCC, 2019a). However, they also contribute disproportionately to total annual anthropogenic GHG emissions globally and influence climate through land use change, processing and transport through emitting CO_2, animal production by increasing methane emissions, and feed and manure production by emitting CO_2, nitrous oxide, and methane, (Rojas-Downing et al., 2017). Mitigation of livestock emissions can be achieved by implementation of various technologies and practices such as improving diets to reduce enteric fermentation, improving manure management and improving animal nutrition and genetics (Rojas-Downing et al., 2017); altering land use for grazing and feed production, altering feeding practices, improving manure treatment and reducing herd size (Zhang et al., 2017). Adaptation strategies in the livestock sector include changes in animal feeding, genetic manipulation, alterations in species and/or breeds (Zhang et al., 2017), shifting to mixed crop–livestock systems (Rojas-Downing et al., 2017), production and management system modifications, breeding strategies, institutional and policy changes, science and technology advances, and changing farmers' perceptions and adaptive capacity (USDA, 2013).

Policies supporting sustainable rangeland management and the livelihood strategies of rangeland users have an outsized influence on both development and climate action (Gharibvand et al., 2015). Climate change adaptation, mitigation practices and livestock production can be supported by policies that encourage diversification of livestock animals (within species), support sustainable foraging and feed varieties (Rivera-Ferre et al., 2016) and strengthen institutions such as agricultural support programmes, markets and intra- and inter-regional trade (Zhang et al., 2017). For example, sustainable pastoralism can contribute to mitigation both by increasing carbon sequestration through improved soil management and by reducing methane emissions through changing the mix and distribution of the herd. Likewise sustainable pastoralism can also contribute to adaptation by changing grazing management, introducing alternative livestock breeds, improving pest management and modifying production structures (Joyce et al., 2013). Another example of rangeland adaptation is diversifying the use of rangelands, such as supplementing with payments for ecosystem services, carbon sequestration, tourism or supplementary assistance for all land-based activities (Gharibvand et al., 2015). However, challenges for climate-smart livestock production systems remain due to a lack of information, limited access to technology and insufficient capital (FAO, 2017). Smallholders in cropping and livestock systems in sub-Saharan Africa and South Asia, for example, face obstacles obtaining climate change mitigation and adaptation synergies due to poor access to markets and relevant knowledge, land tenure insecurity and the common property status of most grazing resources (Descheemaeker et al., 2016). Consequently, the appropriateness of these strategies and measures needs to be further evaluated, particularly in terms of their usefulness for the poor and most vulnerable.

Overall, different farming and pastoral systems can achieve reductions in the emissions intensity of livestock products. Depending on the farming and pastoral systems and level of development, reductions in the emissions intensity of livestock products may lead to absolute reductions in GHG emissions (IPCC, 2019a) (*medium confidence*). Significant synergies exist between adaptation and mitigation, for example, through SLM approaches (*high confidence*).

8.6.1.2.3 Forestry

Forests can support CRD in rural communities and households: they support consumption of energy, food and fibre, provide a safety net in cases of shocks, fill gaps during seasonal shortfalls and are a means to accumulate assets and provide support to emerge out of poverty (Angelsen et al., 2014; Adams et al., 2020). Forest ecosystems are an essential element of climate change mitigation and adaptation, with the potential for synergy and conflict between the two climate action objectives (Morecroft et al., 2019). However, there are varied perspectives on the role of the forests, with some treating conservation and forest management practices as a barrier to livelihood resilience (Few et al., 2017) despite the broader role of forest management in climate mitigation (Houghton, 2012).

Forestry mitigation projects such as forest conservation, reduced deforestation, protected area management and sustainable forest management, can promote adaptation and can also have consequences for the development objectives of other sectors (e.g., expansion of farmland) (Smith et al., 2014). REDD+ (reducing emissions from deforestation and forest degradation, fostering conservation and sustainable management of forest and enhancement of carbon stocks) is a payment programme that may provide adaptation benefits by enhancing households' economic resilience (Sills et al., 2014; Duchelle et al., 2018) and also produce positive livelihood impacts through the employment benefits of supporting conservation and sustainable management of forests (Caplow et al., 2011). Furthermore, the management of ecosystem services may contribute to both mitigation and adaptation. For example, REDD+ projects, such as mangrove conservation and restoration, simultaneously contribute to carbon storage and diversification of incomes and economic activities. At the same time, mangroves protect coastal areas against flooding and hydrological variations, improving capacity for adaptation in local livelihoods (Locatelli et al., 2016).

However, while studies of existing REDD+ programmes noted the moderately encouraging impacts for mitigation and small or insignificant impacts for adaptation options (especially well-being), they underscored the potentially damaging impacts to local livelihoods (Milne et al., 2019; Skutsch and Turnhout, 2020). They suggested improved engagement with local communities, increased funding to strengthen the interventions on the ground, and more attention to both mitigation and adaptation outcomes in implementation for achieving the benefits of REDD+ programme (Duchelle et al., 2018). Moreover, to effectively counter local threats to forests and biodiversity and attain positive biodiversity and development outcomes, REDD+ programmes must be focused on better institutional support for governance, coordinating interventions and monitoring of plans, as well as making explicit linkages between REDD+ activities and national biodiversity conservation efforts (Panfil and Harvey, 2016) and assuring a fair distribution of benefits to local communities (Myers et al., 2018). An analysis of country-specific REDD+ programmes in Cameroon looking at synergies of REDD+ with other national goals, such as poverty reduction, identified two principal modes of strategic interaction management among actors. The first priority relates to specific structures for designing REDD+ giving high priority to social safeguards. The second relates to programming that builds trust, communication and confidence of participants creating an environment for enabling management through commitment and behavioural interaction by creating an overarching institutional framework and unilateral management (Somorin et al., 2016).

To achieve CRD, forestry conservation strategies need to be driven by climate action and forest management policies that benefit both ecological and human systems, and, above all, involve forest communities in programme and project implementation (Cordeiro-Beduschi, 2020). Synergies between mitigation and adaptation of the forestry sector can be enhanced by considering on-the-ground contexts of constraints and social trade-offs that may undermine implemented actions (Few et al., 2017). However, the lack of knowledge about trade-offs and synergies at the local level and between local and global scales makes this challenging.

Despite these constraints, forestry can serve as a foundation for CRD when adaptation and mitigation activities are effectively integrated from the stage of policy formulation with consideration of specific institutional structures and procedures that can help to facilitate such integration (Locatelli et al., 2015). Effectively integrated adaptation and mitigation activities can be achieved by encouraging collaboration between the two activities, promoting research on the impacts of the integrated activities, their cost-effectiveness and their synergies within the complex setting of risks and uncertainty concerning the magnitude of climate change impacts (Bakkegaard et al., 2016), along with facilitating participation of communities in the two activities and defining forest policies (Ngum et al., 2019). Moreover, international donors and funds are also critical to guide countries to identify adaptation–mitigation synergies, through consultation processes, dialogue and awareness raising (Locatelli et al., 2016). Moreover, in order to be effective, nature-based climate solutions such as mixed species plantation, forest expansion and REDD+, must be people-centric and respond to the needs of the rural and Indigenous Peoples who manage ecosystems for their livelihoods, while at the same time supporting the biodiversity of the ecosystems (Temperton et al., 2019; Fleischman et al., 2020).

8.6.1.2.4 Energy

The continued dependence on fossil energy sources for economic development is the primary source of increasing GHGs (Hansen et al., 2017). There is emerging agreement in terms of the importance of the bioenergy sector for climate change mitigation (Jackson et al., 2016; Hansen et al., 2017), however, the options and limitations in terms of transforming the energy systems to support both mitigation and adaptation are still contested.

About 1 billion people globally (12.5% of the world's population) do not have access to electricity (World Bank, 2021), and yet access to electricity is required for basic adaptation strategies, such as the use of air conditioning and fans in homes and working spaces to mitigate heat stress and enable healthier lives, daytime activities and night-time sleep quality. Electrification enables farmers to mechanically pump water from the underground to boost agricultural productivity, stabilise yields and make food security less reliant on erratic rainfall patterns and less vulnerable to dry spells. Access to electricity enables the spread of valuable information through television, radio, computers and smartphones, including weather forecasts and disaster prevention and response (Dagnachew et al., 2018). The increasing access to electricity facilitates SDG 7 coupled with other SDGs and societal goals, including mitigation of climate change (van Vuuren et al., 2018) through reducing energy consumption by the use of efficient technology and appliances. Electricity access can be an important enabler of adaptation action for different purposes in different sectors (Mastrucci et al., 2019).

Low-carbon development strategies can also be compatible with ecological sustainability, as proponents of bioenergy have claimed. Bioenergy can contribute to reducing emissions and energy inefficiencies in agricultural food and bioenergy sectors, while safeguarding food and energy security. However, recent literature also points towards significant tensions and mismatches between increasing bioenergy on agricultural land and local livelihoods and food security (Yildiz, 2019). A growing list of studies have documented the detrimental trade-offs between smallholder food systems and large-scale biofuel production, which include dispossession and impoverishment of smallholder farmers, food insecurity, food shortages and social instability (Hunsberger et al., 2017). Nevertheless, synergies between bioenergy and food security can be promoted by integrated resource management designed to improve both food and water security and access to bioenergy; investments in technology, rural extension, promotion of stable prices to incentivise local production; and use of double cropping and flex crops to provide food and energy (Souza et al., 2017).

Trade-offs of bioenergy can be minimised by replacing land-intensive first-generation biofuels (e.g., oil palm) with second and subsequent generations (e.g., microalgae). However, there are costs of relying on 'sustainable biofuels' as most of the agricultural and non-agricultural land would be needed for cultivation of biofuels along with reduction in patterns of energy consumption a significant reduction in population (Gomiero, 2015). Contrasting impacts on environmental, economic and social sustainability are reported for production and use of biofuels (Azapagic and Perdan, 2011), ranging from positive impacts, such as reduction in GHG emissions, energy security and rural development, to negative impacts, such as risks of increasing food prices, increasing GHG emissions through direct and indirect land use change from production of biofuel feedstocks, and degradation of land, forests, water resources and ecosystems (UNEP, 2009). Biofuel production may cause loss of biodiversity (Jeswani et al., 2020) and may also impact various ecosystem services, such as land, water and food, and may pollute air, water and soil (Scovronick and Wilkinson, 2014). The collective benefits of biofuels could be realised by developing future policies based on integrated systems with a clear understanding about the interactions across sectors and land uses gained by analysing complete value chains (Jeswani et al., 2020).

Clean sources of energy, such as solar and wind, can facilitate both mitigation and adaptation. For example, in South Africa, clean sources of energy provide energy security with huge water savings along with creation of employment, proximity to point of use and, in many cases, less reliance on concentrated sources of energy (Mpandeli et al., 2018). Overall, the increased use of thermal solar panels contributes to reducing GHG emissions and improves air quality, as well as providing benefits to the community and the environment. The differential adoption of solar panels can be managed by simultaneous investment in other technologies that utilise renewable energy along with investment in solar panels (Kaya et al., 2019). Development of a smart electricity grid connected to a renewable energy source reduces GHG emissions and decreases vulnerability to climate change by enhancing the response to changing conditions and providing a more reliable service to the population (Hennessey et al., 2017). Moreover, development of policies for a low-carbon and climate-resilient power system, a local nexus between mitigation and adaptation could be explored (Handayani et al., 2020). For example, use of efficient fuel in urban areas facilitates air pollution reduction and also provides health benefits for urban populations (Ramaswami et al., 2017). Green buildings substantially reduce energy consumption and also improve indoor environmental quality and thus contribute to mitigation and provide societal value in terms of health (MacNaughton et al., 2018). In addition, green-roofed buildings contribute to keeping local temperatures cooler during hot days and thereby reducing energy use for air conditioning and thus contributing to both mitigation and adaptation (Sharma et al., 2016).

Positive synergies between adaptation and mitigation in the energy sector can include changes in production technologies and utilisation of technologies by various industries, changes in consumer or corporate behaviour, and the development of policies that alter the energy sector activities sufficiently to achieve a combination of reduced GHGs emissions and increased benefits for communities (Morand et al., 2015). However, the policy perspective must be based on the country circumstances, especially urbanisation, economic growth and energy consumption matching with the income level of the country (Wang et al., 2018).

8.6.2 Decision-making Approaches for Climate Resilient Development

A range of different traditional economic decision support tools can be used to help guide resource allocation in relation to climate change adaptation (e.g., cost–benefit analysis, cost-effectiveness analysis, multi-criteria analysis) (Watkiss et al., 2016), with a strong focus on monetary values and the present and near-term. There are also tools to assess uncertainty (e.g., iterative risk management) and to guide decision making under uncertainty over longer time frames (through, e.g., real options analysis, robust decision making involving substantial numbers of scenarios, portfolio analysis and rule-based decision support for uncertainty where maximum regrets are minimised). Use of these tools nevertheless requires human capital and skills, and more commonly they are applied to public rather than private (individual/household) adaptation decision processes. Tools grounded in economics can lack sufficient consideration of which groups in society might gain and lose out from particular options (Sovacool et al., 2015; Stringer et al., 2019), neglecting to appreciate non-monetary factors (like well-being) which are non-economic, less tangible and harder to put a value on (see Section 8.3).

This section lists several groups of strategies, including mainstreaming and coherence; dealing with complexities through broader and innovative governance; provision of funding and the associated cost and benefit analysis; and focusing on the community and addressing underlying equity through transformational adaptation.

8.6.2.1 Policy Coherence, Policy Integration and Broader Governance Approaches

Mainstreaming and policy coherence is one of the most proposed strategies for dealing with adaptation and mitigation as a coherent approach, in the context of good governance. Politics, power and interests influence the prospects of achieving integrated climate policy and development goals in practice (Naess et al., 2015). Institutional incoherence has led to inefficiency and ineffectiveness (Di Gregorio et al., 2017). To achieve more coherent institutions and synergies, four major enabling conditions have been identified: (a) planned and/or existing national laws, policies and strategies, (b) existing and planned financial means and measures, (c) institutional arrangements in the country with specific reference to climate change issues and (d) planned and/or existing programmes and initiatives in the country (Kabisch et al., 2016). Another strategy offered is to develop a 'dual track approach' at local/municipality/city level by having a local climate plan and/or mainstreaming plan (Duguma et al., 2014b). This can lead to effective implementation of climate actions and diffusion of climate issues into local sector policies (Reckien et al., 2019). Effective climate policy integration (CPI) calls for four levels of coherence (Di Gregorio et al., 2017), namely between internal coherence (mitigation and adaptation policies objectives and policies), external coherence (climate change and development objectives), vertical integration (mainstream climate change into sectoral policies) and horizontal integration (overarching governance structures for cross-sectoral coordination).

Progress of policy integration varies from the global to local level. Progress in mainstreaming and coherence is emerging globally and has slowly made it down to the national level (Di Gregorio et al., 2017). Adaptation and mitigation should be mainstreamed into planning and implementation on food security programmes, and cross-cutting oversights are required to integrate land restoration, climate policy, food security and disaster risk management into a coherent policy framework (Woolf et al., 2015).

There has been an increase in the literature examining adaptation and mitigation synergy in the Nationally Determined Contributions submitted by countries to the UNFCCC. Agriculture and energy are the two priority sectors for which there have been significant pledges and commitments from countries, with, to some extent, good alignment between adaptation and mitigation. This alignment can provide good opportunities to integrate both into national sectoral policies (Antwi-Agyei et al., 2018a). This suggests that inclusive and sustainable economic and social development can be achieved if national governments focus on developing coherent, cross-sector approaches that deliver potential triple wins of mitigation, adaptation and development.

Different governance approaches, such as polycentric governance, adaptive governance, multi-level governance, collaborative governance or network governance, are increasingly utilised to understand the processes of transitioning towards CRD. The potential of polycentric governance approaches for promoting both climate mitigation and adaptation is well established (Cole, 2015; Abbott, 2017; Morrison et al., 2017a; Warner et al., 2018). Polycentric governance deals with active steering of local, regional, national and international actors, and instigates learning from experience across multiple actors, levels of decision making and temporal scales (Ostrom, 2010). It is the source of power to achieve collective goals. Polycentric actors have the framing power, power by design and pragmatic power (Morrison et al., 2017b). Polycentric governance offers new opportunities for climate action through more opportunities for communication, trust-building, policy experimentation and learning (Cole, 2015). Adaptive governance is understood as various interactions between actors, networks, organisations and institutions towards achieving a desired state of social-ecological systems (Chaffin et al., 2014). It requires a structure of nested institutions, diversity at different levels, connected by formal and informal social networks (Dietz et al., 2003). As Brunner and Lynch (2010) observe, the emergence of community-based initiatives in addressing climate change marks the emergence of adaptive governance.

8.6.2.2 The Water–Energy–Food–Nexus Approach

Increasing demands for water, energy, food and materials are putting pressure on resource supply, and hence the nexus approach can inform transition pathways for interlinked resource systems (Johnson et al., 2019). The nexus approach, especially the water–energy–food nexus, is used to examine synergies and trade-offs between adaptation and mitigation (Howells and Rogner, 2014). As reviewed by Wiegleb and Bruns (2018), early use of the concept was by the World Economic Forum in 2008 where it was emphasised that issues of economic growth need to be considered within water, energy and food resource systems. This was later published as *Water Security: The Water–Food–Energy–Climate Nexus*. Another key activity was the Bonn2011 Nexus conference. Then, in 2015, The Nexus Dialogue Programme was held by the UN and EU Commissions as an approach to implement the SDGs. UN Water underscores the water–energy–food nexus as central to development (Newell et al., 2019). It notes that demand for water, food and energy are rising due to a growing population, rapid urbanisation, changing diets and economic growth, and in most cases, the lack of knowledge on the water–energy–food nexus has often led to mismatches in prioritisation and decision making which hinders sustainable development (Mitra et al., 2020). However, the benefits of nexus approach are not always easily quantified and often accrue to local communities over time (Amjath-Babu et al., 2019).

A well-coordinated and integrated nexus approach offers opportunities to build resilient systems while harmonising interventions, mitigating trade-offs and hence improving sustainability (Biggs et al., 2015). This can be achieved through greater resource mobilisation and coordination, policy convergence across sectors and targeting nexus points in the broader landscape (Mpandeli et al., 2018). Studies utilising the nexus approach to climate change in different places show considerably different results. In the southern African region, climate change is already affecting water–energy–food resources and exerting further pressure on already scarce resources. It is proposed that adaptation can be achieved through cross-sectoral management of resources, by adopting water management practices, aiming to produce more food and energy with less water resources and adopting cleaner and renewable sources of energy. This will result in saving water and ensuring energy security in a region that depends on hydro and coal energy sources (Mpandeli et al., 2018). Applying the nexus approach to the Hindu Kush Himalayan region identified three challenges: increasing population and declining agricultural land, stagnating or declining food production and increasingly water- and energy-intensive food production despite water and energy scarcity (Rasul and Sharma, 2016). Nexus smart adaptation policies need to be complemented with system-wide adaptation, policy coherence and sectoral coordination that targets poverty and vulnerability linkages (Rasul and Sharma, 2016).

8.6.2.3 Community-based Approach

Another important strategy to better determine impacts of adaptation and mitigation and to promote inclusivity, transparency and accountability is the community-based approach. This approach also supports adaptation and mitigation indirectly through the strengthening of capacity and social capital. For example, in Bangkalan, Indonesia, the presence of high social capacity and readily available free agricultural inputs are two decisive factors for effective climate change mitigation and adaptation, as well as for enhancing community livelihood (Sunkar and Santosa, 2018). The calls to consider Indigenous knowledge and Indigenous People to support integrated strategies in adaptation and mitigation are increasing (Ford et al., 2016; Altieri and Nicholls, 2017; Brugnach et al., 2017). Detailed knowledge of local socio-ecological contexts may offer transformational processes to harness synergies (Thornton and Comberti, 2017). A study in the Ukraine on cooperatives shows that it offers a well-established livelihood strategy and means to support agriculture smallholders. Moreover, social capital fulfils key roles in the process of capacity building and implementation of sustainable measures (Kopytko, 2018). In Indonesia, a well-known programme focusing on community-led adaptation and mitigation activities is Proklim. It empowers communities to learn about climate change impacts, record data and plan actions for climate change (Muttaqin and Yulianti, 2019). Multi-stakeholder, participatory planning processes are beneficial to help farmers to screen and prioritise rural livelihood strategies in Indonesia. The necessity of CRD is reflected in standard development interventions: water management, intensification and diversification of agriculture and aquaculture, education, health, food security and skill building for farmers (Wise et al., 2016).

8.6.3. Future Adaptation Finance and Social and Economic Changes within the Context of Poverty, Livelihoods, Equity, Equality and Justice

8.6.3.1 Coverage of Adaptation Finance

There is still some debate on what qualifies as adaptation finance and how such finance should be measured (UNFCCC, 2016). According to the Climate Policy Initiative, adaptation finance is 'finance with the aim of improving preparation and reducing climate-related risk and damage, for both human and natural systems, as short-term climate impacts will continue to exact economic, social, and environmental costs even if appropriate mitigation actions are taken' (CPI, 2019). According to UNEP, the annual costs of adaptation in developing countries could range from USD 140 billion to USD 300 billion by 2030. Globally, adaptation costs are estimated to be even greater, with up to USD 500 billion yr^{-1} by 2050 under a Business-As-Usual scenario (UNEP, 2021). While global climate finance flows reached USD 579 billion on average over the 2017/18 period, there has been a continued heavy imbalance in favour of mitigation finance, with adaptation finance totalling around USD 30 billion (compared to USD 532 billion for mitigation), or 5% of tracked climate finance. The World Bank has, however, committed to increase direct adaptation finance to USD 50 billion over the 2020–25 period, putting the Bank's adaptation finance in developing countries on par with its mitigation investments (World Bank, 2019a). Adaptation finance is also growing alongside finance for actions with both mitigation and adaptation benefits, for example in forestry or agriculture, which rose to just over USD 12 billion (CPI, 2019), as well as increasing focus on adaptation and cross-sectoral projects. Looking only at climate finance flows from developed to developing countries, the OECD estimates a total of USD 78.9 billion mobilised in 2018, with mitigation accounting for 70% (USD 55 billion) of the total, adaptation 21% (USD 16.8 billion) and cross-cutting finance making up the remainder (OECD, 2020a).

Adaptation finance funds actions to adapt to the impacts of climate change, yet such actions are heavily context, scale and time specific. Many mitigation actions in the energy sector can be easily quantified and employed across different jurisdictions. For example, solar photovoltaic (PV) presents an established way across a multitude of countries to produce low-carbon energy at a profit and reduce global GHG emissions. Adaptation needs, however, vary greatly from location to location and short-term solutions, for example investments in irrigation technologies to improve water availability for specific crops in a growing season, may differ from longer-term solutions, for example, switching to different crops altogether. Benefits are not always easily quantified and often accrue to local communities over time rather than to investors looking for the kind of returns realised in mitigation actions.

Development finance institutions mainly draw on market-rate loans and, to a lesser extent, concessional lending and grants to finance adaptation actions. There are regional differences in the choice of instruments, too, owing to the degree of economic development: while most of the adaptation finance flowing to the Asia-Pacific is market-rate debt, the vast majority of adaptation finance flowing to sub-Saharan Africa is in the form of concessional debt or grants (Richmond et al., 2020).

Globally, the main sectors benefiting from adaptation finance to date include water and waste water management; agriculture, forestry, land use and natural resource management; disaster risk management; and infrastructure, energy, and other built environment (Oliver et al., 2018). In recent years, this finance has moved away from concentrating on water and wastewater management to spread out more evenly across the sectors. Between 2015/16 and 2017/18, investment in water and wastewater management dropped from USD 11 billion to USD 9 billion, while investment in agriculture, forestry, land use and natural resource management grew from USD 5 billion to USD 7 billion, and investment in disaster risk management more than doubled from USD 3 billion to USD 7 billion (CPI, 2019). In addition, while mitigation actions are more easily delineated, for example wind farms in the energy sector, adaptation measures often need to be mainstreamed across a number of sectors and investment decisions.

There are strong interconnections between NBS, climate adaptation and mitigation actions. Ecosystem-based adaptation is a nature-based solution that uses ecosystem services to help communities adapt to climate change. Examples of such approaches were covered in Section 8.5.2.2. For example, mangrove restoration provides both climate mitigation (as carbon sinks) and adaptation to climate change (increasing the resilience of coastal communities), while also supporting the implementation of a range of other SDGs (e.g., through increased food security). Research has found that without mangroves, global flood damage costs would increase by more than USD 65 billion a year (Menéndez et al., 2020). There is, therefore, an urgent need to invest in a range of NBS.

Box 8.9 | Adaptation financing for the poor and the need for systems transition: Eastern Indonesian Islands

Summary

A 4-year project in Nusa Tenggara Barat Province, Indonesia, aimed to stimulate an adaptation pathways process. The goal was to support CRD in a context with low stakeholder capacity, high poverty, and rapid environmental and social change. On these archipelagic islands, livelihoods are predominantly rural, far from political and urban centres. The project focused on integrated top-down and bottom-up development planning that could enable CRD at the local level, linked to provincial and national plans.

Lessons learnt

- Substantial gradients in both climate and livelihoods in the island geographies necessitate fine-scale planning and make it difficult to scale up.
- Infrastructural investments, including roads, ports and irrigation, are crucial to CRD. If not well designed, such investments are prone to maladaptation, such as exposure to sea level rise.
- Although some development interventions are delivering climate resilience, such outcomes are often haphazard, rather than strategically conceived, coordinated and delivered (Butler et al., 2016).

New financial instruments can help to support investment in, for example, ecosystem-based adaptation. For example, green bonds can raise significant amounts of capital in support of projects with environmental/climate benefits. The green bond market has quickly developed since the European Investment Bank launched the first green bond in 2007, with issuance growing to USD 257.7 billion in 2019, up more than 50% on the previous year (CPI, 2019). Most green bonds focus on energy, buildings and transport infrastructure but green bond issuance to support sustainable agriculture and forestry has grown from USD 208 million in 2013 to USD 7.4 billion in 2018 (Wilkins, 2019). The Seychelles issued the world's first 'blue' bond in 2018 with the support of the World Bank. Similar to green bonds, blue bonds earmark the use of bond proceeds for specific purposes, here the sustainable use of marine resources (World Bank, 2018). In 2019, the European Bank for Reconstruction and Development issued the world's first ever dedicated climate resilience bond, raising USD 700 million. The 5-year bond will be used to finance the Bank's projects in climate-resilient infrastructure (e.g., water, energy and transport), climate-resilient business, commercial operations, climate-resilient agriculture and ecological systems (Bennett, 2019). While these issuances are still small compared to the overall green bond market, their rapid growth points to enormous opportunities for ecosystem-based adaptation.

Despite the growth of official adaptation funding at international and national levels, for the world's poorest, adaptation to the impacts and opportunities of climate change frequently occurs in response to L&Ds at the individual or household scale, without coordination at larger institutional scales (Section 8.3, 8.4; Barrett, 2014). Discussions of adaptation finance often occur in the context of dwindling resources and trade-offs: triage decisions about other investments that societies can tolerate suspending (Warner and Van der Geest, 2013; Tanner et al., 2015). In many poor, vulnerable countries, complex governance challenges, such as budget austerity or corruption, hamper the provision of such support. In the absence of adaptation funding for the poor, coordinated at higher scales, the costs of adaptation are borne by the poor at community, kin-group and household scales. Bearing the cost of adaptation, thus, can become, in the short term, an erosive process of coping that ultimately increases the likelihood that communities and households will remain trapped in poverty (Antwi-Agyei et al., 2018b). In the long term, measures financing adaptation may be maladaptive, meaning they ultimately leave the poor at greater risk of experiencing climate change impacts (Section 8.4.5; Rahman and Hickey, 2019). Such circumstances highlight the governance gap that drives the poorest to rely on extreme measures to finance adaptation.

Since the AR5, there is greater documentation of the extreme measures and high-risk income alternatives that the world's poorest commonly take to finance adaptation (Dawson, 2017; Ahmed et al., 2019). While still a controversial topic, clear examples of extreme adaptation finance measures include:

- Unauthorised international migration (McLeman, 2018)
- Informal small-scale mining of precious metals and minerals (Hilson and Van Bockstael, 2012; Osumanu, 2020)
- Illegal poaching of flora and fauna, including participation in illegal timber harvesting (Bolognesi et al., 2015)
- Illegal, unregulated or unreported fishing, including within marine protected areas, or the coastal zones of neighbouring countries (Tanner et al., 2014)
- Utilisation of livelihood resources, such as boats, in smuggling activities, including drug and arms trafficking (Belhabib et al., 2020)
- Participation in piracy, extortion or kidnapping economies (Staff, 2017).

Enabling conditions for formal adaptation finance for the poorest are needed to reduce reliance on high-risk, extra-legal sources of income (see Section 8.5.2). In general, the antidote to this emerging problem is access to living wages that the poor can rely on to finance adaptation. There are few examples of pro-poor mechanisms, programmes or institutions that prioritise coordinated, access to credit for proactively adapting livelihoods of the poor (Agrawal and Perrin, 2009). Institutions can reduce incentives for vulnerable people to engage in high-risk activities by including them in the process of adaptation governance, which aims not only to support sustainable livelihood practices (such as farming, fishing and forestry), but also to guarantee land tenure (Wrathall et al., 2019). Also critical for risk reduction to the poor is the ability of authorities across multiple spatial and temporal scales to maintain social protection to reduce the dependency of illegal sources of income and facilitate adaptation (Tenzing, 2020). A range of tools exists for opening access to credit to poor and marginalised people whose livelihoods are most vulnerable (Ribot, 2013): climate insurance tools that are designed and targeted at the poorest and which have been properly assessed to ensure that they do not undermine other coping strategies such as risk spreading, programmes that ease access or subsidise loans for adaptation, mobile banking and mobile-based financial and risk management tools, impact pay-outs in the form of direct transfers and institutional support for hometown associations. International governance arrangements, such as the Warsaw International Mechanism on Loss and Damage, might aim primarily to clear the financing gap between global financial and risk management institutions and the pocketbooks of the poorest (Wrathall et al., 2015).

8.7 Conclusion

The chapter has moved beyond the IPCC WGII AR5 in that it lays out structural elements of vulnerability and provides quantitative information about climate-related vulnerability hotspots globally complemented by the assessment of poverty, local livelihood vulnerability and sustainable development. The assessment of non-economic losses, and enabling and supportive environments for adaptation are also new aspects.

The chapter provides additional evidence on livelihood resources at local levels that have been impacted by different climate hazards and, globally, that specific hazards (namely, drought and rising temperatures) are more threatening and destabilising to livelihoods than others. There is *robust evidence* that coping and adaptive capacities erode with increasing GMT—substantial differences are expected between a GMT increase of less than 1.5°C compared to an increase of more than 3°C—and the frequencies of climate hazards, such as heat waves, droughts or floods is likely to increase substantially. Nevertheless, this assessment also revealed that the adverse impacts of climate change for livelihoods and multidimensional poverty differ substantially between different population groups exposed to climate hazards, based on the socioeconomic and governance context. Consequently, societal impacts of climate change need to be understood in the broader context of development and the development challenges that influence exposure, vulnerability and adaptation.

There is *robust evidence* of the impacts of all climate hazards on the key livelihood resources that the poor depend on. There is *high confidence* that two climate hazards pose high risk to a broad range of livelihood resources: warming trends and droughts. Meanwhile, the livelihood resources that are globally at greatest risk include people's bodily health, food security and agricultural productivity (*high confidence*). Evidence suggests that the fundamental challenge of climate change to livelihoods is that rising temperatures, drought and other hazards endanger human life, and the lives of plants and animals that humans rely on to survive (*high confidence*). There is now *robust evidence* that the impacts of climate change on livelihoods are driving people to migrate in search of alternative incomes, and this tendency will increase with rising temperatures. Of greatest concern are people whose development context is compromised by war, conflict and extreme poverty and inequality, such as refugee populations and displaced people.

This chapter reports quantitative evidence of human vulnerability and therefore identifies various spatial hotspots of vulnerability emerging in regional clusters. It reports that significantly more people are living in highly vulnerable context conditions compared to those living in low vulnerability contexts. The assessment revealed that more than 3 million people are living in countries classified as very highly or highly vulnerable (depending on the assessment method and the number of classes used, and countries included). In contrast, approximately 1.8 billion people reside in low or very low vulnerable country contexts. Studies estimate the population in the most vulnerable regions to almost double by the year 2100 (Section 8.4.5.2). When near-term estimates are used, the population growth in highly vulnerable countries is still significantly higher compared to less vulnerable countries. Consequently, this assessment points towards the fact that even if we do not know how societal or community vulnerability will develop in specific areas, it is *very likely* that in the future, more people will live in destabilised and highly vulnerable country contexts compared to the population today. However, it is important to note that the scientific literature also underscores that trends in vulnerability differ significantly between different world regions and within countries.

The chapter also advances knowledge in terms of the interconnections between human vulnerability, observed losses and adverse consequences. The assessment shows that statistically relevant differences in observed fatalities per hazard event can be explained by hazard intensity and frequency, and are also linked to different levels of vulnerability of a region exposed. Despite all uncertainties about future change, the assessed literature clearly provides an accurate picture of the expected societal impacts of climate change, the requirements for successful adaptation and the need to address the adaptation gap from the perspective of vulnerability.

The chapter shows that intersectionality approaches are becoming increasingly central to grasping how differential vulnerability to climate hazards is experienced by different social groups. Intersectionality recognises that age, gender, class, race and ethnicity are reinforcing social phenomena, shaping social inequalities and experiences of the world, and also intersect with climate hazards and vulnerability. Our assessment reveals the central role of maladaptation with *robust new evidence* on negative consequences of interventions on different social groups. Well-intentioned adaptation can exacerbate past and existing vulnerabilities and undermine livelihoods. There is also evidence that, despite maladaptation, inclusive and sustainable development at the local level can reduce vulnerability.

Since AR5 L&D has taken much more central stage in sustainable development, policy, and poverty and livelihoods discourse. While there is ambiguity about what constitutes L&D, the chapter highlights new evidence of observed L&Ds, including slow-onset impacts (e.g., sea level rise and drought). Our assessment reveals that there is a body of literature that explicitly addresses non-economic losses and that these are experienced everywhere now due to human-induced climate change. These are coupled with advancements in the science of extreme event attribution with new focus on adaptation metrics and vulnerability assessments.

This assessment also identifies emerging evidence of linkages between extreme and slow-onset events, NELD and livelihood shifts. This suggests that losses are leading to a range of shifts in livelihoods, which may be easier for some social groups than others, and which have implications for livelihoods security across transboundary scales. Yet, climate change is only one driver. Untangling the drivers of vulnerability using intersectionality approaches is also critical. Our quantification of vulnerability hotspots supports this concern. It is critical to seek further knowledge on the extent of livelihood shifts among the most vulnerable resulting from specific NELD, for whom, where and at what scale. Gaps in knowledge highlight this as an area that needs further work in order to develop and understand further the full extent and reach of the relationships between extreme and slow-onset climate events, non-economic losses and shifting livelihoods.

This chapter builds on AR5 and the IPCC SR 1.5°C on key limits to the adaptation of natural and social systems that are compounded by the effects of poverty and inequality, such as on water scarcity, ecosystems alteration and degradation, coastal cities in relation to sea level rise, cyclones and coastal erosion, food systems and human health (*high confidence*). Climate change risks could have substantial negative impacts on climate-sensitive livelihoods of smallholder farmers, fisheries communities, Indigenous People, urban poor and informal settlements, with limits to adaptation evidenced in the loss income, ecosystems, health and increasing migration (*high confidence*). The chapter also addresses how ecological thresholds and socioeconomic determinants of vulnerabilities are linked to soft and hard adaptation limits, including the potential and magnitude of livelihood risks in the future. For instance, a hard limit associated with losses of coral reefs in a 1.5°C warmer world will lead to substantial loss of income and livelihoods for coastal communities (*high confidence*), including loss of culture- and place-based attachment (*medium confidence*). Hard adaptation limits are expected for the Arctic ecosystem. Their threshold will affect residents of Arctic regions dependent on hunting and fishing livelihoods (*high confidence*). New emerging considerations to ecological limits to adaptation, such as severe glacier retreat and Amazon forest dieback, is expected to affect the livelihoods of smallholder farmers and Indigenous People through crop yield failures, biodiversity loss, reduced hydropower capacity and health (*medium evidence*). While a knowledge gap remains on the projected risks of increasing global temperature to climate-sensitive livelihoods among Global South countries and specific groups of people, current observations show negative impacts to livelihoods for tens to hundreds of millions of people. Thus, without sustainable, equitable and urgent adaptation measures, maladaptation risks are *likely* to further increase vulnerability, marginalisation and ecological tipping points among the poor within countries (*medium confidence*).

Evidence on the kinds of enabling environment required paints a complex picture. The assessment highlights the interaction of different capital assets within the broader context of key enablers in shaping the overall enabling environment for adaptation, which itself is highly context dependent. In this regard, countries present different starting points for adaptation, with some requiring, for example, more of an emphasis on institutional capacity building; others requiring transformation to the broader legal and political conditions. Capitals are not necessarily substitutable but rather act as an assemblage in shaping both perceptions of climate risk and the necessity and appropriateness of actions. At the same time there is *robust evidence* that livelihoods that depend strongly on natural capital for both subsistence and as a source of income are particularly sensitive to climate risks; and are where perhaps adaptive actions are most urgently needed, even with smaller rises in temperature under the most optimistic scenarios. This applies to both the Global South and the Global North. Investments in any form of capital asset to support adaptation need to be mindful of reinforcing existing inequalities and introducing new ones, particularly if transformation takes place. This also underscores the importance of inclusive, polycentric governance in ensuring the voices of all groups are heard and that wide-ranging knowledge types are incorporated in decision making, nevertheless recognising that trade-offs are inevitable.

The chapter also highlights and provides quantitative evidence that adaptation strategies need to go beyond the idea of adapting to warming levels only. Adaptation strategies have to reduce the adaptation gap and therewith reduce human vulnerability independent of a specific climatic hazard. It has been shown that adaptation strategies that explicitly address poverty and inequities, and also consider rights-based approaches can generate co-benefits for resilience building of most vulnerable groups and for sustainable development.

Frequently Asked Questions

FAQ 8.1 | Why are people who are poor and disadvantaged especially vulnerable to climate change and why do climate change impacts worsen inequality?

Poor people and their livelihoods are especially vulnerable to climate change because they usually have fewer assets and less access to funding, technologies and political influence. Combined, these constraints mean they have fewer resources to adapt to climate change impacts. Climate change impacts tend to worsen inequalities because they disproportionately affect disadvantaged groups. This in turn further increases their vulnerability to climate change impacts and reduces their ability to cope and recover.

Climate change and related hazards (e.g., droughts, floods, heat stress, etc.) affect many aspects of people's lives—such as their health, access to food and housing, or their source of income such as crops or fish stocks—and many will have to adapt their way of life in order to deal with these impacts. People who are poor and have few resources with which to adapt are thus much more seriously negatively affected by climate-related hazards. 'Vulnerability' is when a person or community is not able to cope and adapt to climate-related hazards. For example, if someone who is very rich has their house washed away in a flood, this is terrible, but they often have more resources to rebuild, have insurances that support recovery and maybe even build a house that is not in a flood-prone area. Whereas for someone who is very poor and who does not live in a state that provides support, the loss of their house in a flood could mean homelessness. This example shows that the same climate hazard (flood) can have a very different impact on people depending on their vulnerability (their capacity to cope and adapt to hazards).

It is not just poverty that can make people more vulnerable to climate change and climate-related hazards. Disadvantage due to discrimination, gender and income inequalities and lack of access to resources (e.g., those with disabilities or of minority groups) can mean these groups have fewer resources with which to prepare and react to climate change and to cope with and recover from its adverse effects. They are therefore more vulnerable. This vulnerability can then increase due to climate change impacts in a vicious cycle unless adaptation measures are supported and made possible.

Frequently Asked Questions

FAQ 8.2 | Which world regions are highly vulnerable and how many people live there?

A mix of multiple development challenges, such as poverty, hunger, conflict and environmental degradation, make countries and whole regions vulnerable to climate change. Many of the people in the most vulnerable situations and in the most vulnerable regions are also highly exposed to climate hazards, such as droughts, floods or sea level rise at present and will become increasingly so in the future. Studies estimate that around 3.3 to 3.6 billion people are living in regions classified as highly vulnerable to climate change impacts, which is significantly higher than the number of people who reside in regions classified as least vulnerable. The most vulnerable regions include East, Central and West Africa, South Asia, Micronesia and Melanesia, and Central America.

When a country or region is considered 'vulnerable' to climate change this means that climate hazards (e.g., drought, flood, heatwaves) have a very negative impact because there is a high number of people in these areas that lack the ability or opportunity to cope and adapt to such events, due to, for example, high average poverty, inequality and lack of institutional support. This vulnerability could be due to many different development challenges that all come together and influence each other, such as poverty, lack of access to basic infrastructure services, high numbers of uprooted people, state fragility, low or below average life expectancy and biodiversity degradation. These structural social issues often affect regions for many decades and make it difficult for the state and for individuals to respond to climate change and climate-related hazards.

For example, if a region is already characterised by poverty and struggling to feed its population and provide adequate access to basic infrastructure services, such as water and sanitation, this makes them vulnerable. If this region is then faced with an increased number of extremely dry years, this exposes them to drought and will make things even harder causing more hunger, poverty and worsened health—these are climate impacts.

Most vulnerable regions are in Africa, as well as in South Asia, the Pacific and the Caribbean. In these regions, there are often multiple neighbouring countries that all are highly vulnerable, for example in Central and West Africa. These regional clusters require special attention.

BOX FAQ 8.2 (continued)

There are also highly vulnerable groups and individuals within less vulnerable regions. For example, marginalised, disadvantaged and poor minorities within highly affluent cities. Programmes that aim to support adaptation to climate change need to focus on reducing the vulnerability of individuals, groups, countries and regions.

Frequently Asked Questions

FAQ 8.3 | How does and will climate change interact with other global trends (e.g., urbanisation, economic globalisation) and shocks (e.g., COVID-19) to influence livelihoods of the poor?

A range of local, regional and global economic and political processes already underway have put the livelihoods of the poor at risk. These processes include urbanisation, industrialisation, technological transformation, monetisation of rural economies, increasing reliance on wages, and inequality at national and international levels. Climate change intersects with these processes.

The world's poorest already struggle to provide for themselves and their families in their pursuit of livelihoods. Despite hard work there are many factors beyond an individual's control that can make earning a living very difficult. Climate change is one problem among many that puts stress on livelihoods. Poor and marginal groups disproportionately bear impacts of climate change, in ways that accelerate transitions from traditional livelihoods, such as rural farming, to wage jobs in urban areas. Where adaptation measures are insufficient and where the poor are excluded from decision making, these livelihood transitions can be severely destabilising.

For example, climate change may alter the frequency or intensity of hazards that threaten the viability of a community's traditional farming or fishing livelihoods. Local farmers or fishers are then forced to adapt how they farm or fish or abandon livelihood practices entirely. The latter may mean migrating to a city to find work. As many communities face the same challenge, this intersects with a global trend that is affecting billions of lives and livelihoods—urbanisation—as seen in the rapid growth of informal settlements at the peripheries of cities around the world, particularly rapidly growing mega-cities in Africa, Asia and Latin America. These developments will be accelerated by negative impacts of climate change and increase risks that larger segments of the population enter conditions of persistent poverty.

At the same time, people whose livelihoods have been upended by climate change are subject to new threats, such as the global COVID-19 pandemic, which has shone a light on the plight of the most vulnerable people. For example, the elderly, Indigenous Peoples and Communities of Colour were disproportionately severely impacted by COVID-19; also the indirect economic consequences particularly hit the poor. Hence, COVID-19 demonstrates that the livelihoods of the poorest and most marginalised are vulnerable to other global trends beyond climate change. Also, most severe impacts are expected in regions that are already characterised by high levels of systemic human vulnerability.

Frequently Asked Questions

FAQ 8.4 | What can be done to help reduce the risks from climate change, especially for the poor?

Public and private investment in different types of assets can help reduce risks from climate change. Exactly which assets require investment depends on the specific situation. However, the provision of access to basic services, such as water and sanitation, education and health care as well as the importance of reducing inequity is shown within the assessment for many regions. The poor have fewer resources to invest, so in poorer countries greater public investment is needed. Legal, social, political, institution and economic interventions can alter human behaviour, though care must be taken that these do not amplify existing inequalities, create new inequalities or reduce future adaptation options.

Adaptation can help to reduce risks for the poor and requires both public and private investment in various natural assets (e.g., mangroves, farmland, wetlands), human assets (e.g., health, skills, Indigenous knowledge), physical assets (e.g., mobile phone connectivity, housing, electricity, technology), financial assets (e.g., savings, credit) and social assets (e.g., social networks, membership of organisations such as farmer cooperatives). Often, the poor have the least to invest, so poverty can reduce adaptation options. Sometimes people migrate as a reaction to floods or droughts, though the poorest groups often lack the resources to move. Exactly what needs investing in to reduce risks varies according to the scale and livelihood system in need of adaptation. In general, risks can be reduced through a range of different technological and engineering approaches (for example, building sea defences to reduce storm surge impacts), as well as ecosystem-based approaches (such as replanting mangroves, altering the types of crops grown, changing the timing of farming activities, or using climate-smart agriculture or agroforestry approaches).

At the same time, legal, social, political, institutional and economic solutions can alter human behaviour (e.g., through enforcement of building codes to prevent construction on low-lying land prone to flooding, timely provision of weather information and early warning systems, knowledge-sharing activities, including adaptation strategies grounded in Indigenous knowledge, crop insurance schemes, incentives such as payments to stop people cutting down trees or to enable them to plant them and social protection to provide a safety net in times of crisis).

The poorest groups often require greater public adaptation investments. Efforts to support adaptation need to be mindful of reinforcing existing inequalities and introducing new ones, making sure they are inclusive, culturally sensitive and that the voices of all groups of people are heard. It is also important that adaptations which reduce immediate risks for the poor do not rule out adaptation options that could help them later on or which could cause them to increase their emissions. Political will is needed to put people at the centre of climate change risk reduction efforts, including support for their livelihoods.

Frequently Asked Questions

FAQ 8.5 | How do present adaptation and future responses to climate change affect poverty and inequality?

Present adaptation can help to reduce the current and possibly future impacts of climate change. Future responses to climate change can reduce poverty and inequality, and even help transition toward climate-resilient livelihoods and climate resilient development. Pro-poor adaptation planning is necessary to ensure future risks for the poor are being accounted for and the inequality underlying the poverty is being addressed.

There are many ways in which poverty and inequality are influenced by climate change. The livelihood sources of the poor are likely to be affected and cumulative effects of losses and damages, and may influence future poverty. There are cases when present adaptation worsens future poverty and exacerbates inequality—this is called maladaptation. The risks of maladaptation are greater in societies characterised by high inequality, and in many cases the poor and most vulnerable groups are the ones most adversely affected.

Effective decision making in adaptation should be informed by past, present and future climate data, information and scenarios to cater for reliable plans and actions for climate-resilient livelihoods. Adaptation lessons from the past play an important role in decision making regarding responses to climate change. There is an emerging debate on the role of learning, particularly forward-looking (anticipatory) learning, as a key element or important aspect for adaptation and resilience in the context of climate change. Memory, monitoring of key drivers of change, scenario planning and measuring anticipatory capacity are seen as crucial ingredients for future adaptation and resilience pathways, and, hence overcoming maladaptation. Moreover, climate resilient development calls for ensuring synergies between adaptation, mitigation and development are maximised, while trade-offs, especially those affecting the poor, are minimised.

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